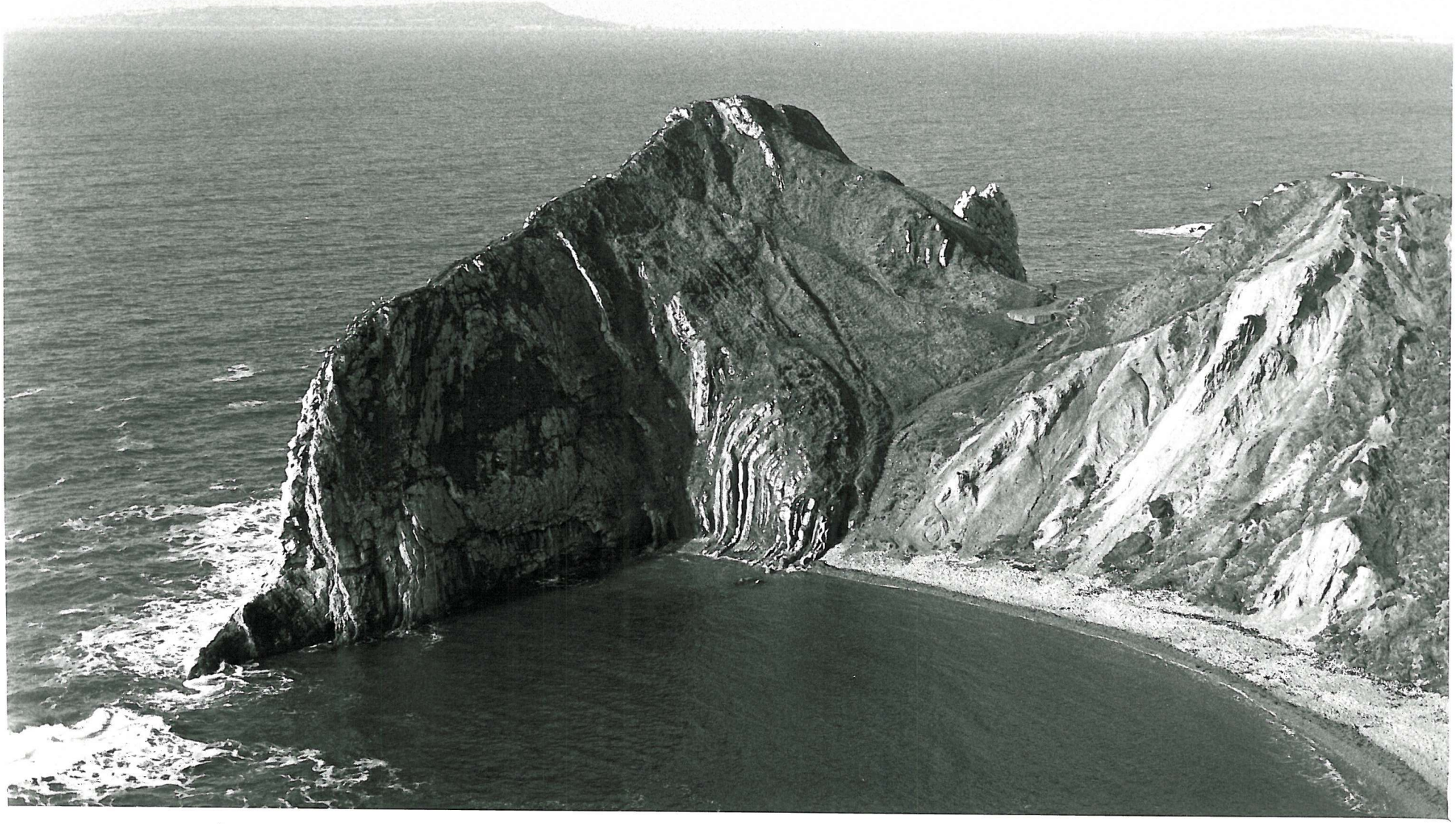
UNIVERSITY OF SOUTHAMPTON

THE PROVENANCE OF UPPER JURASSIC AND LOWER CRETACEOUS COARSE-GRAINED DETRITUS IN SOUTHERN BRITAIN AND NORMANDY

by Ian Ross Garden

SEPTEMBER 1987



I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay undiscovered before me.

Sir Isaac Newton.

(Brewster's Memoirs of Newton, II, Ch.27.)

FRONTISPIECE: The steeply inclined beds of the Portland Limestone, Purbeck and Wessex Formations at Man O'War Cove, Dorset. The beds are part of the central limb of a Tertiary monoclinal fold, which probably formed by reactivation of a Mesozoic normal fault-zone down-throwing to the south (left). The fault-zone probably forms the southern boundary of the Mesozoic structural high, the South Dorset High. Detritus derived from the structure is present in the pebble beds of the Wessex and Gault Clay Formations at this locality.

Location: Man O'War Cove, Dorset (SY 8065 8025); view to the westsouthwest.

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF SCIENCE

GEOLOGY

Doctor of Philosophy

THE PROVENANCE OF UPPER JURASSIC AND LOWER CRETACEOUS COARSE-GRAINED DETRITUS IN SOUTHERN BRITAIN AND NORMANDY

by Ian Ross Garden

The provenance of coarse-grained detritus from the Upper Jurassic Corallian Group and Lydite Beds and Lower Cretaceous Purbeck Formation, Spilsby Sandstone Formation, Wealden Group, Claxby Ironstone Formation, Lower Greensand Group and Gault Clay Formation of southern Britain and Normandy (northern France) has been studied. The coarse-grained detrital suites contain extrabasinal phenoclasts derived from Palaeozoic and Precambrian massifs, and Jurassic and Cretaceous clasts from intrabasinal highs. The former assemblage is dominated by chert derived from Carboniferous limestones and quartz. Sandstones, radiolarian cherts and tourmalinites are locally abundant. The intrabasinal detritus is composed principally of chert, phosphorite and ironstone.

Progressive changes in phenoclast suites provide a means for studying both local variations associated with uplift of intrabasinal structures and regional variations associated with basin development.

Local variations in the intrabasinal pebble suites of Dorset provide evidence of major fault-associated uplift of the South Dorset High during earliest Cretaceous times. Post-faulting subsidence resulted in marine onlap and further erosion of the structure. The South Dorset High is structurally similar to other fault-associated highs in the Wessex and Paris Basins, and it is probable that they have all undergone extensive Early Cretaceous uplift in conjunction with basin rifting.

The Upper Jurassic and Lower Cretaceous phenoclast suites of southern Britain and Normandy are separable into three stratigraphical assemblages. The oldest assemblage, Oxfordian to Early Berriasian in age, is dominated by chert derived from Carboniferous limestones. The two younger assemblages (Late Berriasian to Barremian and Aptian to Middle Albian) are distinguished by a generally higher proportion of quartz. The Aptian to Middle Albian phenoclast assemblage is separable into two subassemblages (Aptian, and Lower to Middle Albian) and the latter shows lateral changes which enable it to be divided into three geographical provinces and five subprovinces.

In the Wessex Basin, a change from chert-dominated to quartz-dominated phenoclast suites occurred at the beginning of the Cretaceous System. This resulted from uplift and erosion of the marginal massifs adjacent to the rifting basin. On the East Midlands Shelf, however, modifications in the detrital suites did not occur until mid-Cretaceous times. The delayed change was caused by limited uplift of the adjacent massifs during Early Cretaceous times and reworking of slightly older pebble beds on the shelf. The marginal highs were then uplifted and eroded during the mid-Cretaceous phase of thermal subsidence in the Southern North Sea Basin.

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CHAPTER I
INTRODUCTION

1.1 GENERAL

The Late Jurassic to Early Cretaceous regional tectonic movements and synchronous fall in sea-level throughout northwest Europe (Ziegler, 1981) caused increased rates of basin subsidence, uplift of structural highs and the complementary lowering of the erosional base levels. These events resulted in the influx into the evolving basins of coarse-grained detritus, the distribution of which was dependent on both basin geometry and structural history and also on the mode of sediment transportation. During episodes of rapid basin submergence, clastic detritus was commonly restricted to basin margins; however, in times of slower basin subsidence, sheets of detritus were spread across the basins.

Progressive changes in the composition of coarse-grained detrital suites provide a means for studying the evolution of areas during uplift and erosion. Prof. Perce Allen, in his classic work on the fluvial Hastings Beds Group rocks of the Weald Basin (P.Allen, 1954, 1960, 1961, 1967a) demonstrated that changes in pebble suite compositions resulted from the progressive uplift of the Anglo-Brabant Massif.

As a result of tectonic movements and sea-level fall, the formerly interconnected Jurassic marine basins of southern Britain were separated into smaller fault-controlled sub-basins between which there was only episodic interconnection (Figs. 1.1, 1.2). In the Wessex Basin, tectonic movements and a fall in sea-level were associated with an increase in aridity towards the end of the Jurassic System. However, by earliest Cretaceous times, rifting, including the opening of the Atlantic Ocean and Bay of Biscay, had resulted in the development of a more humid climate (Sladen, 1983). This climatic change resulted in greater run-off from the rejuvenated highlands and the consequent introduction of large quantities of coarse-grained detritus into the sedimentary basins. The increased rainfall also brought about the formation of the freshwater lakes and alluvial flood plains of the Wessex Basin (P.Allen, 1981). In response to the reduction in elevation of the source areas, sand and gravel influxes into the basins of southern England gradually diminished during Early Cretaceous times (P.Allen, 1981; Sladen, 1983).

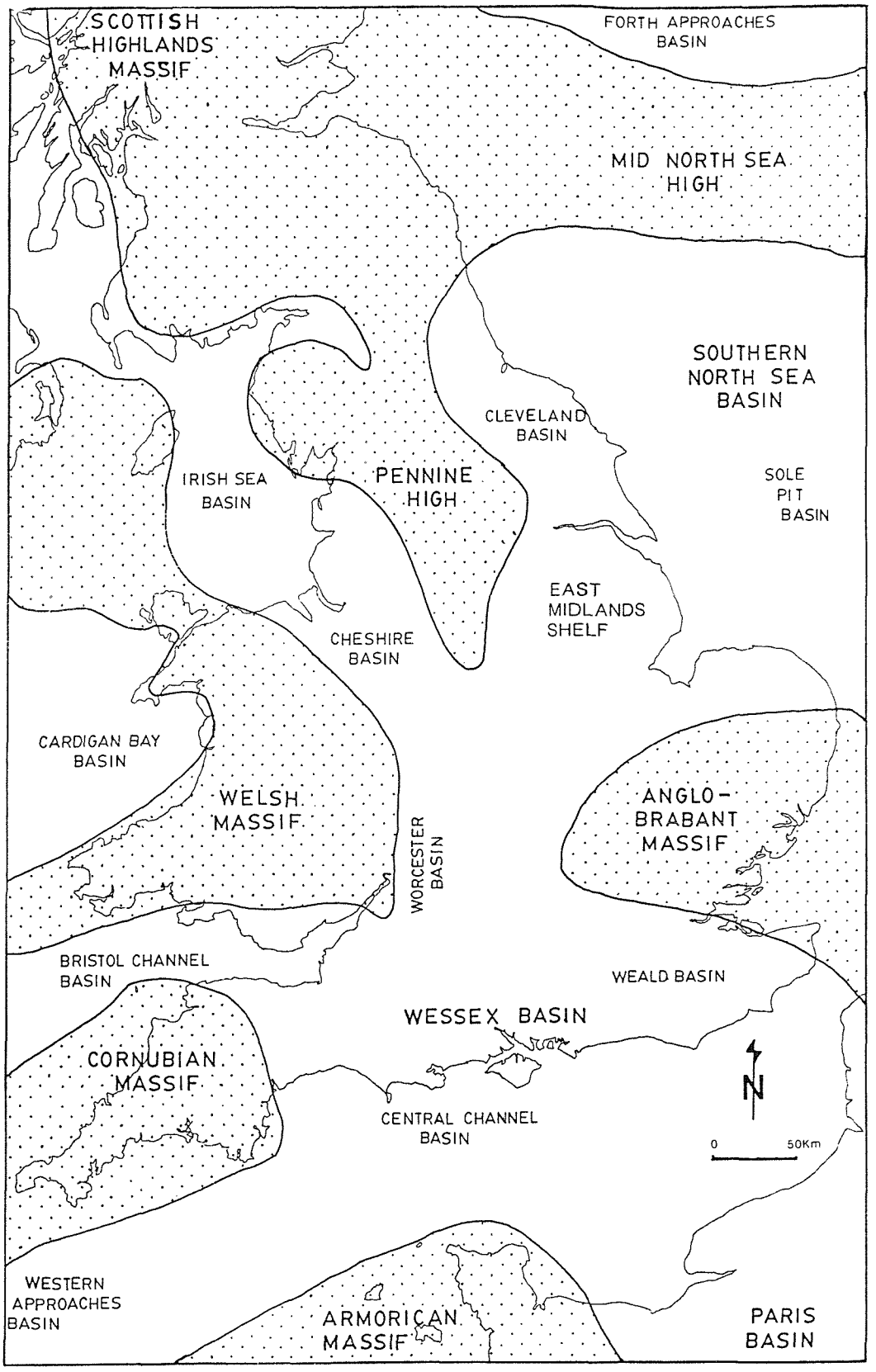


Figure 1.1 The principal Mesozoic structural elements in southern Britain and the adjacent areas.

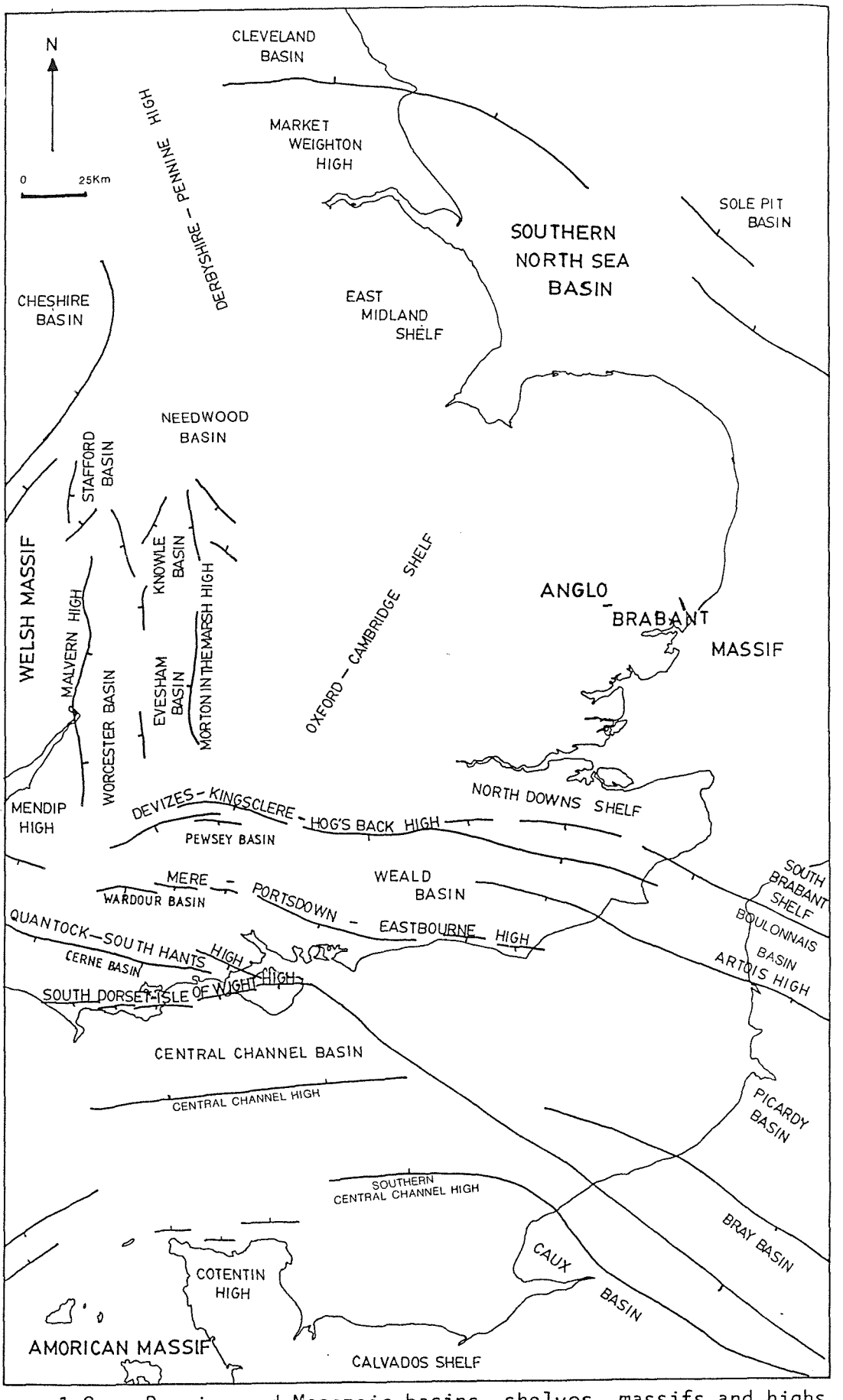


Figure 1.2 Permian and Mesozoic basins, shelves, massifs and highs in southern Britain and adjacent areas (after Sellwood et al., 1985; Whittaker, 1985).

Marine influxes in southern England occurred episodically during Early Cretaceous times (Casey, 1963), but fully marine conditions were not restored until the Aptian Stage (Middlemiss, 1975). Initially, marine sedimentation occurred in restricted embayments, dominated by strong tidal currents (Narayan, 1963). However by mid-Albian times, the deepening seas had extended over most of the former land areas and submerged the principal sources of detritus to depths too great for erosion (Owen, 1971a; Cope, 1984).

North of the Anglo-Brabant Massif, Mesozoic sediments are preserved on the East Midlands Shelf, the Market Weighton High, and the Cleveland Basin (Figs. 1.1, 1.2). In these areas, marine conditions persisted from Late Jurassic to Early Cretaceous times and resulted in the deposition of shallow marine sandstones, mudstones, arenaceous limestones and ironstones. Sedimentation was slow and intermittent, with several breaks in deposition (Rawson & Riley, 1982). The changing patterns of sedimentation resulted from a complex inter-relationship of tectonics, sea-level change and climatic variation, which caused disequilibria in the sedimentary environment. Breaks caused by tectonic or eustatic events tend to be of regional or, in some examples, global extent, and are generally marked by concentrations of coarse-grained detritus. The examination of such detritus provides detail as to the areal extent of such events and the depth to which erosion penetrated. The detrital suites also provide information concerning changes in the palaeogeography of the study area.

1.2 PROJECT OBJECTIVES

The aims of this project are to examine both regional and local variations in the detrital suites of Late Jurassic and Early Cretaceous age in southern Britain and adjacent areas. The information gathered should enable refinements of palaeogeographical and palaeogeological models already in use. Examination of detritus derived from intrabasinal structures may also provide an indication of the burial history of highs.

The project is restricted to the study of the coarse-grained detrital fraction (grains greater than 1mm in length; see Chap. III for details of lithotypes). Such assemblages may, in general, be more readily matched to local sources and the possibility of reworking may be assessed from the compositional and textural

maturity of the suite.

Studies of sand fractions have already been made, both locally and on a regional scale, in the area of study (see Boswell, 1933 for references to early literature; later studies were conducted by P.Allen, 1949; Worrall, 1956; Wood, 1956; Morton, 1982; Hurford et al., 1984) and hence a heavy-mineral investigation has not been attempted. Regional variations in the heavy-mineral suites have been recognised, but are less appropriate for the examination of changes in the detrital suite caused by local factors.

P.Allen et al. (1964) used glauconite as an indicator of the reworking of Jurassic detritus into the Lower Cretaceous Hastings Beds Group. The abundance of authigenic glauconite in the Lower Cretaceous marine sediments, however, precludes the use of this technique in this study. The term glauconite is used in this study to include the group of minerals refered to as glaucony by Odin & Matter (1981). Other clay minerals have been used as provenance indicators (Cosgrove & Salter, 1966; Sladen, 1983; Sladen & Batten, 1984) and abundances have been semi-quantitatively assessed by X-ray diffraction (X.R.D.) techniques. This method appears to be a sensitive indicator of palaeoclimatic conditions, but proves less useful as an indicator of palaeogeology (Sladen & Batten, 1984).

Initially, this project was conceived as an investigation of the evidence of locally derived detritus in central-southern England, but was subsequently extended to cover all British outcrops of Aptian and Albian pebble beds and those of northern France (Figs. 1.3, 1.4; see Chap. II for details of the field localities). The examination of mid-Cretaceous and older pebble beds outside the initial area of study provided an overview of sediment distribution and provenance in the region. Widening the geographical and stratigraphical extents of the investigation restricted the development of computerised methods for data handling. Techniques were standardised where possible, but variations in the range of clast sizes and abundance of clasts within a bed inhibited such standardisation in some cases (see Chap. IV for details).

1.3 THE DISTRIBUTION OF UPPER JURASSIC AND LOWER CRETACEOUS PEBBLE BEDS IN SOUTHERN BRITAIN AND NORMANDY

Pebble beds occur at several horizons in the Upper Jurassic and

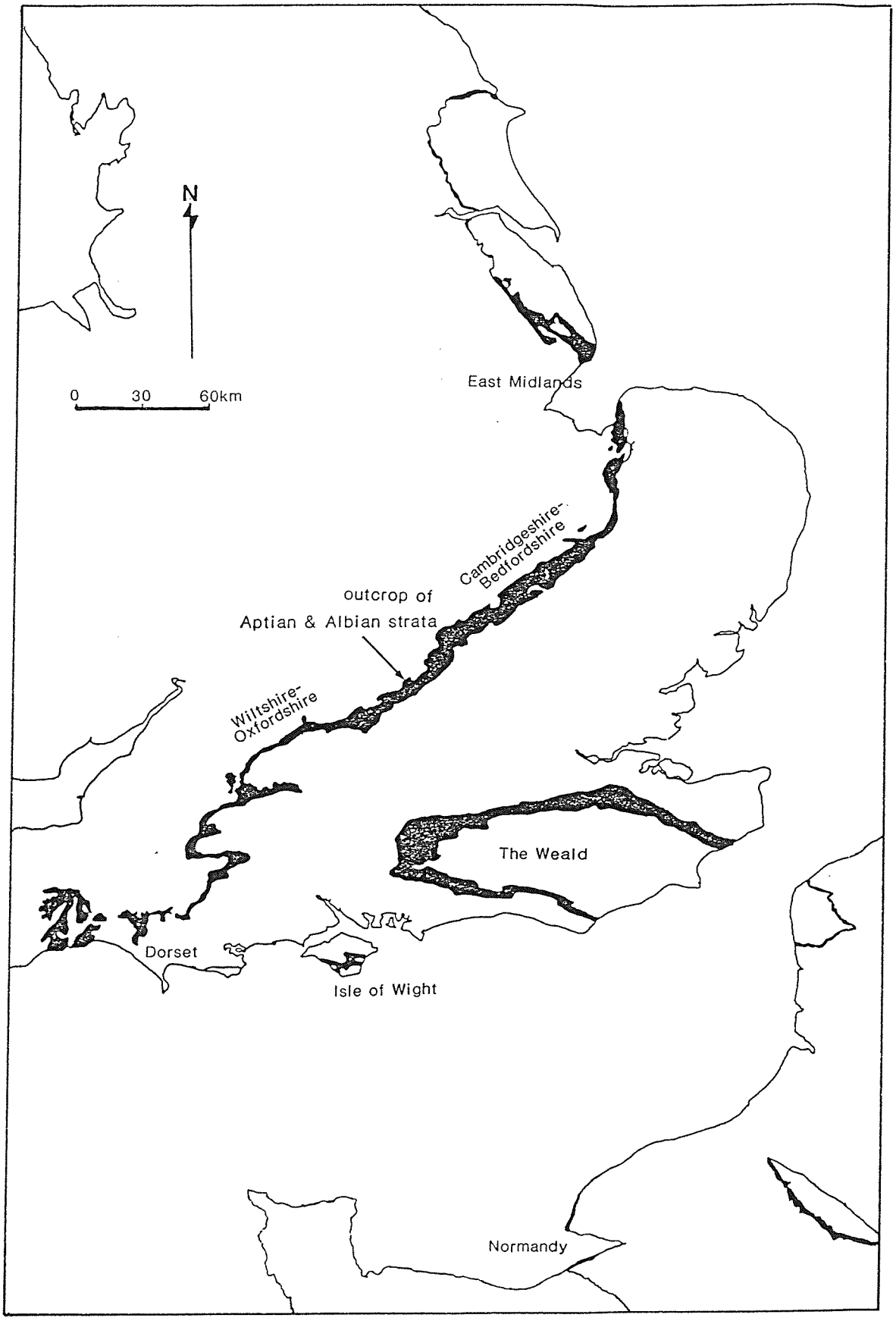


Figure 1.3 An outcrop map for strata of Aptian and Albian age in southern Britain and the adjacent area.

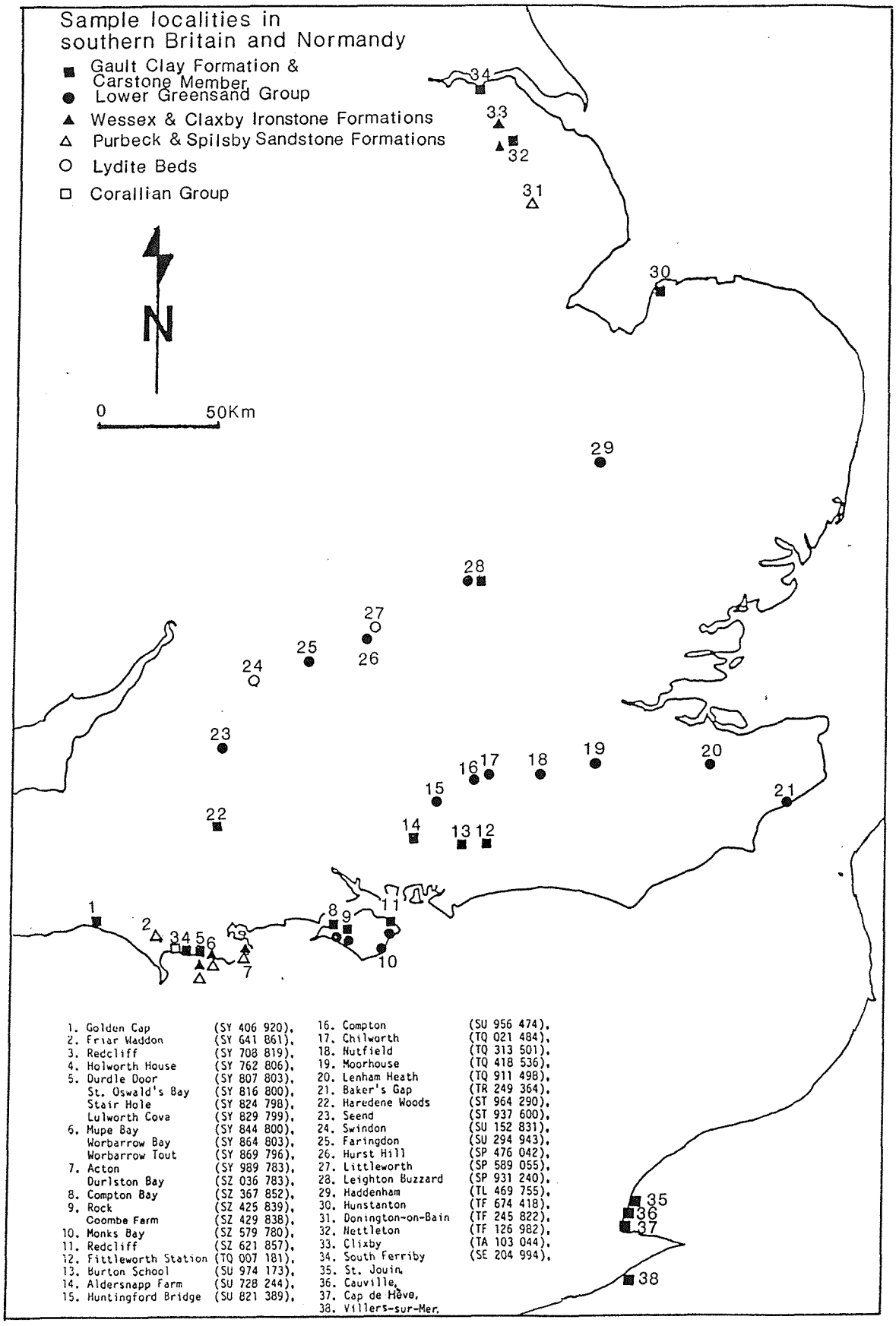


Figure 1.4 Locality map of sample sites used during this study.

Lower Cretaceous rocks in Britain and northern France (see Chap. II). Some horizons (e.g. the basal Gault Clay Formation pebble bed) may be correlated between basins, but more commonly, pebble beds are restricted to a single basin or even to a single sub-basin, for example the Lower Greensand Group of the Weald and the Isle of Wight are quite distinct.

Detailed ammonite biozonal schemes (Zones) have been developed for much of the British Jurassic and Cretaceous sequences (Table 1.1), but control on the age of Upper Jurassic and Lower Cretaceous non-marine deposits in southern England is poor.

The oldest pebble-bearing horizons considered are those of the Corallian Group and the youngest are from the base of the Gault Clay Formation (Table 1.2). Details of the stratigraphic terminology are given in Chapter II and Table 1.2. Where modern terminology has not been developed for specific horizons, earlier names have been retained.

Older pebble beds with exotic clasts derived from sources beyond the Mesozoic basins (extrabasinal clasts) of Rhaetian, Hettangian-Sinemurian and Bajocian age are present in the Mendips area and presumably existed on other structural highs. These pebble beds have not been studied in this investigation.

1.3.1 Corallian Group pebble beds

Pebbles occur in Corallian Group rocks of the southern Midlands and southern Dorset. Two pebble-bearing horizons are present in Dorset, the Preston Grit Member (mid-densiplicatum Zone) and the basal bed of the Osmington Oolite Formation (late densiplicatum Zone; Table 1.3). These beds are correlated respectively with the pebble beds at the base of the Highworth Limestone and the third "Trigonia" Bed in the south Midlands (Arkell, 1933a; Talbot, 1973).

1.3.2 The Lydite Beds

The Lower Lydite Bed (early pallasioides Zone) is a pebble bed in the uppermost part of the Kimmeridge Clay Formation in the Oxford-Cambridge Shelf (Table 1.4). Beyond this area, in the Central Channel Basin, the East Midland Shelf and on the southern flank of the Anglo-Brabant Massif, extrabasinal pebbles are not noted at this

ERA	SYS-TEM	STAGE		STANDARD AMMONITE ZONES
MESOZOIC	EARLY CRETACEOUS	ALBIAN	late	*dispar* *inflatum*
			middle	*lautus* *loricatus* *dentatus*
			early	*mammillatum* *tardefurcata*
		APTIAN	late	*jacobi* *nutfieldiensis* *martinioides*
			early	*bowerbanki* *deshayesi* *forbesi* *fissicostatus*
		BARREMIAN	late	*bidentatum*
			middle	*rude-fissicostatum*
			early	*rarocinctum* *variabilis*
		HAUTERIVIAN	late	*marginatus* *gottschei* *speetonensis*
			early	*inversus* *regale* *noricum* *amblygonium*
		VALANGINIAN	late	(unnamed) *pitrei* *Dichotomites*
			early	*Polypychites* *Paratollia*
		RYAZANIAN	late	*albidum* *stenomphalus* *icenii*
			early	*kochi* *runctoni*
	LATE JURASSIC	VOLGIAN	late	*lampughi* *preplicomphalus* *primitivus*
			middle	*oppressus* *anguiformis* *kerberus* *okusensis* *glaucolithus* *albani* *fittoni* *rotunda* *pallasioides*
			early	*pectinatus* *hudlestoni* *wheatleyensis* *scitulus* *elegans*
		KIMMERIDGIAN		*autissiodorensis* *eudoxus* *mutabilis* *cymodoce* *baylei*
		OXFORDIAN	late	*rosenkrantzi* *regulare* *serratum*
			middle	*glosense* *tenuiserratum* *densiplicatum*
			early	*cordatum* *mariae*

Table 1.1 Standard ammonite Zones for Late Jurassic and Early Cretaceous times (after Cope et al., 1980; Rawson et al., 1978).

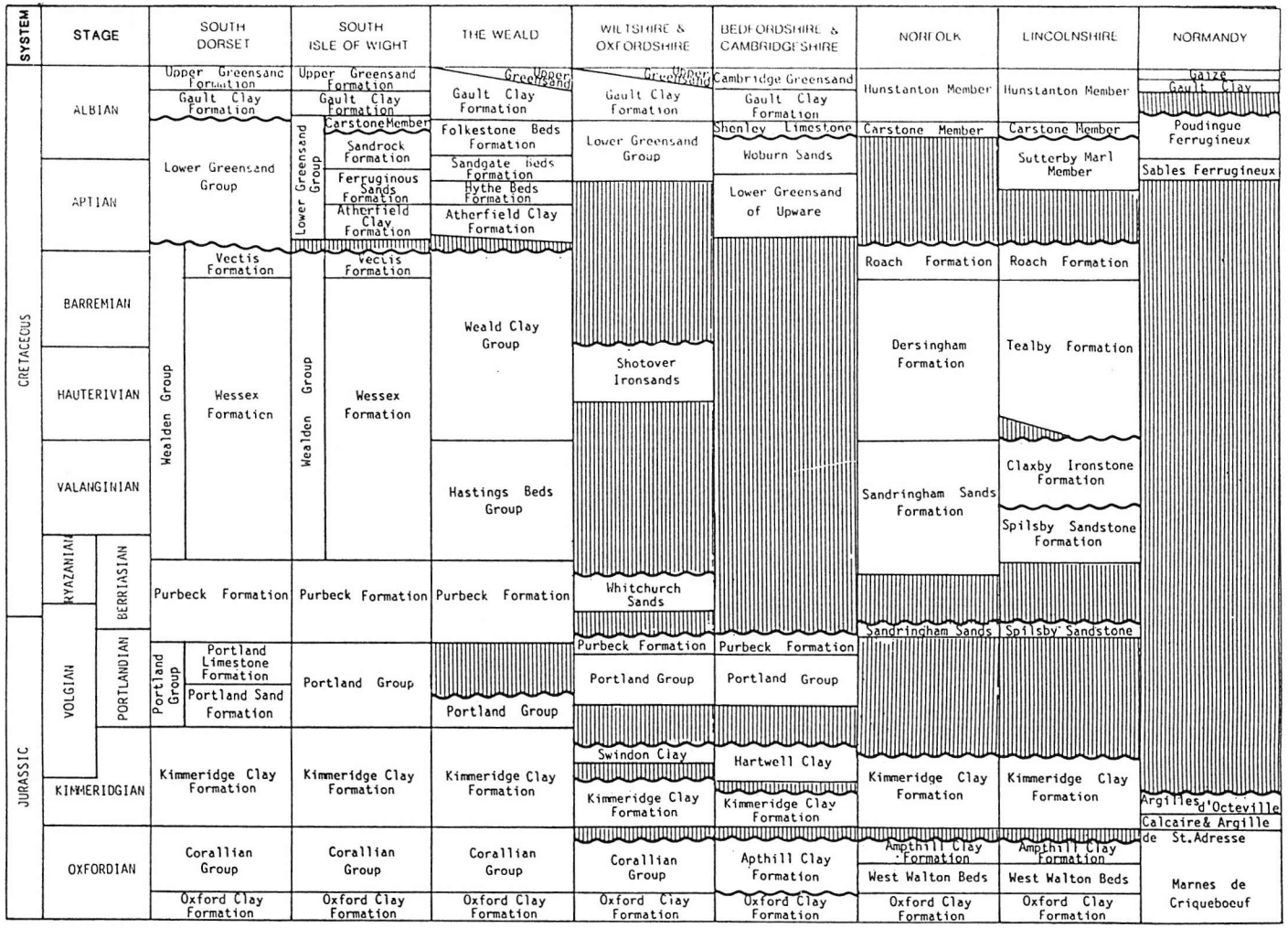


Table 1.2 Simplified Upper Jurassic and Lower Cretaceous lithostratigraphy for southern Britain and Normandy.

STAGE	GROUP	FORMATION	MEMBER
KIMMER-IDGIAN		KIMMERIDGE CLAY	
OXFORDIAN	CORALLIAN	RINGSTEAD	Osmington Mills Ironstone
			Ringstead Clay
		SANDSFOOT	Sandsfoot Grit
			Sandsfoot Clay
		TRIGONIA CLAVELLATA	Red Beds
			Clay Band
			Chief Shell Beds
			Sandy Block
		OSMINGTON OOLITE	Nodular Rubble
			Shortlake
			Upton
		REDCLIFF	Bencliff Grit
			Nothe Clay
			Preston Grit
		NOTHE GRIT	undivided
		OXFORD CLAY	

Table 1.3 Lithostratigraphy of the Corallian Group in Dorset (after Wright, 1986).

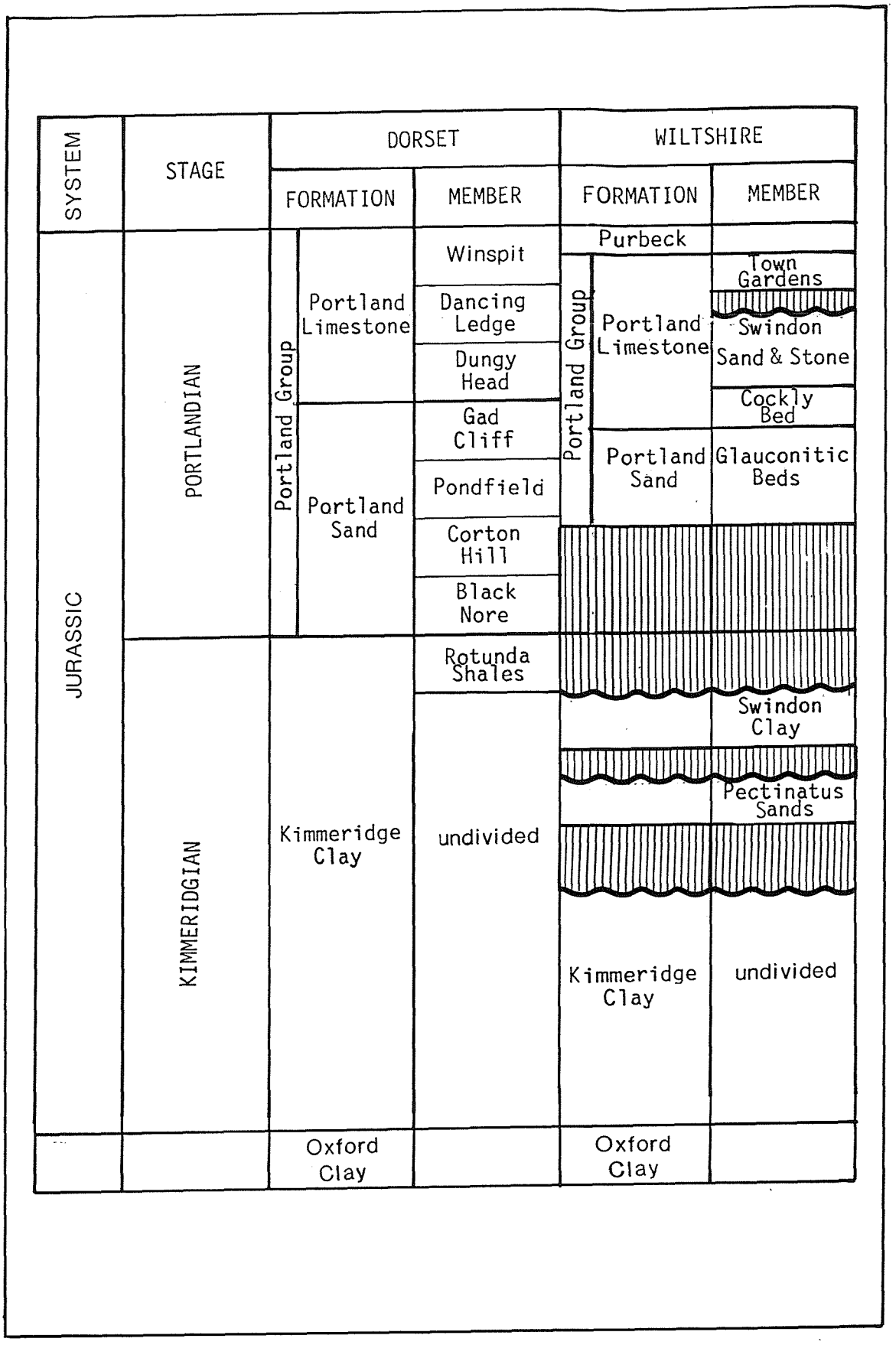


Table 1.4 Lithostratigraphy of the Kimmeridge Clay Formation and the Portland Group in Dorset and Wiltshire (after Townson, 1975; Wimbledon, 1976; Cope et al., 1980).

horizon, but phosphorite nodules are locally developed (e.g. Dorset, Arkell, 1947a; Warlingham, Worssam & Ivimey-Cook, 1971).

The Upper Lydite Bed (early glaucolithus Zone) was recorded by Reid (1903) as far south as the Vale of Wardour and is traceable northwards to Aylesbury (Arkell, 1933a). Pebbly sands reported in the Warlingham borehole were assumed by Worssam & Ivimey-Cook (1971) to be of rotunda Zone age, but Cope et al. (1980) interpreted this horizon as being of earliest albani Zone age. The pebble beds in the Portland Group of the Portsdown borehole were considered by Spath (in Taitt & Kent, 1958) to be younger than the Lower Lydite Bed and were correlated with the Upper Lydite Bed.

Casey & Gallois (1973) and Kelly (1980) noted that pebbly phosphate nodule horizons are present at the base of the Lower Spilsby Sandstone Member and Roxham Member (early oppressus Zone). Phosphorite horizons are also present at the base of the Runcton Member (early preplicomphalus Zone) and at the base of the lower Mintlyn Member (early kochi Zone; Casey & Gallois, 1973), but extrabasinal pebbles are not noted. Rawson et al. (1978) considered that strata of Late Volgian and Early Ryazanian age are absent on the Oxford-Cambridge Shelf.

1.3.3 Purbeck Formation pebble beds

Pebbles have been collected from the Intermarine Member, Scallop Member and the Chief Beef Member of the Purbeck Formation in Dorset (Table 1.5). The detrital suite includes both intrabasinal and extrabasinal detritus. Pebbles are not concentrated in specific horizons.

Casey (1963), in a litho- and biostratigraphical comparison of the basins of southern and eastern England, correlated the deposits of the two areas with those of the East Midlands. Refinements of Casey's work were made by comparison of the molluscan fauna (Kelly, 1983; Morter, 1984). Kelly (1983) proposed that the Intermarine Member is of late runctoni Zone age and its equivalent on the East Midlands Shelf is the nodule bed at the base of the lower Mintlyn Member. The Scallop Member in the Purbeck Formation is correlated with the lower Mintlyn Member (early kochi Zone). Wimbledon & Hunt (1983) also favour a runctoni Zone to kochi Zone age for the middle Purbeck Formation of Dorset. In contrast, Morter (1984)

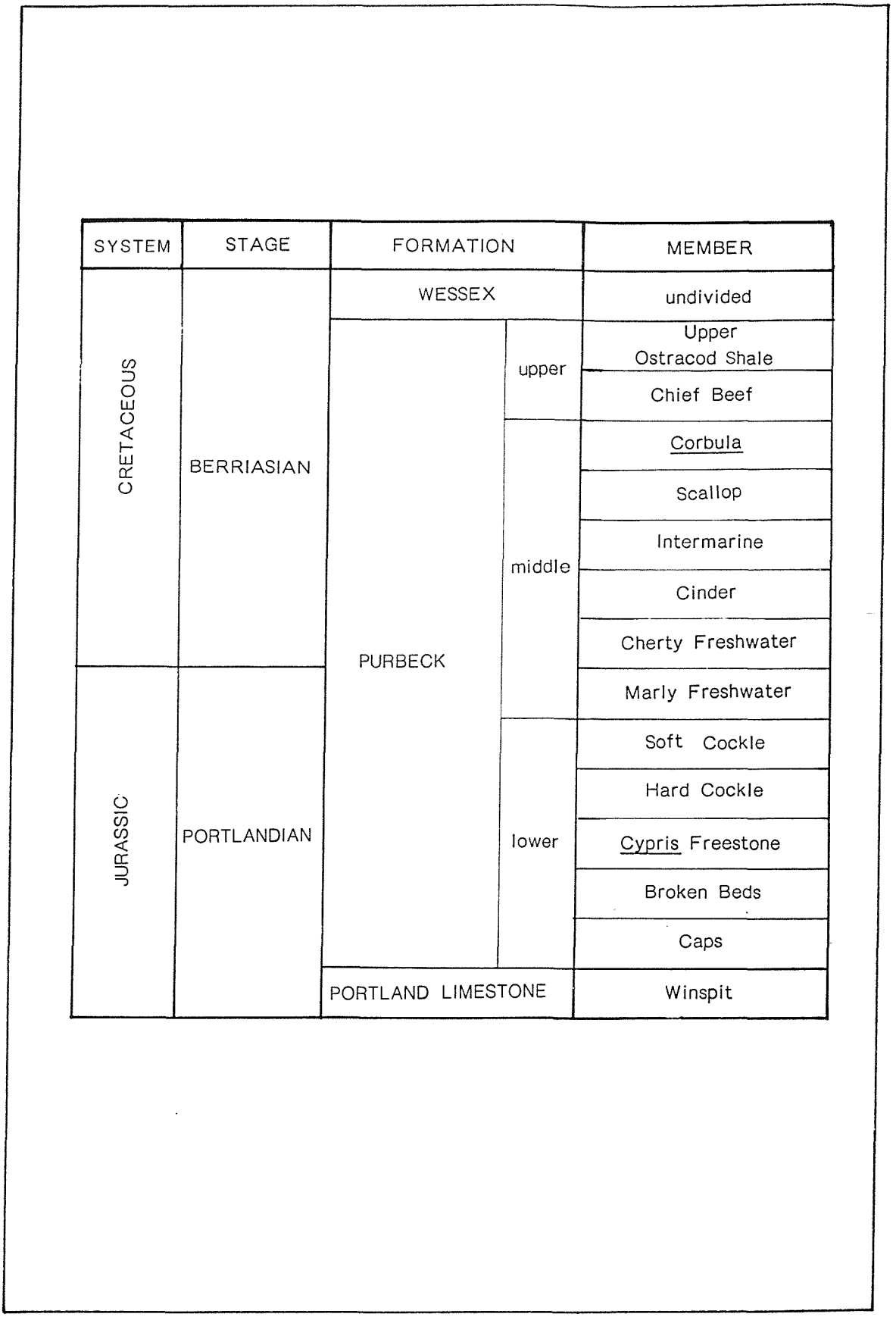


Table 1.5 Lithostratigraphy of the Purbeck Formation in Dorset (after El-Shahat, 1977).

suggests that, in the Purbeck Formation of the Weald Basin, the Intermarine Member is of kochi Zone age and the Scallop Member is of early icenii Zone age. It is apparent that no strong palaeontological evidence has yet been produced to support the correlation of the marine beds in the East Midlands with the non-marine beds in southern England.

1.3.4 "Neocomian" pebble beds

On the East Midlands Shelf, pebble beds are present at the base of the Upper Spilsby Sandstone Member (early stenomphalus Zone) and at the base of the Claxby Ironstone Formation (late albidum Zone; Table 1.6). To the south, sedimentation ceased on the margins of the Anglo-Brabant Massif, whilst fluvial and lacustrine sediments were being deposited in the Wessex Basin. Correlation of the continental deposits with the marine sequence to the north is poor. Pebbly horizons from the Hastings Beds Group and the Weald Clay Group (Table 1.7) have been studied by P.Allen (1949, 1960, 1961, 1967a, 1975). The most laterally persistent are those of the top Ashdown Beds Formation pebble bed (Early Valanginian), the Telham and top Cuckfield pebble beds (Early Valanginian) and the top Lower Tunbridge Wells Sands Formation pebble bed (mid-Valanginian).

The Weald Clay Group pebble beds include those of Warnham, Gossops Green, Ewhurst and Newdigate and are restricted to the northwest Weald Basin (Worssam, 1978). Weald Clay Group deposition is considered to span much of the Hauterivian and Barremian Stages (Casey, 1973; Anderson & Bazley, 1971; P.Allen, 1975; Worssam, 1978). The pebble beds have not been dated more accurately.

The Wealden Group deposits of the western Central Channel Basin are in general coarser grained than those of the Weald Basin and pebble beds are common. The most conspicuous is the Coarse Quartz Grit, dated as Late Valanginian to Early Hauterivian by Hughes & Croxton (1973). The Wessex Formation of the Isle of Wight contains intraformational conglomerates (Stewart, 1978, 1981a), but extrabasinal detritus is rare.

1.3.5 Lower Greensand Group pebble beds

The earliest Aptian marine transgression is marked by a pebble lag at the base of the Lower Greensand Group (mid-fissicostatus Zone)

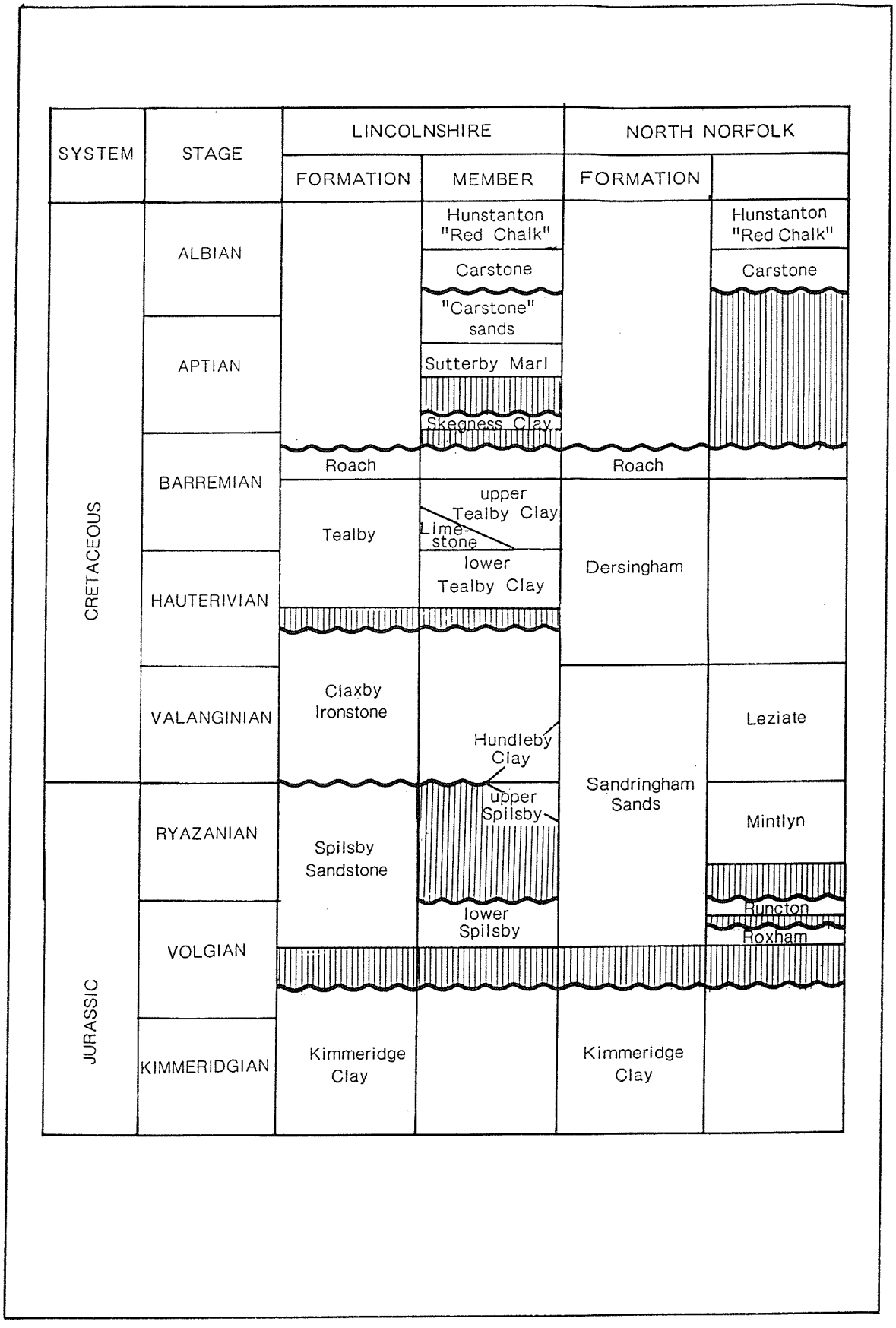


Table 1.6 Lithostratigraphy of the Upper Jurassic and Lower Cretaceous rocks in Norfolk and Lincolnshire (after Kelly & Rawson, 1983).

<table>
<tr><th rowspan="2">SYSTEM</th><th rowspan="2">STAGE</th><th colspan="2">ISLE OF WIGHT</th><th colspan="3">WEALD</th></tr>
<tr><th>GROUP</th><th>FORMATION</th><th colspan="2">GROUP</th><th>FORMATION</th></tr>
<tr><td rowspan="14">EARLY CRETACEOUS</td><td rowspan="2">ALBIAN</td><td></td><td>GAULT CLAY</td><td colspan="2"></td><td>GAULT CLAY</td></tr>
<tr><td rowspan="6">LOWER GREENSAND</td><td>Carstone Member</td><td rowspan="6">LOWER GREENSAND</td><td>FOLKESTONE BEDS</td></tr>
<tr><td rowspan="2">APTIAN</td><td>SANDROCK</td><td>SANDGATE BEDS</td></tr>
<tr><td>FERRUGINOUS SANDS</td><td>HYTHE BEDS</td></tr>
<tr><td rowspan="2">BARREMIAN</td><td></td><td>BARGATE</td></tr>
<tr><td>ATHERFIELD CLAY</td><td>ATHERFIELD CLAY</td></tr>
<tr><td rowspan="2">HAUTERIVIAN</td><td rowspan="8">WEALDEN</td><td>VECTIS</td><td rowspan="8">WEALDEN BEDS</td><td rowspan="2">WEALD CLAY</td><td rowspan="2">undivided</td></tr>
<tr><td rowspan="5">WESSEX</td></tr>
<tr><td rowspan="4">VALANGINIAN</td><td rowspan="6">HASTINGS BEDS</td><td>UPPER TUNBRIDGE WELLS SANDS</td></tr>
<tr><td>GRINSTEAD CLAY</td></tr>
<tr><td>LOWER TUNBRIDGE WELLS SANDS</td></tr>
<tr><td>WADHURST CLAY</td></tr>
<tr><td rowspan="2">BERRIASIAN</td><td>ASHDOWN BEDS</td></tr>
<tr><td>FAIRLIGHT CLAY</td></tr>
<tr><td></td><td>PURBECK</td><td colspan="2"></td><td>PURBECK</td></tr>
</table>

Table 1.7 Lithostratigraphy of the Lower Cretaceous rocks in the Isle of Wight and the Weald (after Stewart, 1983; Casey, 1961; Lake & Shephard-Thorn, 1985).

in parts of the Wessex Basin. In the Potton, Upware and Sutterby areas of Cambridgeshire and at Hunstanton in Norfolk, nodule beds present at the base of the Lower Greensand Group (early fissicostatus Zone) were described by Casey (1961). Younger horizons with derived fossils of Late Aptian age were also found in these areas (Keeping, 1880; Casey, 1961). In the Weald Basin, pebble beds are absent in the Atherfield Clay Formation and lower Hythe Beds Formation (Table 1.7) but pebbly sands are present in the upper Hythe Beds Formation of Surrey (bowerbanki Zone).

The early nutfieldiensis Zone transgression occurred following minor tectonic uplift in both the Weald and Central Channel Basins. This event is marked by pebble beds in the Isle of Wight (base of group XIII as defined by Fitton, 1847; Ferruginous Sands Formation), the western Weald Basin (basal Bargate Beds Formation) and the outliers in Wiltshire and Oxfordshire (Faringdon Sponge Gravel).

The Seend Ironsand in Wiltshire and the Red Sands at Uffington, Oxfordshire are pebbly and are dated as late nutfieldiensis Zone and jacobi-tardefurcata Zone respectively (Casey, 1961; Rawson et al., 1978). The Folkestone Beds Formation of the Weald contain impersistent pebble beds and pebbly sands and are of jacobi-early tardefurcata Zone age. The pebbly sands of the Sandrock Formation in the Isle of Wight and the Woburn Sands in Bedfordshire are of similar age.

1.3.6 Gault Clay Formation and Carstone Member pebble beds

The pebbly sandstones of the Carstone Member in the East Midlands contain Aptian fossils at their base (jacobi Zone) and pass up into the Middle Albian, Hunstanton "Red Chalk" Member (dentatus Zone). In Bedfordshire, the junction of the Woburn Sands and the Gault Clay Formation (dentatus Zone) is marked by a concentration of coarse-grained detritus, both of intra- and extrabasinal origin (Owen, 1972). The pebbly sandstones of the Carstone Member in the Isle of Wight are of mammillatum Zone age and pass up into the Gault Clay Formation (Owen, 1971a). A pebble bed is present at the base of the Gault Clay Formation (dentatus Zone) in Dorset and the southwest Weald. In the former area, the Gault Clay Formation is diachronous and youngs to the west.

1.4 PROVENANCE STUDIES OF BRITISH JURASSIC AND CRETACEOUS SEDIMENTS: PREVIOUS WORK

The Mesozoic strata of southern Britain have been studied for stratigraphical, palaeontological and sedimentological purposes and the presence of coarse-grained detritus has been noted at certain horizons. Although all the horizons examined during this investigation have been studied previously, the composition of detritus has rarely been described. As a consequence of the large amount of published literature available, it is considered unnecessary to give a full listing of the previous literature describing each horizon and location documented in this study. The more recent reports, however, are listed below and these contain references to earlier literature. Investigations of the provenance of the detritus were made in some cases and a more complete list of such references is provided.

1.4.1 The Corallian Group

Detailed studies of the Corallian Group in southern England were made by Arkell (1933a, 1936, 1939a). Pebble beds were noted in the limestones of Oxfordshire (Arkell, 1933a), but detailed descriptions of the detritus were not given. Sedimentological aspects of the Corallian Group were investigated by Wilson (1966, 1967), Talbot (1973, 1974), Brookfield (1973a) and Wright (1981, 1986) and palaeoecological studies were made by Fursich (1975, 1977). Syntheses of the Late Oxfordian palaeogeography were given in Wilson (1968) and Brookfield (1973b, 1978). The provenance of the sand detritus was noted briefly in Wilson (1968); Talbot (1972 unpublished) briefly described the heavy mineral and pebble suites of the Corallian Group and their provenance.

1.4.2 The Kimmeridge Clay Formation and the Portland Group

The rocks of the upper Kimmeridge Clay Formation and Portland Group of Oxfordshire and Wiltshire were described by Chatwin & Pringle (1922) and Arkell (1947b). Recent studies of the Portland Group were made by Townson (1971, 1975) and Wimbledon (1976). The petrography of the deposits and their provenance were considered in some detail by Neaverson (1925). Latter (1926) investigated the heavy-mineral suite of the Portland Group of Dorset.

1.4.3 The Sandringham Sands and Spilsby Sandstone Formations

The Sandringham Sands Formation has been described by Larwood (1961), Casey & Gallois (1973) and Casey (1973). Mention is made of the presence of pebbles in the beds, but their provenance has not been determined. Casey (1973) noted that the basal pebble beds of the Lower Spilsby Sandstone Member and the Mintlyn Member were probably equivalent to those of the Lower and Upper Lydite Beds and concluded that the clasts were from a similar source.

The Spilsby Sandstone Formation of the Lincolnshire area has been described by Swinnerton (1935, 1936-55), and more recently by Kelly (1980, 1984). The petrography of the sands was described by Ingham (1929), but the interpretation of sediment provenance was inconclusive. Glennie & Boegner (1981), in a study of the Sole Pit Trough, suggested an eastern source for the sands because of evidence of uplift in this area during Early Cretaceous times.

1.4.4 The Purbeck Formation

Sedimentological, palaeontological and palaeoecological studies of the Purbeck Formation in Dorset have been made (West, 1964, 1975; Brown, 1964; Pugh, 1968; Clements, 1969; Anderson, 1973, 1985; Francis, 1983a, 1984; El-Shahat & West, 1983), but studies of sediment-provenance have been limited. Sladen (1983) described the clay minerals of the Formation and El-Shahat (1977) examined the heavy-mineral suite. Ensom (1985a) noted pebbles and derived fossils in the middle Purbeck Formation. Pebbles from the upper Purbeck Formation were described by West & Hooper (1969).

1.4.5 The Wealden Beds (Wealden, Hastings Beds and Weald Clay Groups)

The Wealden Beds (Table 1.7) of southern England have been described in detail in the works of P.Allen (1949, 1954, 1959, 1962, 1967b, 1975, 1981). Further descriptions are given by Taylor (1963), Lake & Thurrell (1974) and Worssam (1978). Sedimentological studies in the Wealden Group of the Isle of Wight and the Hastings Bed Group at Hastings were made by Stewart (1981a, 1981b, 1983). With respect to the provenance of detritus, the Wealden Beds sediments are certainly the most exhaustively studied of the Jurassic and Cretaceous strata in Britain. Both heavy-mineral and pebble investigations have been made (Groves, 1931; Kirkaldy, 1939a, 1947a;

P.Allen, 1949, 1959, 1960, 1961, 1967a, 1969, 1972, 1975). In a short note, Oakley (1947) described pebbles of radiolarian chert from the Wessex Formation of Dorset. Dating of zircons from the Hastings Beds and Weald Clay Groups in the Weald by fisson-track analysis has been attemped by Hurford et al. (1984; & in Allen, 1981).

1.4.6 The Lower Greensand Group

Descriptions of the Lower Greensand Group in England are numerous, the most comprehensive being by Casey (1961), in which much of the previous work is covered. More recent studies include the sedimentological investigations of Narayan (1963, 1971); J.R.L.Allen & Narayan (1964) and J.R.L.Allen (1981a, 1981b) and the palaeoecological investigations of Middlemiss (1962a, 1962b). Several of the sedimentological aspects of the Lower Greensand Group of the Weald Basin were summarized by Middlemiss (1975). The sedimentology of the Lower Greensand Group of the Isle of Wight was described by Dike (1972a, 1972b) and noted briefly by Nio (1976). Appraisal of sedimentation during the Aptian and Albian Stages in southern England was made by Kirkaldy (1939b, 1963) and Bridges (1982).

Descriptions of heavy-mineral suites in the Lower Greensand Group of the northwest Weald Basin were given by Davies (1915) and Wood (1956) and for the eastern Weald Basin by Worrall (1956). An examination of quartz-sand provenance in the Sandgate Beds and Hythe Beds Formations was made by Greensmith (1963). Dike (1972b) made a study of the heavy-mineral suite of the Lower Greensand Group in the Central Channel Basin and also examined some of the pebble detritus. Studies of palynomorphs (Duxbury, 1983) revealed reworked Palaeozoic forms in the Lower Greensand Group of the Central Channel Basin. The coarse detritus from the Lower Greensand Group of the Weald Basin was described in detail by Wells & Gossling (1947) and material from the horizons studied was described further by Wells (1947). The provenance of Lower Greensand Group detritus in the Weald Basin, the Central Channel Basin and East Midlands Shelf was considered by Kirkaldy (1947a). Earlier mention of reworked clasts in the Lower Greensand Group was made by Arkell (1939b) in his examination of the derived fauna of the Bargate Beds Formation. Holmes (1981) described the basal Cretaceous pebble suite from the Chislet Colliery workings in Kent.

Summary descriptions of the rocks of Aptian and Early Albian age on the East Midlands Shelf were made by Swinnerton (1935) and Swinnerton & Kent (1975). The Carstone Member was mentioned briefly by Gallois & Morter (1982), and the provenance of the detritus was considered by Versey & Carter (1926) and Rastall (1919, 1930).

1.4.7 The Gault Clay Formation

The Gault Clay Formation and the junction beds at the top of the Lower Greensand Group were described by Owen (1971a, 1971b, 1972), Kirkaldy (1935), Wright & Wright (1948) and Casey (1950, 1955, 1961). Arkell (1947a) described pebbles of chert from the Portland Limestone and Purbeck Formations in the Gault Clay Formation in the western Central Channel Basin, but detailed descriptions of the coarse-grained detritus in this horizon were not carried out.

1.4.8 The Sables and Poudingue Ferrugineux

The Lower Cretaceous strata of the Normandy coast were described by Destombes (1958), Owen (1971a), Juignet et al. (1973) and Destombes et al. (1977). Studies of Upper Jurassic and Lower Cretaceous sediments were made by Juignet (1971) and Robaszynski (1981). Juignet et al. (1973) described the composition of the pebble suite of the Poudingue Ferrugineux and the heavy-mineral suites of the Poudingue and Sables Ferrugineux. Earlier heavy-mineral studies of these beds and the Lower Greensand Group in the Isle of Wight were made by Pomerol (1963).

1.5 THE MESOZOIC STRUCTURAL FRAMEWORK OF SOUTHERN BRITAIN AND THE SURROUNDING AREA

Sedimentation in Britain during Late Jurassic and Early Cretaceous times was restricted to basins flanking a group of basement highs. The relief on the highs varied through time, being controlled by phases of uplift and downwarping of the erosion base level (e.g. sea- or lake-level). From Late Jurassic to mid-Cretaceous times the massifs were probably land areas which were subsequently submerged during a series of mid and Late Cretaceous transgressions (Hancock & Kauffman, 1979; Cope, 1984). The principal massifs were Anglo-Brabant, Wales, Cornubia, Armorica and Scotland (Fig. 1.1). The Lake District, the Pennines, the Market Weighton

structure and the Mid-North Sea Ridge were probably also structural highs, but of a smaller size (Figs. 1.1, 1.2).

The principal areas of sediment accumulation were the Southern North Sea Basin, the Wessex Basin, the Irish Sea Basin, the Cardigan Bay Basin, the St. George's Channel and the South Celtic Sea Basin. Onshore in Britain, sediments of Late Jurassic and Early Cretaceous age are preserved only in the Southern North Sea Basin and the Wessex Basin, with small relics present also in the Inner Hebrides. The two English basins were sites of deposition throughout the Mesozoic Era and their configurations were controlled by basement structures.

On the exposed western margin of the Southern North Sea Basin, the East Midlands Shelf, the Market Weighton High and the Cleveland Basin, the basement is concealed by Mesozoic and Palaeozoic rocks. Magnetic and gravity surveys of the area reveal deep-seated structures with a northwest-southeast trend, probably within the Caledonian basement (Ziegler, 1981; Smith, 1985).

The Wessex Basin, as defined by Kent (1949) and Whittaker (1985), incorporates the Weald, Isle of Wight, Dorset, east Somerset and southern Wiltshire. The dominant structural trend in this area is east-west, but deviates to a northwest-southeast trend in Kent. As early as 1856, Godwin-Austen noted that the structures in the Mesozoic basins were parallel to the dominant lineation in the Upper Palaeozoic rocks of Devon, Cornwall and Ferques (northern France). The basement fabric is principally the result of Variscan deformation which produced the basement thrusts and associated hangingwall anticlines recognised beneath the Mesozoic basins in southern England (Chadwick et al., 1983). The Wessex Basin is not a single structure but a series of smaller sub-basins separated by fault-bounded highs (Chadwick et al., 1983; Sellwood et al., 1985; Chadwick, 1985a, 1986). The shape and size of the Mesozoic sub-basins appear to have been controlled by basement structures which reactivated as normal faults. Subsidence occurred within a series of half grabens bounded by major faults (Chadwick, 1985a, 1986). Thick sedimentary sequences accumulated in the immediate hangingwalls to these faults, while their footwalls were places elevated sufficiently to have acted as local structural highs and depositional minima (Sellwood & Jenkyns, 1975; Chadwick, 1986).

CHAPTER II

FIELD OBSERVATIONS AND INTERPRETATIONS

2.1 GENERAL

The study of the provenance of Lower Cretaceous sediments has involved sampling throughout southern Britain and from selected localities in northern France. Samples were collected from the Weald, the Isle of Wight and from scattered localities along the western margin of the Cretaceous outcrop, from Dorset to the Humber (Figs. 1.3, 1.4). In France, Albian pebble beds were examined on the Calvados and Caux coasts.

2.1.1 Conditions of deposition

Pebble beds are formed where conditions are suitable for winnowing out the finer fractions and concentrating the coarsest detritus. Gravel deposits forming as a response to a single depositional event are rarely laterally extensive (e.g. gravel bars in rivers; flood sheets on alluvial fans; gravel lenses on beaches). In contrast, local environmental changes may result in the concentration of detritus. Areas of rapid subsidence adjacent to faults are particularly prone to the concentration and preservation of coarse-grained detritus (Leithold & Bourgeois, 1984). Notable examples of rocks deposited in such situations include the Violin Breccia (Pliocene) in California; this alluvial fan unit is up to 11km thick and extends along the San Gabriel fault for about 30km, but is only 1.5km wide, passing laterally into sandstones (Link & Osborne, 1978). A second example is the submarine fan deposits of the Brae Formation (Late Jurassic) which occur adjacent to the eastern bounding faults of the Fladen Ground Spur in the northern North Sea. The conglomerates of the Brae Formation are over 2km thick, but extend far less than 5km from the fault complex. Regional environmental changes, however, may result in the more widespread concentration of coarse-grained detritus. This is particularly the case in marine or lacustrine environments where strand-line retreat or advance is of importance. Coarse-grained detritus previously held in the foreshore or nearshore zone or in fluvial channel deposits may be reworked or stranded on the shelf during such events. Deposits of this type are generally of negligible thickness but may be laterally extensive. The depositional environments of pertinence to the present study are summarised.

2.1.1.1 Fluvial pebble beds

Conglomerates in fluvial regimes are typically associated either with alluvial fans at basin margins or with areas of more persistent subaqueous transportation, in particular channel deposits. In river systems remote from areas of resistant rock types or with well-developed alluvial plains, conglomerates are commonly composed of intraformational clasts (e.g. Stewart, 1981a). In contrast, where the fluvial system is close to sources or is capable of transporting detritus for long distances, extrabasinal clasts may predominate. Miall (1977), in a study of braided-fluvial depositional environments, recognised three types of clast-supported fluvial conglomerate. Subsequently, Rust (1978) and Miall (1978) recognised a fourth gravel lithofacies. The four gravel types are:

1. massive gravels,
2. trough cross-stratified gravels,
3. tabular cross-stratified gravels, and
4. matrix-supported gravels.

1. Massive gravels are laterally persistent for hundreds of metres and are up to 1m in thickness. The gravel units have erosional bases and are typically overlain by similar deposits or cross-stratified gravels. Massive gravels are moderately well-sorted and clasts may be imbricated. Poorly defined horizontal stratification or low-angle cross-stratification may be recognised, particularly if the clasts are of low sphericity (Fig. 2.1a). Infiltration matrices of sand or silt are present in some conglomerates (Rust, 1978) and thin impersistent sand and silt laminae may overlie gravel beds. Miall (1977) considered the massive gravels to have been deposited as longitudinal bars. The horizontal lamination and low-angle cross-stratification in such deposits results from lateral accretion (Fig. 2.1a).

2. Trough cross-stratified gravels are lenticular in form with erosional basal surfaces. Beds commonly cross-cut one another and single beds often fine upwards. Such units were interpreted as minor channels filled by migrating bars.

3. Tabular cross-stratified gravels consist of beds up to 4m thick, each composed of a single set or cosets of smaller, tabular units.

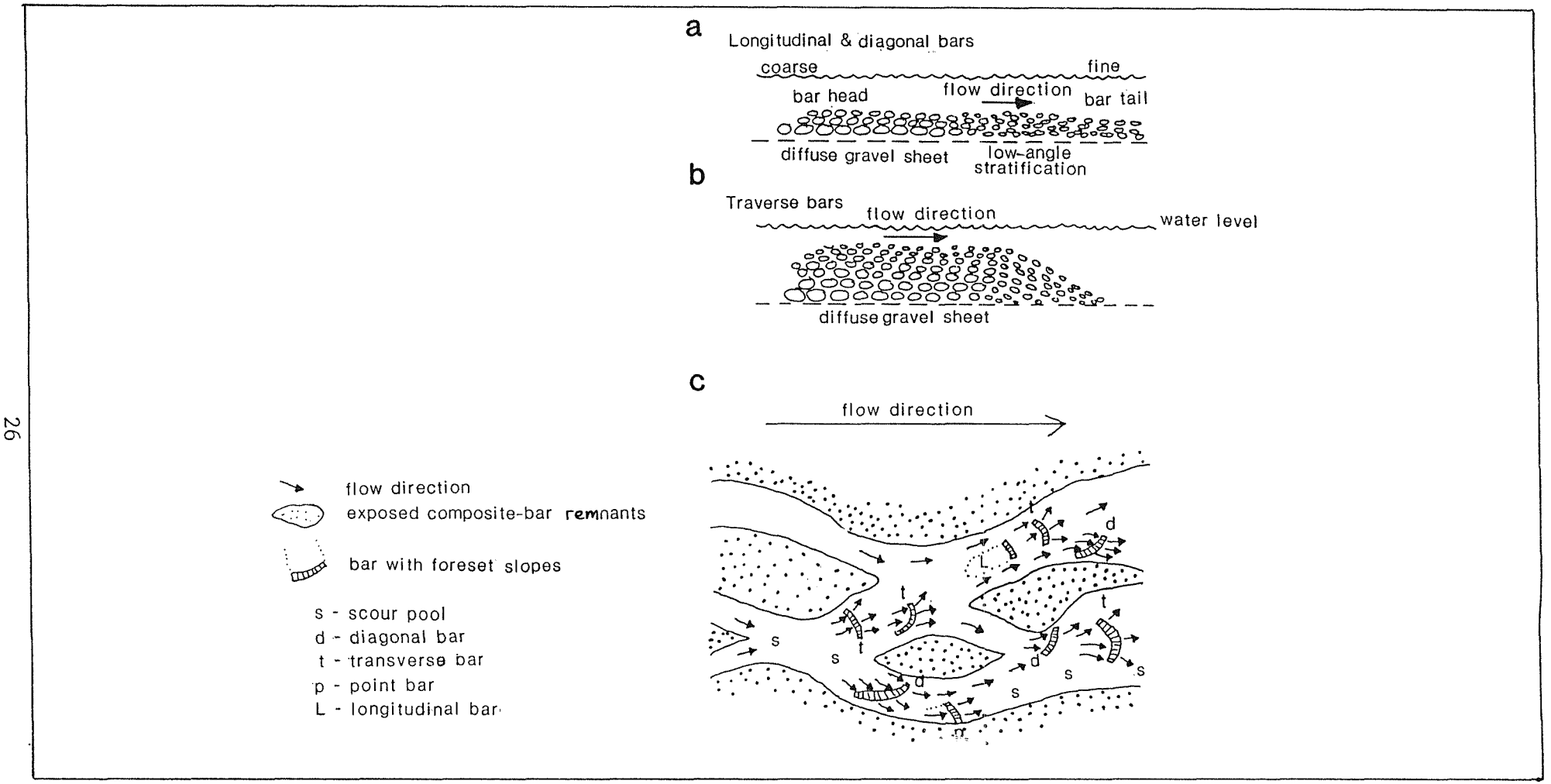


Figure 2.1 Cross-section of longitudinal, diagonal and transverse gravel bars (a,b) and the types of bar in a gravel-dominated fluvial system (c; after Hein & Walker, 1977).

Low-angle reactivation surfaces may be present in the beds. The tabular gravels are considered to be linguoid bar deposits or micro-deltas generated from older bar remnants (Fig. 2.1).

4. Matrix-supported gravels have basal erosion surfaces and contain clasts supported in a finer-grained matrix. These deposits were suggested to be debris-flow deposits; such sediments were considered to be common on alluvial fans and to be one of the criteria used to distinguish alluvial fan deposits from gravel braid-plain deposits (Rust, 1979).

These four gravel types occur principally in areas where there is a sufficent supply of coarse-grained detritus. In more sandy sequences, gravels are generally restricted to unstratified lags either at the base of channel deposits or within cross-stratified sand units.

2.1.1.2 Strand-line pebble beds

High-energy shoreline environments are important traps for pebble-grade detritus. The processes active on and adjacent to shingle beaches have been extensively studied, but ancient pebble beach deposits are not common and are not well understood. Studies of Pleistocene shore-line gravels are moderately common but older gravels are less well described. In the recent investigation by Bourgeois & Leithold (1984) of nearshore pebbly sandstones of Miocene age, three principal gravel lithotypes were recognised:
1. low-angle cross-stratified gravels,
2. lenticular gravels, and
3. tabular gravels.
Dispersed pebbles and shell debris are also present in the interbedded sand units.

1. Low-angle cross-stratified gravels: are composed of pebbles and coarse-grained shell debris concentrated in thin beds (0.1-0.5m thick) and interbedded with pebbly sands. They are considered to have been deposited as shoreward-migrating nearshore bars possibly similar to those described by Hunter et al. (1979). Such deposits were probably formed on the lower shoreface, below the zone of normal surf-action (Fig. 2.2a).

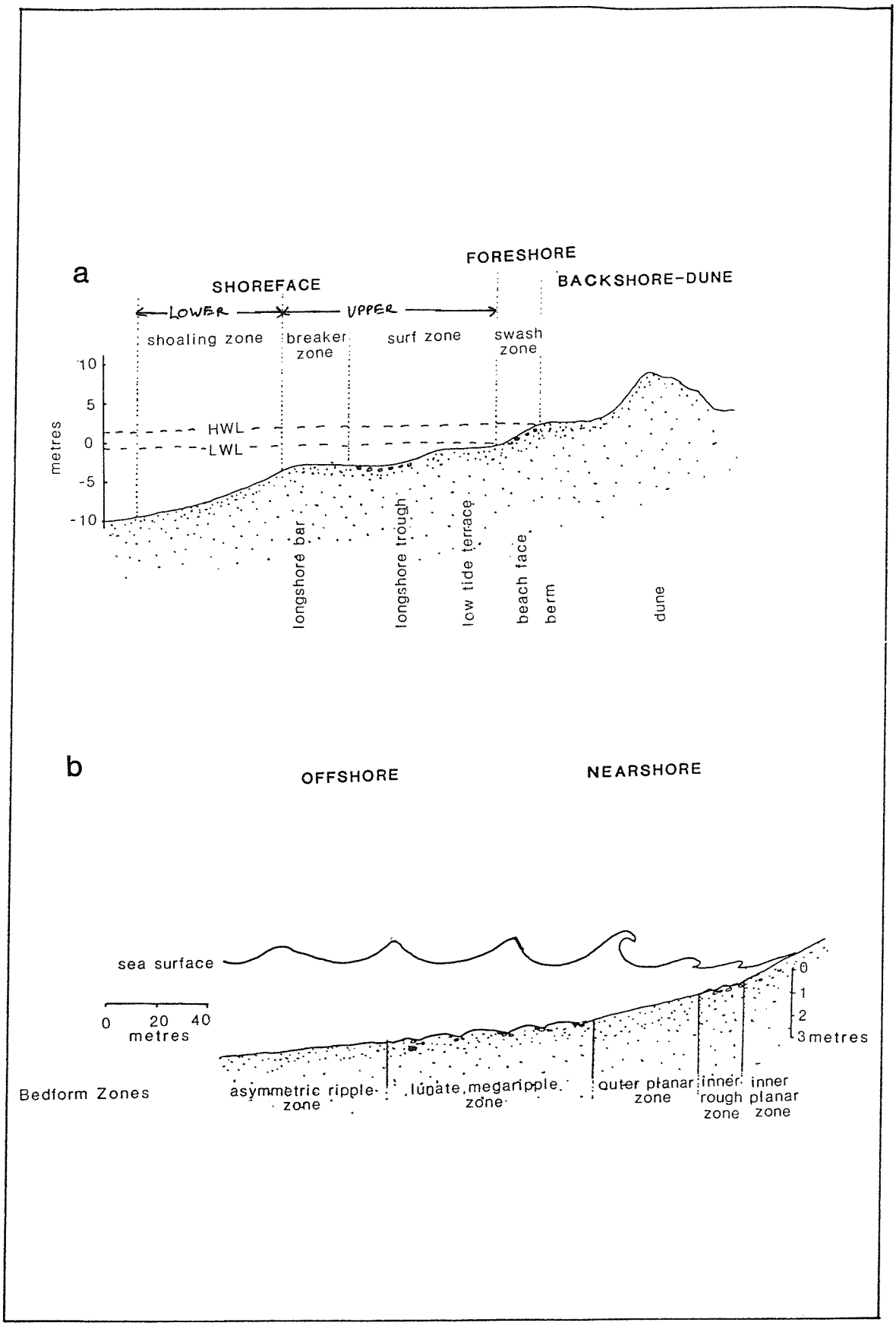


Figure 2.2 Generalised beach profile (a) with nearshore bedform zones (b; in part after Clifton et al., 1971).

2. Lenticular conglomerates: are 0.1-0.3m thick and extend 0.5-1.0m laterally. The pebbles are concentrated in troughs, with coarser-grained basal lags. These gravels are commonly associated with the low-angle cross-stratified gravels and are assumed to have formed in the troughs between migrating nearshore bars. The lenticular gravels are possibly the equivalents of the pebbly, lower shoreface deposits present in troughs and scour pools between landward-migrating lunate megaripples (Fig. 2.2b; Clifton et al., 1971).

3. Tabular pebble units: are notable for their lateral persistence. They are up to 0.6m thick and extend for greater than 30m. The presence of gravel megaripples at the tops of the tabular units led Bourgeois & Leithold (1984) to conclude that the deposits had been subjected to subsequent reworking by waves. The lateral extent and sheet-like form of the deposits were considered to be indicative of a storm-induced reworking of gravel and possibly associated rip-current transportation. The megaripples are possibly comparable to the recent deposits noted by Yorath et al. (1979) and the ancient deposits described by Wright & Walker (1981) and Cotter (1985). The gravels were considered to be upper shoreface deposits periodically reworked by storm-induced currents and waves (Bourgeois & Leithold, 1984). Clifton et al. (1971) described similar structures in the "rough zone" of the upper shoreface (Fig. 2.2b). The general high sphericity of the pebble suite examined by Bourgeois & Leithold (1984) excluded any possible imbrication in the gravels. However, it has been realised for some time that clast-imbrication on gravel beaches is a common feature (Dobkin & Folk, 1970; Clifton et al., 1971).

Other features described and discussed by Bourgeois & Leithold (1984) and which are possibly of importance as shore-line or nearshore indicators are pebble-filled burrows and furrows. They identified burrows (Ophiomorpha?) which had been open for some time prior to being filled with pebbles. Pebble-filled burrows and collapse structures were also reported in pebble beds deposited on high-energy offshore bars (Phillips, 1984).

The preservation potential of upper shoreface deposits during a

transgression is low, since the landward migration of the surf-zone is likely to result in the erosion of such deposits (Hunter et al., 1979). Lower shoreface deposits have a better preservation potential, but are also likely to be subject to reworking during storm events and by shelf processes. Commonly strand-line transgressions are marked by an erosion surface (ravinement) covered by a thin pebble lag, which is overlain by offshore marine deposits (Clifton, 1967, 1973). The preservation of strand-line deposits during regressions is also improbable because of subsequent weathering and sub-aerial erosion.

2.1.1.3 Marine-shelf pebble beds

Processes acting on marine shelfs are commonly considered to be either of meteorological or tidal origin, but it is probable that in many cases there is an interaction of the two processes.

Shelves dominated by meteorological currents: on shelves dominated by meteorologically-induced currents, reworking of pebbles may occur under certain conditions. The sand-bar deposits off the coast of the eastern United States are considered to have formed in response to storm-track currents orientated sub-parallel to the coast (Swift et al., 1973). Pebbles are concentrated towards the top of such structures through helical flow (Fig. 2.3a).

Pebble beds in marine-shelf deposits are generally considered to be reworked strand-line sediments (Belderson & Stride, 1966) or less commonly are introduced from a fluvial system (e.g. Harms et al., 1981). Wright & Walker (1981) and Cotter (1985) proposed that pebbles were transported from the shore-line onto the shelf by rip currents or down-welling currents induced by storms. Pebbles, up to 45mm in length, transported up to 15km from the shore were envisaged by Wright & Walker (1981). Cotter (1985) postulated gravel bars up to 25km from the shoreline, with transportation of pebbles offshore. Modern examples of down-welling currents are noted in the tropics (Short, 1985), where hurricanes can produce offshore flows and cause transportation of coarse-grained sand (cf. Hurricane Carla, 1961; Fig. 2.3c). Seaward transportation of pebble-grade detritus, however, has only been tentatively suggested and such processes have not been proved to occur. Where rip-currents and down-welling

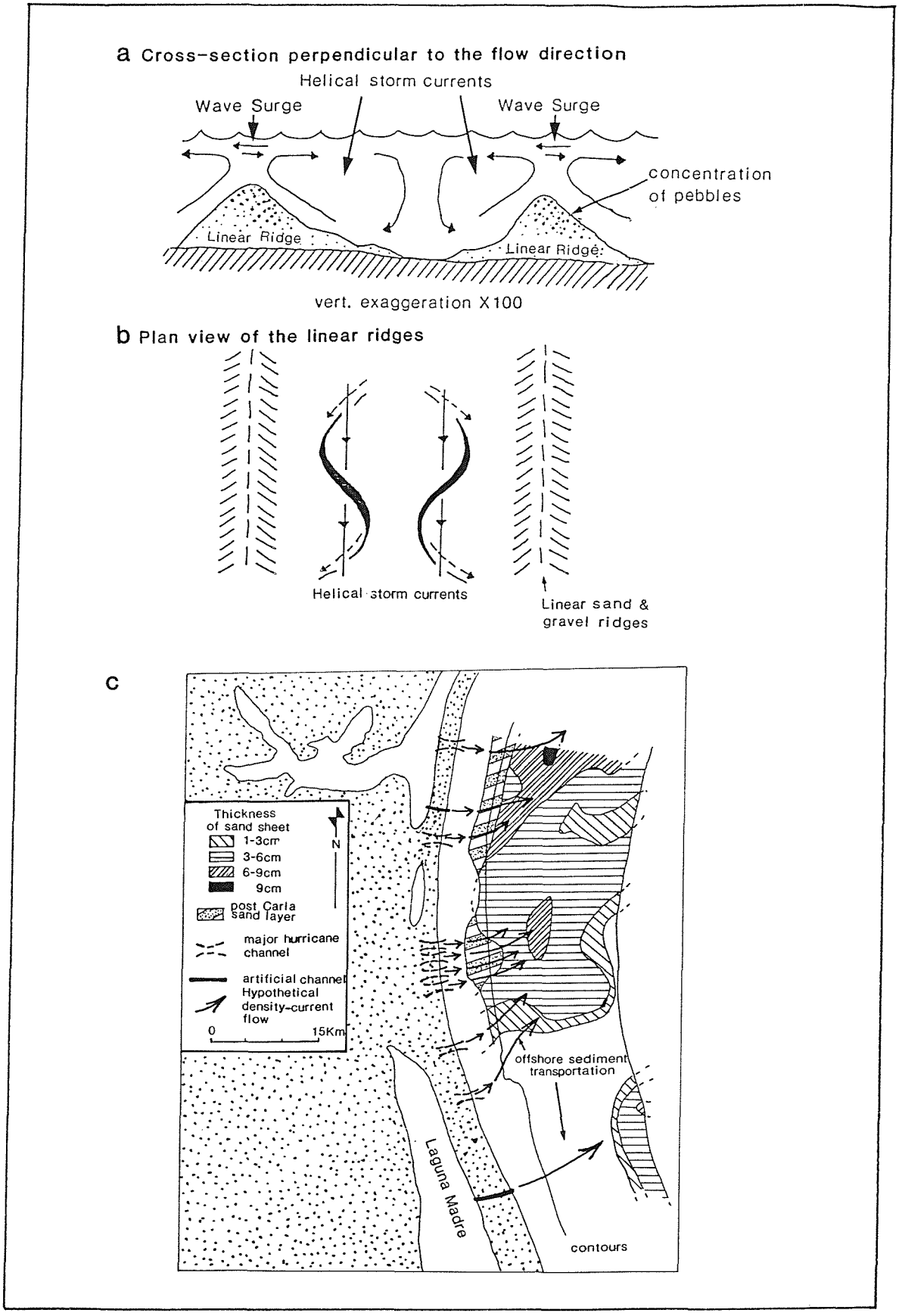


Figure 2.3 Linear sand ridges and their mode of formation by secondary (helical) flow currents and storm-induced wave surge (a,b; after Swift et al., 1973) and seaward-directed density currents, Texas, USA, following Hurricane Carla, 1961 (b; after Hayes, 1971).

currents are active, the direction of transportation is assumed to be sub-perpendicular to the shoreline. Shelf meteorological or tidal currents may result in a further migration of detritus.

Shelves dominated by tidal currents: tidal currents influenced by local basin geometry may be sufficiently rapid to cause the entrainment of pebble-grade clasts (Dyer, 1972; Hammond et al., 1984). It is probable that pebbles are transported only during extreme conditions (e.g. storm-enhancement of tidal currents; Anderton, 1976). In periods of relative quiescence, clasts are stranded on the shelf or concentrated in winnowed lags. The transportation of sand and granule-grade detritus parallel to the dominant tidal flow results in the creation of pebble lags in areas of bed-load parting (Kenyon & Stride, 1970).

Pebbles may be transported in sandwave bodies, but are uncommon in such deposits and are dispersed in the sand. The pebbles in sandwaves ("large flow-transverse bedforms coupled to oscillatory boundary-layer currents of tidal origin", J.R.L.Allen, 1980) are typically small. Sandwaves are semi-permanent structures typically of asymmetrical form, with the steeper limb of the structure forming to the lee of the dominant current direction. Internally such structures are composed of large-scale tabular cross-sets, with either uniform or bimodal set-orientations (Fig. 2.4a). The internal structure of the cross-sets may reveal evidence for alternating episodes of pebble, sand and silt deposition with sandwave destruction and reconstruction. Detailed examination of such structures may provide information concerning the periodicity of the tides and bed-load transportation rates (J.R.L.Allen, 1981a, 1981b, 1982; P.A.Allen & Homewood, 1984).

Destruction of the sandwaves was suggested (P.A.Allen & Homewood, 1984) to occur during spring tides and construction during neap tides. The destruction of sandwaves with pebbly sands may result in the formation of pebble lags. This may occur through normal changes during a tidal cycle or can result from the cumulative effect of tidal currents and complimentary storm-surge conditions (Anderton, 1976; Fig. 2.4b).

The transport direction of sand-grade detritus in sandwave

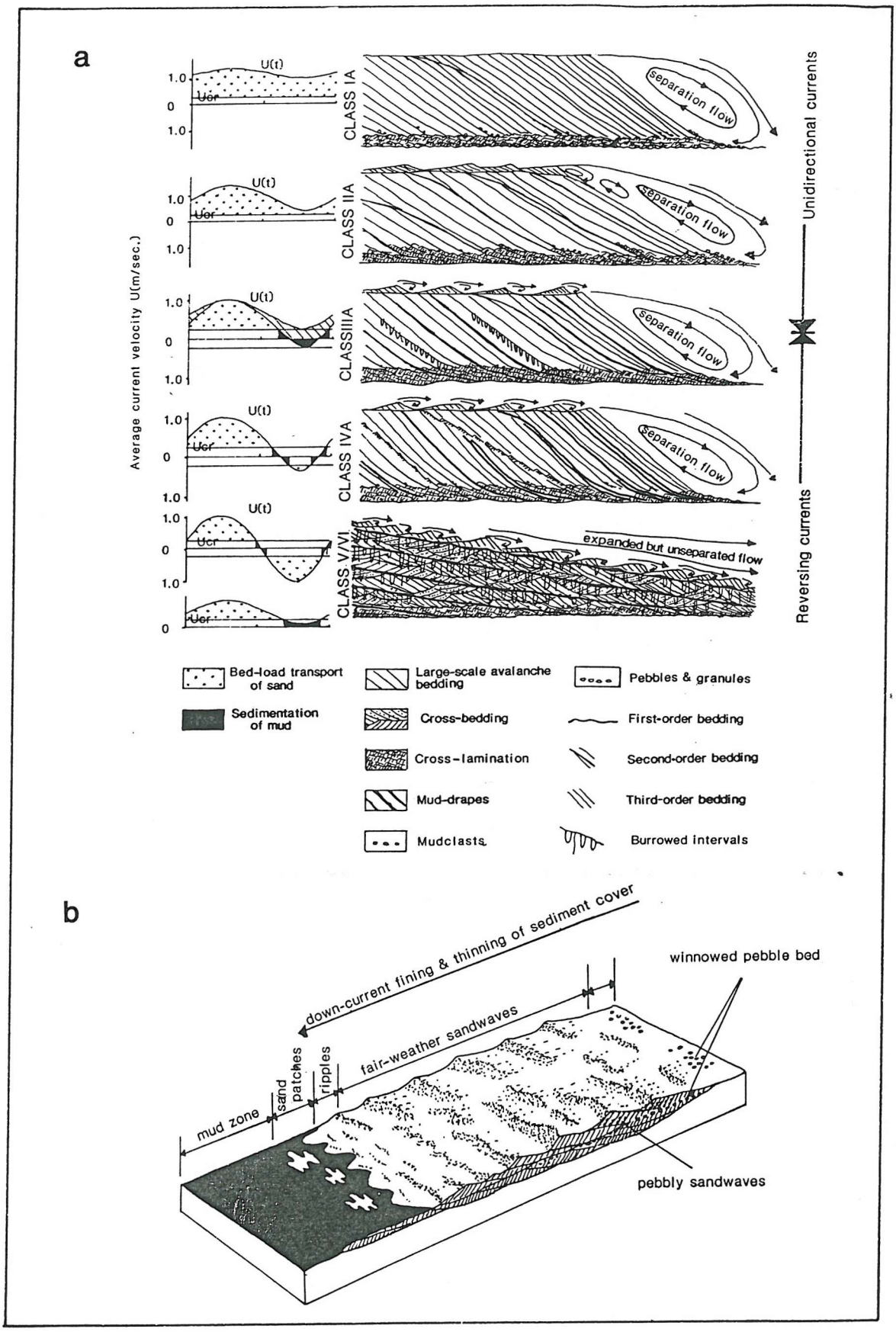


Figure 2.4 Sandwave types and their internal structures (a; after J.R.L. Allen, 1980) and a diagrammatic representation of the build-up and migration of fair-weather sandwaves (b; after Anderton, 1976).

bodies is parallel to the dominant tidal-current direction (Kenyon & Stride, 1970). The direction of transportation of pebble-grade detritus is assumed to be similar.

2.2 UPPER JURASSIC AND LOWER CRETACEOUS PEBBLE BEDS OF SOUTHERN BRITAIN AND NORMANDY

Studies have been made of a number of the Lower Cretaceous pebble beds in southern Britain and northern France, but it has not proved possible to sample all horizons to the same extent. In response to this, pebble suites from a restricted stratigraphical range were examined and compared. Selected samples from other pebble horizons were studied. Those of Early and Middle Albian age were chosen for the detailed study, being the most laterally extensive of the Lower Cretaceous pebble-bearing deposits.

A study of regional variation in the detrital suites defined seven distinct areas; six in southern Britain and a further one in northern France (Normandy). Each of the areas contains a characteristic pebble suite. In some cases boundaries between regions are not well defined and are probably transitional. The seven areas are:

1. Dorset,
2. Isle of Wight,
3. the Weald,
4. Oxfordshire and Wiltshire,
5. Bedfordshire and Cambridgeshire,
6. Lincolnshire and north Norfolk,
7. Normandy.

2.2.1 The Dorset area

The Dorset area, as defined from this study, extends from Swanage to Lyme Regis. The western boundary is delimited by the extent of the youngest pebble bed studied, the basal Gault Clay Formation. The northern boundary of the area is indistinct because of the Upper Cretaceous and Tertiary cover. The area does not extend as far north as the Vale of Wardour and is possibly restricted to the

area south of the Purbeck Monocline. The Dorset area does not extend as far east as the Isle of Wight, but probably includes the eastern part of the Isle of Purbeck. The southern limit of the area lies somewhere beneath the English Channel.

Coarse-grained detritus was collected from the Corallian Group, Purbeck Formation, Wessex Formation and from the base of the Gault Clay Formation. All the horizons contain distinctly different pebble suites and were deposited in different sedimentary environments. Coastal sections provide the best outcrops, but stone-quarries in the Purbeck Formation limestones are also accessible.

2.2.1.1 The Corallian Group

The Corallian Group of southern England is a sequence of marine limestone-clay-sand alternations of Middle to Late Oxfordian age. The Group was separated into a series of "cycles" by Arkell (1933a, 1936). Talbot (1973) later redefined the limits of the cycles and interpreted them as the result of four transgressive-regressive couplets, deposition occurring in offshore, nearshore and lagoonal environments. Eustatic sea-level changes were believed to be the controlling factor for this variation in sedimentation. In a reinterpretation of the Corallian Group of northern Dorset, Wright (1981) refuted Talbot's four-fold division. He suggested that there were at least nine sedimentary episodes, which resulted from tectonic disturbances in addition to eustatic changes in sea-level.

The stratigraphic terminology used by Wright (1986) has been adopted for the present study. The terms are generally derived from earlier works, but where they differ distictly from those of Arkell (1947a), the latter's names are also noted.

In Dorset, coarse-grained detritus is present at the bases of Talbot's second and third cycles (Talbot, 1973), that is, the Preston Grit Member at the base of the Redcliff Formation (the '<u>Trigonia</u>' <u>hudlestoni</u> Bed of Arkell, 1947a) and the basal beds of the Osmington Oolite Formation, respectively (Table 1.3). Only the Preston Grit Member was sampled.

Preston Grit Member (mid-densiplicatum zone), Redcliff, Dorset (SY 708 819)

The Redcliff section provides a good exposure of the top of the first and base of the second of Talbot's cycles in Dorset (Pl. 1-1). The section was described by Arkell (1947a, p.51-53).

Description: The Preston Grit Member is a sandy, bioclastic limestone, 1.0-1.5m thick, overlying the fine- to medium-grained arenites of the Nothe Grit Formation. The top of the Preston Grit Member is gradational and passes up into calcareous and argillaceous mudstones of the Nothe Clay Member. The limestone is composed of thin lenticular units of medium- to coarse-grained bioclastic and quartzose sand. The Preston Grit Member contains a diverse marine fauna predominantly of bivalves and echinoderms (Arkell, 1947a). Burrows of Thalassinoides, Spongiomorpha and Rhizocorallium are present (Fursich, 1975). Trough cross-stratified shell-sands are preserved in parts of the bed, but bioturbation has largely destroyed original stratification. The limestone displays crude upwards coarsening.

Pebbles are concentrated in the coarse shell lag and are also found scattered through the sandy limestone. The clasts are on average less than 5mm in diameter and composed of dark, subrounded chert and translucent or white, well-rounded quartz (Sect. 4.2.1.1).

Interpretation: The fauna of the bed indicates that the limestones were deposited in waters of normal marine salinity (Talbot, 1973). The presence of Thalassinoides, Spongiomorpha and Rhizocorallium burrows is consistent with deposition in the sub-tidal environment (Fursich, 1975). The variation in the grain size of the deposits suggests that deposition occurred under variable energy conditions. Periodic winnowing probably resulted in the concentration of coarser-grained debris. Talbot (1973) suggested that the bed was an offshore shell-bank deposit.

The source of the pebbles in the Preston Grit Member is uncertain. The most obvious potential source, the underlying Nothe Grit Formation, contains no pebbles. Thus a laterally distinct source has to be sought. The Nothe Grit Formation is interpreted as

PLATE 1

DORSET

PLATE 1

DORSET

1-1. Preston Grit Member, Ringstead Formation, Corallian Group, Redcliff, Dorset. Sandy, bioclastic marine limestone, 1.70m thick, above the sands of the Nothe Grit Formation and beneath the Nothe Clay Member. View to the south.

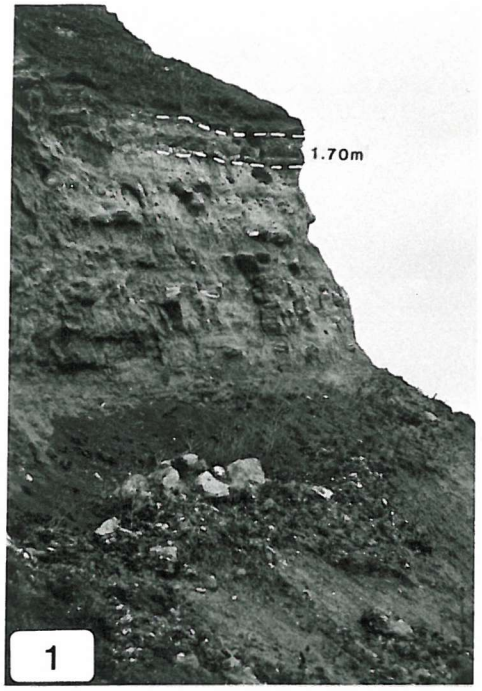
1-2. Composite limestone in the Intermarine Member, Purbeck Formation, Worbarrow Tout, Dorset (Bed 145 of Ensom, 1985b). The lowest part of the limestone is a fine to medium-grained skeletal grainstone, with trough cross-sets and dinosaur footprints. The upper part of the limestone is a very coarse-grained skeletal grainstone (biosparrudite). Lens cap diameter: 50mm. View to the north.

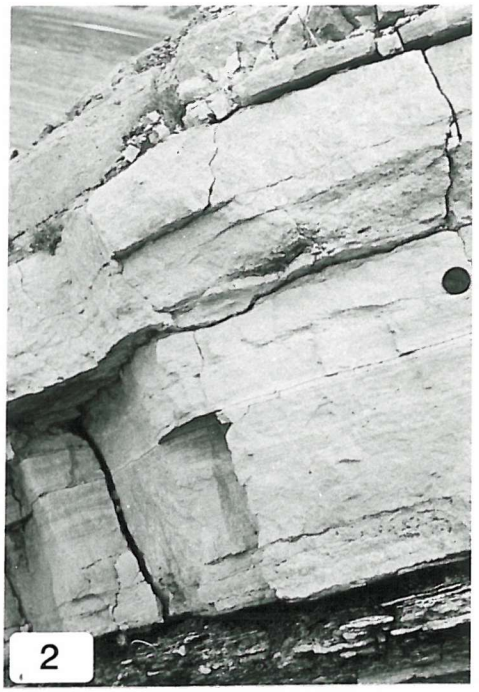
1-3. The top of the Scallop Member and the Corbula Member, Purbeck Formation, Worbarrow Tout, Dorset. Extrabasinal pebbles are present in the bioturbated grainstones of the Scallop Member (bottom left; Bed 153 of Ensom, 1985b). View to the north.

1-4. Bioclastic and intraclastic grainstone with intraformational limestone pebbles, New Vein (Bed DB 101 of Clements, 1969), Cherty Freshwater Member, Purbeck Formation, Durlston Bay, Dorset. Note the pre-compaction silicification of the limestone and of a pebble (centre of the chert nodule). The limestone contains small-scale, fining-up laminae (10-15mm thick).

1-5. Cross-stratified bioclastic grainstone, Intermarine Member, Purbeck Formation, Harden's Quarry, Acton, Dorset. The cross-stratified shelly sands contain extrabasinal granules and pebbles. Set thickness: 0.58m. View to the north.

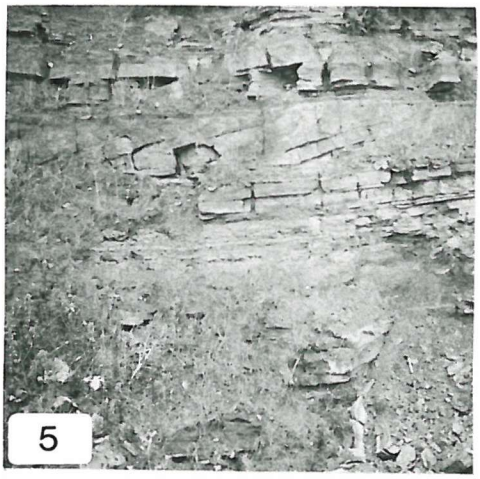
1-6. Chert pebble in a bioclastic sandstone of the Scallop Member (Bed 153 of Ensom, 1985b), Purbeck Formation, Worbarrow Tout, Dorset (to the left of the lens cap; lens cap diameter: 50mm). Extrabasinal clasts are exceptionally rare in the limestones of the middle Purbeck Formation.











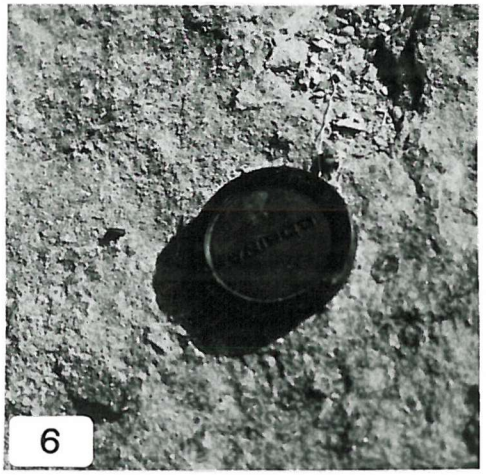


PLATE 1

a nearshore deposit (Talbot, 1973; Fursich, 1977) which could have passed laterally into strand-line gravels or pebbly sands. However, reworking of strand-line deposits is possibly not the sole source of coarse-grained detritus. The size of the pebbles is consistent with those associated with shelf deposits (cf. Lower Greensand Group of the Weald; Sect. 2.2.3.1) and transportation of the pebbles across the shelf by tidal or meteorological currents is likely.

2.2.1.2 The Purbeck Formation

The Purbeck Formation of Dorset is a sequence of lagoonal and tidal-flat deposits, including limestones, mudstones and replaced evaporites. The sedimentology of the basal Purbeck Formation has been studied by West (1961, 1964, 1965, 1975), Brown (1963, 1964) and Francis (1983b, 1984). Sedimentological aspects of the middle Purbeck Formation were described by El-Shahat (1977) and El-Shahat & West (1983).

The stratigraphic terminology of Wimbledon & Cope (1978) and El-Shahat (1977) is used in the present study (Table 1.5). The former three-fold division of the Purbeck Beds has been used for ease of description, although such terms have no stratigraphic basis.

Pebbles are common in the Purbeck Formation limestones, but the majority are of intraformational origin and are rip-up clasts, desiccation flakes or algal nodules (Ensom, 1985a). The Dirt Beds are probably the best known of the Purbeck Formation pebble beds in Dorset. The Dirt Beds are palaeosols; they contain subrounded, black (dark brown) and white micritic limestone pebbles (Francis, 1983b). West (1975) proposed that the pebbles were derived from limestones underlying the Dirt Beds and that the clasts were originally beach deposits, prior to their incorporation in the soil horizons. Francis (1983b), in a detailed study of the Dirt Beds and their flora, noted that only intraformational limestone pebbles were present in these horizons.

Intraclasts are common in the limestones of the middle and upper Purbeck Formation, but pebbles of extrabasinal origin are very rare. Clasts from strata of Late Jurassic age have been found in the Scallop Member, Chief Beef Member and "Unio" Member (Table 1.5) and

pebbles possibly from the basal Purbeck Formation are present in the Cherty Freshwater Member and the Scallop Member. Pebbles of extrabasinal origin are present in the Intermarine Member, the Scallop Member and the Chief Beef Member.

2.2.1.2a Intermarine Member, Scallop Member and Chief Beef Member (kochi to icenii Zone)

The Purbeck Formation limestones have been sampled at a number of localities in southern Dorset. Pebbles of extrabasinal origin have been found only at Worbarrow Tout and in quarries at Acton.

Worbarrow Tout, Dorset (SY 869 796)

Pebbles are found in several of the middle Purbeck Formation limestones on Worbarrow Tout, the oldest are those of the Intermarine Member. The descriptions of the section at Worbarrow Tout were made by El-Shahat (1977) and Ensom (1985b).

Description: The pebble-bearing limestones of the middle Purbeck Formation may be separated into two lithofacies types (Pls. 1-2, 1-3). The more common pebble-bearing limestones are laminated coarse-grained bioclastic grainstones, 0.1-0.3m thick (Pl. 1-3). They have sharp bases, overlie dark shales or calcareous mudstones, and are composed of bivalves and occasionally gastropods. The bivalves are disarticulated, abraded and in some beds have micritic envelopes.

The tops of the limestones are planar and there is commonly an abrupt boundary with the overlying shale or mudstone. Symmetrical ripples are common and dinosaur footprints are present on some beds.

Internally the limestones exhibit planar horizontal lamination, 0.10-0.15m thick. Fining-upwards laminae are occasionally recognised (Pl. 1-4). These are on two scales; larger-scale units, 0.05-0.10m thick, and small-scale laminations up to 10mm thick.

The beds of the Scallop Member differ from the other limestones. They are shelly quartz arenites with calcite cements. Physically they resemble the bioclastic grainstones, but are intensely

bioturbated.

Pebbles in the limestones and shelly sandstones are not common and the dominant detrital clasts are micritic limestones. These large clasts, up to 40mm in length, are bladed to platy and composed of micrite with clotted and algal fabrics (Ensom, 1985a). Biomicrite intraclasts are rare, but ostracods, serpulids and charophytes have been recognised in the clasts. Purbeck Formation faunal and floral remains only have been identified in the clasts and Portland Limestone Formation pebbles are unknown. Small extrabasinal pebbles and granules, less than 8mm in length, are scattered throughout the limestones (Pl. 1-6). The clasts are predominantly of dark chert, with lesser amounts of quartz. Phosphorite pebbles have been found in the Chief Beef Member and include an ammonite cast, probably a pavlovid (Ensom, 1985a), and a bivalve cast (Protocardia).

The second type of the pebble-bearing lithofacies is composite limestones. The uppermost limestone in the Intermarine Member is an example of such a unit (Pl. 1-2). The limestone is composed of very coarse- to fine-grained bioclastic grainstones. The base of the limestone is sharp, but the top is less distinct, with thin mudstone partings. The coarse or very coarse-grained bioclastic grainstones are similar to the limestones described above, but the fine-grained bioclastic limestones are cross-stratified. The cosets are trough-shaped and 20-50mm thick. Dinosaur footprints are present in the middle of the limestone and the top of the unit is rippled, with desiccation marks.

Pebbles are present towards the top of the Intermarine Member composite limestone in the coarse-grained bioclastic grainstones. Sparse clasts occur in the fine-grained limestones in the middle of the unit. The detrital clasts are of the small siliceous types described above.

Interpretation: The sharp planar bases and equally sharp tops of the limestones indicate that sudden changes in the conditions of deposition occurred for the formation of the beds. The shell beds are death assemblages and transportation of the bioclasts occurred prior to deposition. The fining-up laminae probably result from deposition during waning flows. Storm- or wave-induced currents may

have caused such laminae in the Purbeck Formation lagoon. Erosion of the lagoon floor or margin would have produced intraclasts. Brown & Woods (1974) discussed the importance of storms on sedimentation in the Nilemah embayment of Western Australia.

The structure of the trough cross-stratified sets is similar to that recognised in fluvial linguoid ripples and the sediments are interpreted as similar structures. The fragmentation of the shells is reminiscent of that occurring on the shoreface. The limestones were possibly deposited as megaripples or shoreline bars on shallows in the Purbeck lagoon. The coarse-grained bioclastic grainstones are possibly shell-ridge deposits or upper shoreface deposits (Grinnell, 1974; Salazar-Jimenez et al, 1982).

Harden's Quarry, Acton, Dorset (SY 799 793)

At the northern end of this quarry, the limestones of the Intermarine Member are exposed. The section has been described previously by El-Shahat (1977).

Description: A sharp-based limestone, 9.5m below the top of the Intermarine Member in Harden's Quarry, contains small siliceous pebbles. The limestone is a solitary planar cross-stratified set, 0.6-0.9m thick, and composed of medium- to coarse-grained skeletal debris, predominantly disarticulated bivalves (Pl. 1-5). The bed is overlain by parallel laminated bioclastic sands.

Pebbles occur scattered throughout the bed and are compact, subrounded to rounded. Dark chert pebbles are the most conspicuous, but translucent and white quartz pebbles also occur (Sect. 4.2.1.2). The overlying limestone is also cross-stratified but does not contain pebbles.

Interpretation: The pebbly limestone was probably deposited as a migrating bedform. In size, the structure is similar to megaripples described by Dalrymple (1984) from intertidal deposits in the Bay of Fundy and the unit is similar to tidal-sand bodies (cf. de Raaf & Boersma, 1971). However, the absence of indicators such as bimodal set-inclination, regular grain-size variations or reactivation surfaces, argue against a tidal origin. It is probable that the bed

was formed during a short-lived unidirectional, constant flow, possibly in association with storm-activity or flood-surge. Brown & Woods (1974) described large-scale bed-forms created during cyclonic storms in a lagoonal environment.

2.2.1.2b "Unio" Member

Pebble beds in the upper Purbeck Formation have been described by West & Hooper (1969) and Ensom (1984a) in the Friar Waddon area of Dorset. These beds are no longer exposed but samples in the collection of Dr. I.M.West (University of Southampton) have been examined.

The "Unio" Member has been studied elsewhere in Dorset, but clasts have been found only at Stair Hole and Lulworth Cove.

Stair Hole (SY 824 798) and Lulworth Cove (SY 829 799), Dorset

Descriptions of the Purbeck Formation at these locations were made by Arkell (1947a; p.141).

Description: Pebbles were collected from green sandy limestones containing abundant "Unio" and Viviparus shells, fish teeth and small fragments of bone. The sandy limestones are interbedded with bioclastic wackestones and lime mudstones. The bed contacts are sharp and planar.

Sparse subrounded pebbles, up to 6mm in length, of grey limestone and black chert are present in the sandy limestones. Small granules of rounded black chert and white quartz, of the types found in the middle Purbeck Formation (Sect. 2.2.1.2a) were not seen.

Interpretation: The fauna of the limestones was noted to be indicative of freshwater conditions (Arkell, 1947a). Evidence for the mode of deposition of the sandy limestones is sparse. The pebbles are not concentrated at the bases of the beds, as reported by Ensom (1984a) in the "Unio" Member pebble bed at Friar Waddon, but are dispersed throughout the bed and therefore are not lag deposits. The lack of structure in the limestones is unlikely to result purely from bioturbation and although dewatering structures are evident in

the interbedded mudstones, there is no evidence of such a process having been active in the sandy limestones. It is possible that the beds were originally massively bedded and formed by mass flow. In a lagoonal environment such deposits could potentially be produced by fluvial sheet-flood or storm-surges.

2.2.1.3 The Wessex Formation

The Wealden Group of Dorset is a sequence of conglomerates, sandstones, siltstones and mudstones of fluvial and lacustrine origin. The section at Swanage exposes the greatest thickness of Wealden Group in Dorset (715m), but to the west the unit thins and becomes sand-dominated (Fisher, 1856; Strahan, 1898). The westward reduction in thickness, 430m at Worbarrow Bay, c.230m at Mupe Bay, c.170m at Lulworth Cove and c.66m at Man O'War Cove, is considered to result from both tectonic thinning (?intra and post-Cretaceous faulting) and original depositional thinning of the sedimentary sequence towards the basin margin (Arkell, 1947a). The presence of a thin sheet of alluvial gravels and sands to the west of the present outcrop was postulated by Kirkaldy (1947a). Pebble beds are restricted generally to the lower unit of the Wealden Group, the Wessex Formation.

Wessex Formation pebble beds have been sampled from six localities in southern Dorset; Durdle Door promontory, St Oswald's Bay, Stair Hole, Lulworth Cove, Mupe Bay and Worbarrow Bay. Samples were collected from a number of the channel-sand deposits, but the conspicuous Coarse Quartz Grit was studied in detail. Wessex Formation clasts are of three types:

1. intraformational clasts comprising mudstones, rolled cornstones and ironstones. These are present at the bases of some sandstone bodies;
2. extrabasinal clasts, which are more common in complex interstratified lenticular conglomerate units, and are dominated by white polycrystalline quartz, tourmalinite (siliceous tourmaline-bearing pebbles), black laminated chert, sandstone and jasper (Sect. 4.2.1.4). These pebbles are small, commonly less than 15mm in length, compact to compact-bladed and angular to subrounded. Larger pebbles up to 40mm in length are present at

the bases of some units and are bladed to compact-bladed and subrounded to well rounded.

3. intrabasinal pebbles of subrounded to angular porcellanous chert derived from the Portland Limestone Formation are present in some of the beds and are also found in association with intraformational clasts.

2.2.1.3a Coarse Quartz Grit

The Coarse Quartz Grit is a conglomerate body in the Wessex Formation, extending from Man O'War Cove eastwards to Worbarrow Bay. To the east of Worbarrow Bay, the unit is not easily traced and the coarse-granular sands of Swanage were considered by Hughes & Croxton (1973) to be older. Two pebbly facies have been recognised:

1. Massive pebble beds,
2. Pebbly cross-stratified sandstones.

1. Massive pebble beds: unstratified lenticular pebble beds, 0.3-0.5m thick resting on erosion surfaces (Pl. 2-1). They are composed of small extrabasinal pebbles, 10-15mm in diameter, in a matrix of fine-grained sand and silt (Pl. 2-2). Intraformational mudstone pebbles and larger extra- and intrabasinal siliceous pebbles are present at the base of some units. In a few cases the pebble beds pass upward into granular sands with small pebbles.

   Interpretation: The thickness of the pebble beds and their complex interstratified form indicates that they are not simply channel lags. The lenticular bed-shape and the absence of grading in the beds is similar to structures present in braided-river gravels (Miall, 1977; massive gravel facies). The beds are interpreted as diffuse gravel lags or longitudinal-bar deposits formed over obstacles or channel lag (Fig 2.1; Sect. 2.1.1.1). This possibly accounts for the presence of coarser-grained detritus at the bases of some beds.

2. Pebbly cross-stratified sandstones: trough cross-stratified, coarse to granular sandstones, 0.1-0.6m in thickness. The sets are graded vertically, with pebble and granule lags at the bases of the foresets and bottomsets (Pl. 2-3). Topsets are not recognised. The cross-stratified sand units are lenticular, have

PLATE 2

DORSET

PLATE 2

DORSET

2-1. Massive conglomerates and sandstones of the Coarse Quartz Grit, Wessex Formation, Wealden Group, Worbarrow Bay, Dorset. Lenticular conglomerates are interbedded with massive or cross-stratified sandstones. Note book 0.2m in length. View to the northnortheast.

2-2. Pebbles in a massive conglomerate unit of the Coarse Quartz Grit (formation and location as in Plate 2-1). The extrabasinal clasts are predominantly of quartz, with lesser quantities of black chert and tourmalinite. View to the north.

2-3. Cross-stratified, pebbly sandstone in the Coarse Quartz Grit (formation and location as in Plate 2-1). Note the concentration of small platy pebbles on the foresets. View to the north.

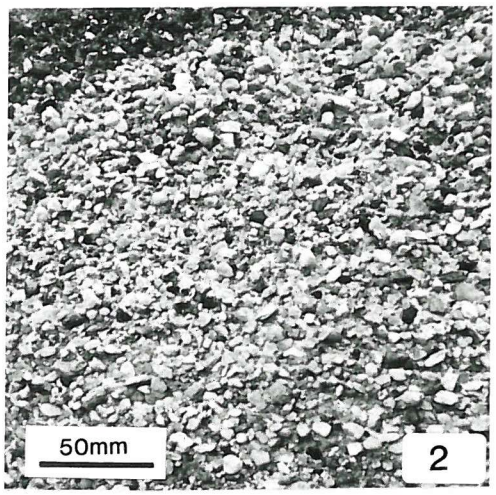
2-4. Basal Gault Clay Formation pebble bed at Golden Cap, Dorset. The sandstones and iron-cemented pebble beds at the base of the Gault Clay Formation (above the hammer shaft) overlie the Lower Jurassic Downcliff Sands. Hammer length: 0.32m. View to the northeast.

2-5. Inverted mudstones and the basal conglomerate of the Gault Clay Formation (bottom left) beneath siltstones of the Wessex Formation, St. Oswald's Bay, Dorset. Clay-filled burrows extend from the Gault Clay Formation into the siltstones. The unconformity is displaced along low-angle, southerly-dipping thrusts. Lens cap diameter: 50mm. View to the east.

2-6. Rhaxella chert cobble, aligned parallel to bedding (vertical) at the base of the Gault Clay Formation at Durdle Door promontory (west side), Dorset. Pale grey sandstones of the Wessex Formation are present to the right of the clast. Hammer head thickness: 25mm. View to the east.







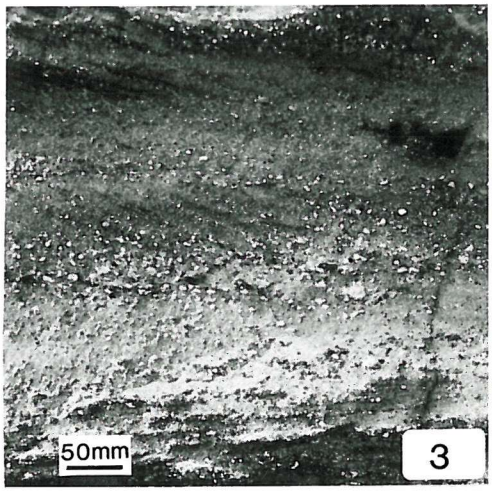






PLATE 2

sharp bases, commonly overlie massive pebble beds and are overlain by unstratified sands, thin siltstones or massive pebble beds. Pebbles in the sands are small, generally less than 8mm in length and are of extrabasinal origin.

Interpretation: These beds are interbedded with, or pass laterally into massive pebble beds. This suggests that the two bed types are related and probably formed in response to variations in flow-velocity. The beds resemble the bar-front sands described by Rust (1972) and were probably deposited during low-water stages. The presence of pebble laminae on the foresets indicates that currents were pulsatory. The absence of symmetrical rippling of the sands indicates, according to Rust (1972), that the bars remained at depth during the low stand and are unlikely to have been exposed.

Interpretation of the Coarse Quartz Grit: The conglomerates and sandstones of the Coarse Quartz Grit are an amalgamated unit which shows a general fining-upwards trend. The complex inter-relationships of conglomerate and sandstone bodies and the scarcity of siltstone and mudstone beds is consistent with deposits of braided-channel origin (Miall, 1977; Sect. 2.1.1.1). The absence of lateral accretion surfaces, clay plugs and the general coarse-grain size of the sediment, distinguishes this unit from the meandering channel sand bodies recognised by Stewart (1978, 1981a, 1981b) in the Wessex Formation of the Isle of Wight and at Swanage.

Alluvial-fan deposits are reported in the western part of the area by Stewart (1978, 1981b) and P.Allen (1981). The evidence for the Coarse Quartz Grit being part of such a unit is inconclusive and Miall (1977) noted that the distinction between distal-fan and proximal-stream deposits cannot be readily defined.

2.2.1.3b Pebble beds in other Wessex Formation deposits

Description: The majority of the other pebble beds studied from the Wealden of Dorset have been pebble lags at the base of channel sands. The lags are 10-100mm thick, with pebbles up to 40mm in length. The majority of the clasts are of intraformational origin, but a number of horizons contain weathered porcellanous intrabasinal chert.

Pebbles of less than 10mm in diameter are composed of quartz, dark chert and tourmalinite.

Interpretation: The pebble lags occur at the bases of channel sands and were probably transported as a diffuse gravel on the channel floor (Sect. 2.1.1.1).

2.2.1.4 The Gault Clay Formation (dentatus zone)

The Albian transgression in Dorset resulted in a progressive westward overstep of the Gault Clay Formation across faulted and folded Jurassic and Lower Cretaceous strata (Owen, 1971a).

The pebble beds at the base of the Gault Clay Formation have been studied at four localities in Dorset; Durdle Door promontory, St. Oswald's Bay, Holworth House and Golden Cap.

Durdle Door promontory (SY 806 803) and St.Oswald's Bay east (SY 816 800)

At both localities, the Gault Clay Formation rests unconformably on the Wessex Formation and the basal beds are similar in appearance. The pebble beds are in the central limb of the Purbeck Monocline and are overturned and dip steeply to the south. The St. Oswald's Bay section is cut by a series of sub-horizontal thrusts (Pl. 2-5).

Description: The pebble beds are 0.5-0.7m thick, contain cobbles and pebbles set in a muddy, ferruginous sandstone and fine rapidly upward into micaceous mudstones. Bioturbation of the basal sandstones is intensive. Burrows also extend down into the underlying Wessex Formation siltstones and sandstones to depths of 0.15m (Pl. 2-6).

The pebble suites of the basal beds are trimodal. Larger clasts are angular to subangular pebbles and cobbles, up to 450mm in length (Pl. 2-6), of pale coloured, weathered chert. The finer grained fraction consists of rounded pebbles up to 50mm in length, but averaging 15-25mm. These clasts are of white quartz (commonly fibrous), black chert, bluish-black tourmalinite and quartzite (Sect. 4.2.1.5). A third, minor group of pebbles comprises subangular to subrounded clasts of brownish black phosphorite up to 35mm in length.

Interpretation: The basal Gault Clay Formation pebble bed is a lag deposit, laid down during the mid-Albian transgression (Owen, 1971a). The thickness and the lateral persistence of the bed (Owen, 1971a) and its position above a major unconformity is consistent with a strand-line retreat deposit (Clifton, 1967, 1973; Sect. 2.1.1.2). The poor sorting of the bed and the presence of clay-filled burrows extending down below the unconformity indicate that the deposits are unlikely to be high-energy, upper shoreface deposits. The mixing of gravel, sand and mud is more consistent with deposition in the nearshore zone on the lower shoreface (McCubbin, 1982).

Holworth House, Dorset (SY 762 806)

Description: The exposure at this locality is poor and samples were only collected after minor excavation. The pebble bed is 0.2m thick and rests on a planar truncation surface above the bioclastic limestones of the Portland Limestone Formation. Pebbles are set in a matrix of sandy clay and are overlain by blue-black mudstone.

The pebble suite at this locality is bimodal with the finer-grained fraction similar to the quartz and dark chert subsuite of the basal Gault Clay Formation at Durdle Door promontory and St. Oswald's Bay east. The coarser grained fraction is composed of chert clasts. The large chert clasts are unweathered, unlike those in the basal Gault Clay Formation to the east. The cherts are up to 70mm in length, subangular to subrounded, vitreous and black or dark brown in colour. Discussion of the processes causing alteration of chert clasts is given in Appendix IV.

Interpretation: Comparison with the stratigraphically equivalent pebble beds to the east suggests that the basal Gault Clay Formation pebble bed at this locality was deposited as a strand-line lag. The absence of limestone pebbles and of a hardground fauna on the underlying limestones, probably indicates that the retreat of the shoreline was rapid. The absence of relief on the erosion surface implies that the surface was peneplanated during the transgression.

Golden Cap, Dorset (SY 406 920)

The basal Cretaceous unconformity at Golden Cap is well-exposed in landslip scars. The pebble beds at this locality were noted by Jukes-Browne (1900) and redescribed by Wilson et al. (1958, p.148-149).

Description: The basal beds of the Gault Clay Formation are clean, glauconitic sandstones with three thin pebble beds (Pl. 2-4). The oldest pebble bed rests unconformably on the Lower Jurassic Downcliff Sands, but the youngest is 0.9-1.0m above the unconformity. The sandstones and pebble beds are overlain by grey, silty sandstones and mudstones.

The pebble beds which overlie sub-planar erosion surfaces are 0.1-0.2m thick and composed of small clasts less than 15mm in diameter. Larger pebbles, up to 40mm in length, occur at the base of the lowest pebble bed. The pebble beds are overlain by medium- to coarse-grained bioturbated glauconitic sandstones which contain minor amounts of clay. Ophiomorpha-type burrows are present in the sandstones.

White quartz is the dominant pebble-type in the beds, but chert, tourmalinite and sandstone are also present (Sect. 4.2.1.5). The sandstone pebbles are slightly larger than the other clasts. All the pebbles are rounded to well-rounded and bladed to compact-bladed in shape.

The basal pebble bed overlies fine-grained, muddy sand of the Downcliff Sands (Pliensbachian). Burrows of two types extend down from the unconformity surface into these Jurassic sandstones:

1. small tubular structures, 7-10mm in diameter, penetrating to depths of 0.2m, and filled with medium-grained glauconite-rich sand or small pebbles and granules.
2. vertical bifurcating shafts, 20-30mm in diameter (Fig. 2.5). The burrows are clay-lined and their infill, of pebbles in coarse-grained sand, is continuous with the overlying pebble bed. None of the burrows contain any remains of the burrowing organisms.

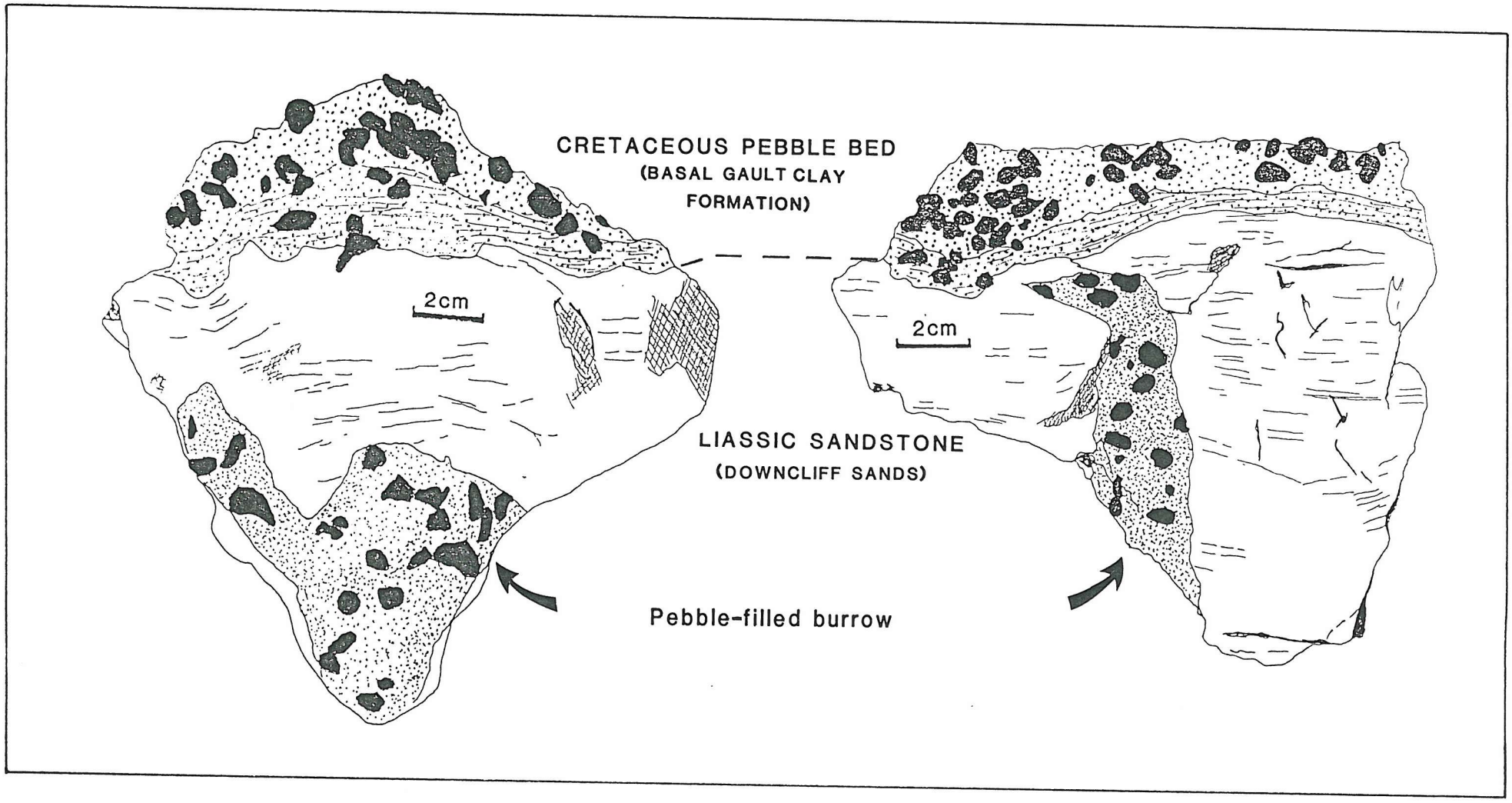


Figure 2.5 A pebble-filled burrow from the Gault Clay Formation – Downcliff Sands unconformity at Golden Cap, Dorset.

Interpretation: The pebble beds of the Gault Clay Formation are lag deposits. The absence of preserved stratification in the interbedded sandstones suggests that they are neither upper shoreface nor beach deposits. The lack of stratification is probably in part the result of bioturbation, but the sandstones may always have been massively bedded. Thin pebble lags at the base of sand units were described by Bourgeois & Leithold (1984) and were considered to have been deposited from storm-surge currents. The seaward movement of rip-currents would account for the transportation of pebble-grade detritus away from the shoreface. The basal Gault Clay Formation pebble beds were probably formed by a similar process.

The absence of phosphate nodules in the pebble beds suggests that breaks in sedimentation were not prolonged. Burrows extending below the unconformity imply that the sand cover was thin and impersistent. The absence of burrowing organisms suggests that they were mobile and abandoned their burrows before infilling took place. Similar features were described by Bourgeois & Leithold (1984) in nearshore deposits and by Phillips (1984) in offshore shallow-water conglomerates.

Clast-roundness distinguishes the basal Gault Clay Formation pebbles from the clasts of the Wessex Formation in east Dorset and direct reworking of alluvial gravels is unlikely.

2.2.2 The Isle of Wight area

The Wealden and Lower Greensand Groups of the Isle of Wight outcrop to the south of the Chalk ridge and the best exposures are found on the coastal sections around the island.

The Lower Cretaceous sediments of the Isle of Wight are thicker than to the west in Dorset, but were deposited in the same sedimentary basin (Central Channel Basin). This basin was separated from the Weald Basin to the northeast by a structural high (Mere-Portsdown-Eastbourne High) which episodically was a barrier to sediment transportation (P.Allen, 1981). The Lower Greensand Group thins northwards in the Isle of Wight and is thin or absent in the northern part of the island (Whittaker, 1985).

Extrabasinal detritus is common in the Lower Greensand Group in the Isle of Wight, but is rare in the Wealden Group. The pebble beds of the former have been studied in detail, but the latter were examined only briefly.

2.2.2.1 The Lower Greensand Group

The Lower Greensand Group of the Isle of Wight has been studied by numerous workers in the past, in particular concerning the stratigraphy and palaeontology of the deposits. Work has also been carried out on sedimentological and palaeoecological aspects of the unit (Middlemiss, 1962a; Dike, 1972a, 1972b).

The earliest comprehensive descriptions of the area were made by Fitton (1843, 1847) and Ibbetson & Forbes (1845). Fitton's work was of importance since he separated the Lower Greensand Group of Atherfield Bay into sixteen divisions. It was found, however, that these divisions could not be traced across the island and in the Geological Survey memoirs by Bristow (1862) and Reid & Strahan (1889) the Aptian and Albian sediments were separated into four units; Atherfield Clay, Ferruginous Sands, Sandrock and Carstone (Table 1.7). Dike (1972b) separated the Lower Greensand Group into three formations; Atherfield Clay, Ferruginous Sands and Sandrock. The Carstone was defined as a member and is included in the Lower Greensand Group but sedimentologically it probably forms the basal unit to the Gault Clay Formation. In the present study the stratigraphic units of Dike (1972b) are adopted.

The greatest thickness of Lower Greensand Group in the Isle of Wight is exposed in the section from Atherfield Point to Rocken End Point on the southwest coast of the island. To the northeast the Aptian and Early Albian sediments thin, except for the Carstone Member which thickens appreciably. Casey (1961) and Dike (1972b) reported a significant break below the Carstone Member at Redcliff in the east of the island (Pl. 3-1) where part of the Sandrock Formation is absent. The third main outcrop of the Lower Greensand Group in the Isle of Wight is at Compton Bay in the west of the island where the unit is thinner than at Redcliff.

The westward thinning of the Lower Greensand Group has been

PLATE 3

THE ISLE OF WIGHT AND NORMANDY

PLATE 3

THE ISLE OF WIGHT AND NORMANDY

3-1. The northward-dipping Lower Greensand Group at Redcliff, Isle of Wight. The Ferruginous Sands Formation forms the high cliffs to the left, the quartzose and muddy sandstones of the Sandrock Formation are exposed in the middle-ground, and the pebbly sands of the Carstone Member are exposed to the top right. View to the southeast.

3-2. The northward-dipping Carstone Member and the overlying Gault Clay Formation in the disused sandpit between Coombe Farm and Rock, Isle of Wight. View to the northeast.

3-3. The northward-dipping upper part of the Sandrock Formation and the basal part of the Carstone Member in the Coombe Farm sandpit, Isle of Wight. Exposed in the pit are:

A. eastward inclined, large-scale sets in the lower Sandrock Formation,

B. interbedded sandstones and mudstones of the upper Sandrock Formation,

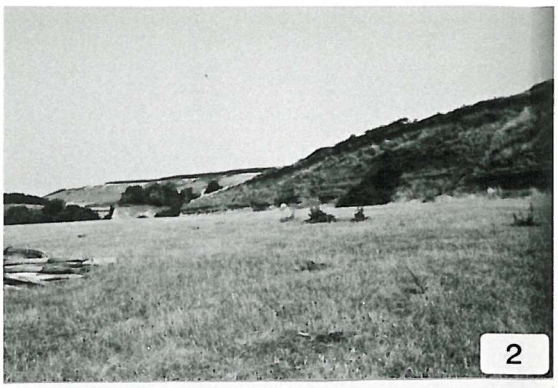
C. pebbly ferruginous sands of the Carstone Member.

Pebble beds exist at the base of units B and C. View to the east.

3-4. Pebble bed (CB1) at the base of the Fitton's Group XIII (Casey, 1961) in the Ferruginous Sands Formation at Compton Bay. The pebble suite is dominated by weathered phosphorite clasts (grey), but also containing silicified Purbeck Formation evaporite clasts (white). The phosphorites include rolled Kimmeridge Clay Formation ammonite and bivalve casts. Lens cap diameter: 50mm. View to the northnortheast.

3-5. Pebbles of quartz and Carboniferous chert infilling an erosional hollow within the Sandrock Formation. Pebble bed CB3, Compton Bay, Isle of Wight. Pencil for scale. View to the north.





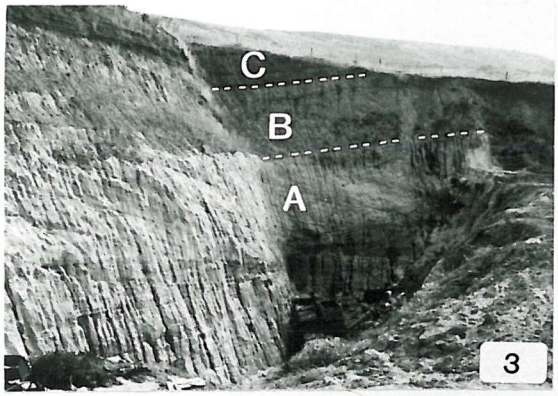










PLATE 3

3-6. Erosion surface at the base of a large-scale cross-stratified set in the Sandrock Formation. Small pebbles and granules are concentrated on the foresets and in the trough. Rock, Isle of Wight. Lens cap diameter: 50mm. View to the eastnortheast.

3-7. The Sables Ferrugineux (bottom), Poudingue Ferrugineux (middle) and the base of the Gault Clay Formation (top) at Cauville, Caux, France. Hammer length: 0.32m. View to the east.

recognised to result from the proximity to the western margin of the basin. Dike (1972b) suggested that the basin margin lay close to the southern coast of the Isle of Wight and that sedimentation took place in a restricted marine embayment. Subsequent evidence from oil exploration wells in the north of the Isle of Wight (Whittaker, 1985) suggests that the basin margin during the mid-Cretaceous lay to the north of the present exposures, not to the south.

The number of pebble beds in the Lower Greensand Group, in particular in the Ferruginous Sands Formation, is greater in the northern exposures. The sections at Compton Bay and Redcliff (Pl. 3-1) were therefore sampled extensively, with additional material being collected from the exposure of the upper part of the Lower Greensand Group at Monks Bay.

2.2.2.1a Ferruginous Sands Formation (deshayesi Zone to jacobi Zone): Compton Bay (SZ 367 852) and Redcliff (SZ 621 857)

Three types of pebble bed have been recognised in the Ferruginous Sands Formation. They are distinguished by phenoclast type, phenoclast size and bed thickness. The three pebble bed types are those with predominantly:

1. intrabasinal and intraformational phenoclasts;
2. intrabasinal and extrabasinal phenoclasts;
3. extrabasinal phenoclasts.

1. Pebble beds with intrabasinal and intraformational phenoclasts: this group of pebble beds includes the lowest of the Ferruginous Sands Formation pebble beds (43m beneath the base of the Carstone Member at Compton Bay, CB1 and the pebble beds 38m and 39m beneath the base of the Carstone Member at Redcliff, RC4, RC3; depths taken from White, 1921).

These pebble beds are 0.10-0.15m thick and contain pebbles of brown phosphate and red-brown flakes of goethite, up to 20mm in length, in a matrix of fine-grained sand. Bioclasts are rare. The beds rest on erosion surfaces with pebbles infilling hollows. At Compton Bay, the pebble bed (CB1) overlies a coarse-grained glauconitic sandstone and is overlain by a white, bioturbated sandstone with small-scale cross-stratification. The pebble beds

at Redcliff overlie clean quartzose sandstones and grade upwards into bioturbated silty sandstones with pockets of pebbles.

Interpretation: The pebble beds are lag deposits composed principally of intrabasinal clasts. The upward fining of the pebble beds at Redcliff suggests that they were deposited during a series of waning events. The interbedded sediments contain little evidence for reworking by tidal currents, but do appear to have been free of fines. This suggests that they are shallow water sediments probably deposited in the nearshore zone.

2. Pebble beds with intrabasinal and extrabasinal phenoclasts: These beds contain rolled phosphate clasts, ironstone flakes and angular white chert pebbles (pebble bed 41m beneath the base of the Carstone Member at Compton Bay, CB2 and 44m and 43m beneath the base of the Carstone Member at Redcliff, RC1, RC2; depths taken from White, 1921). The beds are 0.05-0.25m thick with pebbles concentrated in hollows (Pl. 3-4). Phosphoritic ammonite and bivalve casts are found, the former including pavlovids. Pebbles of quartz and chert are also present in the beds and are up to 25mm in length. Pebbles are set in a matrix of coarse-grained quartz sand and are overlain by a fine-grained, bioturbated sandstone with scattered pebbles.

Interpretation: The pebble beds are composed principally of intrabasinal clasts, including phosphorite derived from the Kimmeridge Clay Formation and Jurassic chert. The lateral persistence of the horizon is consistent with a strand-line deposit. The enclosing bioturbated sandstones were possibly deposited on the the lower shoreface or in the nearshore zone.

3. Pebble beds with extrabasinal phenoclasts: At Compton Bay, a pebble bed in the Ferruginous Sands Formation, 34m below the base of the Carstone Member (CB3), contains small siliceous pebbles. The bed is 0.05-0.17m thick and overlies an irregular erosion surface. The beds underlying the pebble bed are white, cross-stratified sandstones, with sets 0.16-0.22m thick. The pebble bed is overlain by a wavy laminated sandstone with scattered fragments of wood.

Interpretation: The pebble bed is a lag deposit resting on a minor erosion surface. This pebble bed differs from the two lower Ferruginous Sands Formation pebble beds at Compton Bay (CB1, CB2), being composed predominantly of siliceous clasts and containing no bioclasts. This suggests that it is a more mature pebble suite and implies either that the source of intrabasinal clasts no longer existed or that the bed is composed of a concentration of resistate clasts. The beds are probably strand-line or shallow-marine lag deposits.

2.2.2.1b Sandrock Formation (jacobi Zone to tardefurcata Zone): Compton Bay (SZ 367 852), Coombe Farm (SZ 429 838) and Monks Bay (SZ 579 780)

Two types of pebble bed are recognised in the Sandrock Formation. They are distinguished from the Ferruginous Sands Formation pebble beds by the scarcity of intrabasinal and intraformational phenoclasts. Two types of pebble bed are recognised:

1. quartz and sandstone-rich pebble beds;
2. quartz and chert-rich pebble beds.

1. Quartz and sandstone-rich pebble beds: The glauconitic sandstones at the base of the Sandrock Formation at Compton Bay contain a number of impersistent pebble beds up to 0.1m thick (CB4, 33m beneath the base of the Carstone Member; depth taken from White, 1921). The beds are lenticular and the pebbles fill small troughs on erosion surfaces. They are remarkable for their high content of sandstone pebbles and virtual absence of chert pebbles. The pebbles are rounded to subrounded and 4mm to 20mm in diameter. The underlying beds are mottled sandstones with Ophiomorpha burrows and clay laminae. The overlying beds are granular, glauconitic sandstones with lenses of pebbles towards the base.

Interpretation: The high glauconite content of these sandstones and the presence of Ophiomorpha burrows implies that they are shallow marine deposits. The absence of large-scale bed forms indicates relatively weak current activity. Burrowing probably destroyed any small and medium-scale traction structures originally present. The concentration of pebbles above an erosion

surface is consistent with descriptions of strand-line lags (McCubbin, 1982). Reworking of the pebbles is likely to have occurred on the sea floor in an area starved of sediment and with the accumulation of glauconitic sands.

2. Quartz and chert-rich pebble beds: The second of the Sandrock Formation pebble bed types is found at Compton Bay (CB5, 5m beneath the base of the Carstone Member; depth taken from White, 1921), Coombe Farm (CF1, 8.7m beneath the base of the Carstone Formation; Pl. 3-2) and at Monks Bay (MB1). The pebble beds (0.15-0.20m thick) which overlie clean or linsen-bedded quartz sandstones, have a matrix of coarse-grained sand (Pl. 3-3). Pebbles infill small hollows or open burrows (Pls. 3-5, 3-6). The clasts, up to 15mm in length, are principally of quartz, with lesser quantities of dark chert. The cross-sets in the underlying sandstones are up to 2m thick and dip dominantly in one direction, but reverse-dipping sets and clay drapes are also present. The pebble beds are overlain by muddy sandstones with rippled sets and Ophiomorpha burrows.

Interpretation: The pebble beds are lag deposits of siliceous pebbles. The large-scale sets in the lower sandstones indicate that they were current-sorted deposits laid down under a moderate-energy environment. The clay drapes and reverse-inclined sets are characteristics commonly associated with tidal deposits (de Raaf & Boersma, 1971; Nio, 1976) and the large scale cross-sets resemble sandwave deposits (J.R.L.Allen, 1980). The bioturbated interlaminated sandstones and mudstones are assumed to have been deposited under lower energy conditions. These deposits resemble those described from restricted nearshore, estuarine and intertidal environments by McCubbin (1982). The presence of a pebble bed above an erosional surface is consistent with deposits associated with shore-line retreat. The pebble-filled burrows were a feature recognised in Miocene nearshore deposits by Leithold & Bourgeois (1984) and are possibly characteristic of a nearshore or shoreline depositional environment.

2.2.2.1c Carstone Member (mammillatum Zone): Compton Bay (SZ 367 852), Redcliff (SZ 621 857) and Rock (SZ 425 839)

Two types of pebble bed are identified in the coarse-grained rocks of the Carstone Member. They are distinguished by sedimentary structures, the pebble subsuites being similar. The two types are:

1. pebble beds at the bases of fining-upward sequences;
2. pebble beds at the bases of coarsening-upward sequences.

1. Pebble beds at the bases of fining-upward sequences: The pebble beds at the base of the Carstone Member at Compton Bay (CB6) and Rock (CF2) are concentrates of pebbles, 0.10m thick, composed of pebbles up to 40mm in length, with an average pebble size of 20-25mm. Quartz and dark chert pebbles predominate, but phosphate and ironstone pebbles are also present. At Rock (Pl. 3-2), pebbles of weathered, white chert are present in the bed. The pebbles are set in a ferruginous sandstone matrix and grade upward into ferruginous sandstones with scattered pebbles. The ferruginous sandstones also fine upward, becoming increasingly muddy and bioturbated.

   Interpretation: The muddy ferruginous sandstones overlying the pebble beds are poorly sorted. They were probably accumulated through the concentration of pebbles between periods of slow sedimentation. The poor sorting of the deposits is inconsistent with a shoreline environment. The absence of indicators for regular variations in the depositional energy and current orientation suggests that sandstones were not deposited from tidal currents. Poorly-sorted pebbly sands have been noted on shelves dominated by meteorological currents (Swift et al., 1973).

2. Pebble beds at the bases of coarsening-upward sequences: The Carstone Member at Redcliff does not contain a basal lag, the lower part being composed of ferruginous pebbly sandstones. A pebble bed is present 3m beneath the base of the Gault Clay Formation (RC5). It has a planar base and is 0.10-0.15m thick. Pebbles are rounded, up to 35mm in length and are composed of quartz and dark chert. The pebble bed is overlain by medium-grained sandstones which coarsen upward and contain scattered pebbles up to 20mm in length at the top.

Interpretation: The pebble bed is a lag deposit at the base of a coarsening-up unit. As in the other Carstone Member deposits, the poor sorting is inconsistent with strand-line accumulation deposits. Ophiomorpha burrows in the pebbly sandstones probably indicate shallow-marine conditions (Dike, 1972a). The coarsening-upward unit recognised at the top of the Carstone Member is reminiscent of pebble sandbar deposits described by Swift et al. (1973). The pebbles were probably concentrated towards the tops of bars winnowed by currents, the pebble lags forming during severe winnowing events.

2.2.3 The Weald area

The early Tertiary compressional phase in northwest Europe caused folding and uplift in southeast England, and the exposure of sedimentary rocks of Late Jurassic to Early Cretaceous age on the core of an anticlinorium (Ziegler, 1978). The Weald anticlinorium was demonstrated to have formed in the position of a Mesozoic basin by Lamplugh (1919). The Mesozoic strata thin out at the northern margins of the basin against the Anglo-Brabant Massif and its surrounding shelves (Smalley & Westbrook, 1982). To the south of the basin, Jurassic and Cretaceous sequences diminish in thickness onto the Portsdown-Eastbourne High (Whittaker, 1985). The western margin of the Weald area is marked by the Upper Cretaceous cover in Hampshire and Surrey. However, the Jurassic and Lower Cretaceous sediments extend further to the west where the Lower Cretaceous sedimentary rocks are preserved in fault-bounded basins (Chadwick et al., 1983; Whittaker, 1985).

Pebbly horizons are present at several levels in the Lower Cretaceous sequences of the Weald. The pebble beds of the Hastings Beds Group (e.g. top Lower Tunbridge Wells Sandstone Formation pebble bed, top Ashdown Beds Formation pebble bed, Cuckfield pebble bed) have been described by P.Allen (1954, 1959, 1960, 1961 and 1967a) and those of the Weald Clay Group were mentioned by P.Allen (1975). The Wealden pebble beds were not studied in this investigation, but pebble samples from Prof. P.Allen's collection (University of Reading) have been examined.

Much of the earlier work on the beds of Aptian and Albian age

involved descriptions of sections, palaeontological finds and lateral variations in the units of the Lower Greensand Group. Kirkaldy (1933a, 1935, 1939b) made palaeoenvironmental interpretations of local areas. Detailed sedimentological studies were made by Narayan (1963, 1971) and J.R.L.Allen & Narayan (1964). Middlemiss (1962a, 1962b) interpreted the positions of former shorelines from studies of the brachiopod suites. Kirkaldy (1939b) described the Lower Greensand Group as shallow marine deposits. Narayan (1963, 1971) demonstrated that the Hythe Beds and Folkestone Beds Formations were tidal-shelf deposits similar to those identified in the southern North Sea at present.

Studies of the provenance of the Lower Greensand Group rocks have been limited in comparison with those of P. Allen for the Wealden. Wood (1956) and Worrall (1956) gave descriptions of the heavy-mineral suites. Arkell (1939b), Wells & Gossling (1947) and Kirkaldy (1939a, 1947a) discussed the provenance of the pebbles. The stratigraphic terminology of Stewart (1983) has been adapted for the Hastings Beds and Weald Clay Groups and the terminology of Lake & Shephard-Thorn (1985) has been used to divide the Lower Greensand Group.

2.2.3.1 The Lower Greensand Group

The Bargate Beds and Folkestone Beds Formations have been investigated during this study with a brief examination of exposures of the Hythe Beds Formation. The Bargate Beds Formation is limited in extent to the northwest Weald and passes laterally into the muddy sands of the Sandgate Beds Formation in Sussex and Surrey. The Folkestone Beds Formation is traceable throughout the Weald, but the unit fines to the southeast and pebble beds become less frequent.

2.2.3.1a Bargate Beds Formation (nutfieldiensis Zone): Compton, Surrey (SU 956 474)

The basal beds of the Bargate Beds Formation are carbonate-cemented sandstones and sandy limestones. Exposures are present in disused quarries and road cuttings. The locality studied was described by Dines & Edmunds (1929, p.26), but has been disused for some time.

Description: The pit contains 6-7m of cross-stratified, medium- to coarse-grained calcareous sandstones, with scattered pebbles (Pl. 4-1). Sets are 0.75-1.25m thick and include clay laminae and symmetrical-ripple surfaces. The sands become finer upward along set laminae, with pebbles concentrated on the bottomsets and at the base of the foresets. The sandstones are overlain by a pebble bed, in which the pebbles are small, 10-15mm in length, and composed predominantly of black chert, white quartz, dark red ironstones and black phosphorite (Sect. 4.2.3.1). Pebbles of ironstone and phosphorite include ammonite casts. The former are well preserved, the latter are commonly rounded. The pebble bed is massive without cross-stratification, but contains lenticular sandstone bodies.

Interpretation: The pebble bed and pebbly sandstones were deposited from currents with fluctuating velocities, allowing the deposition of sand and mud. The sand bodies resemble the "Class VIA" type sandwave deposits of J.R.L.Allen (1980) and are interpreted as the product of deposition from tidal currents. The pebble bed is a winnowed lag deposit. The size of the pebbles is slightly coarser than that of the underlying sandstone and therefore transportation may not have been purely by tidally-induced processes. The lag possibly resulted from winnowing of the sediment by storm-induced currents, as was suggested by Anderton (1976) for pebble beds in the Jura Quartzite.

2.2.3.1b Folkestone Beds Formation (middle jacobi Zone to late mammillatum Zone)

The Folkestone Beds Formation of the Weald consists of quartz sands containing varying quantities of goethite and glauconite. Pebble beds are found at a number of horizons in the sands, but correlation between beds is rarely possible. The Folkestone Beds Formation was sampled across the Weald. Inland exposures of the sands are found in road cuttings and sandpits.

Huntingford Bridge Sandpit, east Hampshire (SU 821 389)

This disused sandpit was described by Knowles & Middlemiss (1958) and Thurrell et al. (1968, p.92-93).

PLATE 4

THE WEALD

PLATE 4

THE WEALD

4-1. Large-scale, cross-stratified sandstones in the Bargate Beds Formation, Compton, Surrey. The hammer (length: 0.32m) rests on a lag of fine pebble-grade clasts above the sandstones. Note the ripple sets and associated clay drapes on the foresets of the sandstones (centre-bottom). View to the east.

4-2. Sandwave deposits with large-scale cross-stratification in the Folkestone Beds Formation, Moorhouse, Kent. The goethite-stained sandstones overlie a bioturbated mud with scattered pebbles (Pl. 4-5). Set thickness: c.3m. View to the northeast.

4-3. Granular sandstones of the Folkestone Beds Formation, Lenham Heath, Kent. Pebbles are concentrated on the foresets and bottom sets of large-scale cross-stratified sandstones. Hammer length: 0.32m. View to the westnorthwest.

4-4. Compound cross-stratification with small-scale cross-sets in the Folkestone Beds Formation, Moorhouse, Kent. Note the concentration of granules and small pebbles in laminae on the foresets. Hammer head thickness: 30mm. View to the eastnortheast.

4-5. Bioturbated mudstone with scattered pebbles, above cross-stratified sandstones in the Folkestone Beds Formation, Moorhouse, Kent. Hammer length: 0.32m. View to the northnorthwest.

4-6. Basal Gault Clay Formation pebble bed (centre) at Fittleworth Station, Sussex. The bed overlies reddened quartz sandstones of the Folkestone Beds Formation (bottom) and is overlain by slumped mudstones of the Gault Clay Formation (top). Hammer length: 0.32m. View to the west.













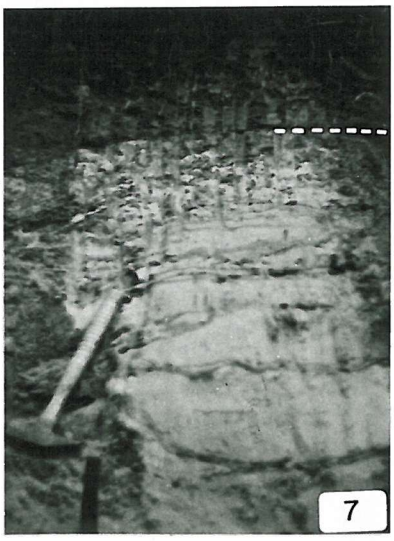


PLATE 4

4-7. Compound cross-stratified sandstones with clay and carbonaceous matter drapes in the Folkestone Beds Formation (bottom) are overlain by a phosphate-cemented pebble bed at the base of the Gault Clay Formation (top). Aldersnapp Farm, Hampshire. Hammer length: 0.32m. View to the west.

Description: Pebbles are present in ferruginous sandstones of the upper Folkestone Beds Formation in the northern part of the pit. The sandstones are cemented towards the top of the section by cavernous concretions of goethite which obscure the large-scale cross-stratification. Pebbles are concentrated on the bottomsets and foresets of the sandstones and are also present in thin impersistent seams parallel to bedding or erosion surfaces. Clay drapes are observed on some foresets.

Pebbles are small, up to 8mm in length, and are of quartz, dark chert and platy grains of ironstone (Sect. 4.2.3.2). The siliceous clasts are rounded to subrounded and are predominantly of bladed and compact-platy forms.

Interpretation: The variable grain size of the unit provides evidence of deposition under variable flow conditions and the large-scale cross-sets are similar to sandwaves formed by tidal-current action (J.R.L.Allen, 1980). Pebbles and sands were apparently transported together. The rounding of the siliceous clasts indicates that the extrabasinal pebble suite is mature and possibly reworked from older pebble beds.

Chilworth, Surrey (TQ 021 484)

A poorly exposed section in a road cutting, north of Chilworth, revealed a pebble bed in the upper Folkestone Beds Formation. The bed was described previously by Dines & Edmunds (1929).

Description: The pebbles are up to 25mm in length and set in a matrix of weakly goethite-cemented sandstone. The pebble bed is 0.1m thick with pebbles scattered throughout the overlying sandstones. The dominant pebble type is rounded chert, a small proportion of which has white cortices. Quartz and phosphorite pebbles are scarce, but ironstone pebbles are moderately abundant. The enclosing beds are not well-exposed, but appear to be goethite-cemented quartz arenites. Large-scale cross-sets, 0.4-0.6m thick, are observed in part of the overlying sandstones.

Interpretation: The poor exposure of the pebble bed and the surrounding strata prevents a full interpretation of the environment

of deposition. The pebbly horizon is a lag deposit within pebbly sandstones. In comparison with the upper Folkestone Beds Formation elsewhere in the Weald area, the pebble bed is probably in a tidal-sand complex.

Moorhouse Sandpit, Westerham, Kent (TQ 418 536)

The sandpits in the Westerham district have been worked for some time and it is from these pits that pebbles were collected for description by Wells & Gossling (1947). The strata in the pit were described by Gossling and published by Kirkaldy (1947b).

Pebbles are present in the upper Folkestone Beds Formation as laminae within the foresets of fine to coarse-grained cross-stratified sandstones. Two scales of cross-sets are recognised:

1. small-scale sets, 0.2-0.3m thick, and
2. large-scale sets, 3.0-4.0m thick.

1. Small-scale sets with pebble and granule laminae: pebbles and granules are concentrated on the foresets of the sandstones and are interlaminated with fine-grained sandstones (Pl. 4-4). The sets have angular foresets and rest on planar erosion surfaces above sets with similar structure. Set-orientation is predominantly unidirectional. Pebbles are small, less than 12mm in length and are of quartz, chert and sandstone (Sect. 4.2.3.2). The cherts are commonly weathered with white cortices. Chert and quartz pebbles are rounded, the sandstone pebbles subrounded to subangular.

2. Large-scale sets: the large-scale sets are composed of medium to coarse-grained sandstones, with scattered pebbles (Pl. 4-2). The sets are similar to those described in the Huntingford Bridge Pit.

A coarser-grained pebble bed is present at the base of a large cross-stratified unit and overlies a sandstone with similar large-scale stratification. This pebble bed is 0.38m thick and contains pebbles supported in a grey clay and sand matrix (Pl. 4-5). Pebbles in the bed are similar to those of the small-scale sets, but

are up to 20mm in length. The intermixing of clay and sand in the pebble bed appears to have resulted from bioturbation.

Interpretation: Two types of primary traction structure are recognised. Both contain evidence of regular fluctuations in current velocity and occasional bidirectional currents which caused variations in grain-size and bimodal set-orientations. These features are consistent with tidal-sand deposits (de Raaf & Boersma, 1971) and the scale of the primary structures implies that the sandstones were deposited in marine sandwave complexes.

The smaller structures were probably produced by the migration of megaripples (e.g. Dalrymple, 1984) and the larger-scale structures by accretion on the slip faces of sandwaves (e.g. Nio, 1976; Buck, 1985). The stacking of small-scale structures in marine tidal deposits is reminiscent of inclined cross-bedding described by Dalrymple (1984) and the intra-set cross-stratification noted by Blakey (1984). Both structures were considered to form part of sandwave complexes of "Class V" type (Fig. 2.4a) classified by J.R.L.Allen (1980). P.A.Allen & Homewood (1984) interpreted similar structures in Miocene sandstones of Switzerland as the product of sandwave construction by the migration of megaripples during peak spring-tide flow. The large-scale sets in the Folkestone Beds Formation resemble J.R.L.Allen's "Class IA" or "Class IIA" sandwaves (Fig. 2.4a).

The bioturbated pebbly lag, above a large-scale set, appears to have resulted from the concentration of coarser-grained detritus under conditions not typical for the deposition of the finer grained sand bodies. The association of a lag gravel and mud drape was noted in the Jura Quartzite by Anderton (1976). This was considered to have resulted from storm-events remoulding the sandwave deposits and concentrating the coarsest grained detrital fraction. In subsequent post-storm periods, fines in suspension settled out before the sandwaves could be re-established. A similar mode of formation is envisaged for the Folkestone Beds Formation pebble lag.

Lenham Heath, Kent (TQ 911 498)

In the area around the village of Lenham Heath, a number of sandpits in the Folkestone Beds Formation were reported by Worssam

(1963, p.55).

Description: The sandstones of the upper Folkestone Beds Formation in the pit are coarse-sand to granule grade, with scattered pebbles. They are cross-stratified, with large-scale and some small-scale sets similar to those at Moorhouse. The pebbles are concentrated on the foresets and bottomsets of the large-scale structures and are up to 8mm in length (Pl. 4-3). They consist predominantly of quartz and sandstone, with lesser quantities of dark chert (Sect. 4.2.3.2). Sandstone pebbles are elongate or platy, subangular to rounded and grey or red in colour. Quartz pebbles are white or stained red and orange at the surface, and are subangular to subrounded.

The pebbles are concentrated on foresets up to 0.6m thick and are interlaminated with sand and silt. The silt laminae thicken to the base of the sets. Asymmetrical ripples are observed on the foresets, with inclination of the laminae opposite to that of the main set. The large-scale sets dip predominantly to the southwest.

Interpretation: The variable grain-size and bimodal set-orientation are probably indicative of tidal current transportation. The large-scale sets are similar to structures described by Dalrymple (1984) and shown to have been produced by the migration of megaripples on sandwaves. Such deposits are probably included in the "Class V" type sandwaves (Fig. 2.4a) described by J.R.L.Allen (1980). The angularity of the quartz and sandstone clasts is indicative of local derivation.

Baker's Gap, Folkestone, Kent (TQ 249 364)

The type section of the Folkestone Beds Formation, to the north of the town centre at Folkestone, has been described frequently in the past (Fitton, 1836; Price, 1874; Hinde, 1885; Casey, 1939, 1961). Pebbles were collected from a number of horizons, principally of mammillatum Zone age.

Description: The pebble beds are thin, 20-70mm thick, composed of granules and small pebbles, on average less than 6mm in diameter. The pebbles are subangular to subrounded and are composed of white quartz and sandstone, with minor quantities of black chert (Sect.

4.2.3.2). Phosphorite nodules are common in the pebble beds and some horizons contain concentrations of phosphoritic bioclast casts and shelly debris.

The pebble beds are interbedded with glauconitic sandstones with parallel lamination or small-scale cross-stratification. Bioturbation of the sands is common.

Interpretation: The Folkestone Beds Formation at Folkestone differs from that of western Kent in containing little evidence for a strong tidal-current influence on sedimentation. The concentration of pebbles in phosphorite-bearing, glauconitic sandstones probably implies that the beds were formed by winnowing on a shelf starved of coarse-grained clastics (Odin & Matter, 1981).

Bridges (1982) suggested that the Folkestone Beds Formation in east Kent was deposited in a bed-load convergence zone, similar to those recognised in the shelf areas around Britain (Kenyon & Stride, 1970). The east Kent pebble suite was probably transported into the area by tidal currents, possibly supplemented by storm-induced currents.

2.2.3.2 The Gault Clay Formation (dentatus Zone)

In the Weald Basin, the base of the Gault Clay Formation is commonly marked by phosphorite horizons and in some areas by winnowed lags of coarse-grained sand and granules (Casey, 1961; Owen, 1971a). The base in the southwest Weald is marked by a pebble bed and this horizon has been sampled at four localities.

Aldersnapp Farm, Petersfield, Hampshire (SU 728 244)

The sandpit at Aldersnapp Farm described by Middlemiss (1962c) is now disused, but the top of the Folkestone Beds Formation and the base of the Gault Clay Formation are still exposed.

Description: The base of the Gault Clay Formation is a thin pebble bed, 0.10-0.15m thick, with small pebbles and pale phosphate nodules. The bed has a sharp base above the clean sandstones of the Folkestone Beds Formation and passes upward into the blue-black

mudstones of the Gault Clay Formation (Pl. 4-7). The pebble bed has an argillaceous matrix with glauconitic sand and is locally cemented by phosphate. The pebbles are less than 15mm in length and are composed principally of quartz and chert. Sparse rounded clasts of white, weathered chert are also present in the pebble suite.

The underlying Folkestone Beds Formation consists of fine to medium-grained cross-stratified sandstones. The sets are 0.2-0.3m thick and contain mud drapes and concentrations of carbonaceous matter on the foresets. Sandstones with symmetrical ripples are also present.

Interpretation: The pebble bed is a winnowed-lag deposit. The presence of phosphate nodules in the bed suggests that the rate of deposition was slow, nutrient levels and organic productivity were probably high. Such conditions were considered to occur during high sea-levels by Heckel (1977) and could therefore be correlated with marine transgressions. In southern Britain, the mid-Albian transgression probably caused such conditions and would also restrict the quantity of sand entering the Weald Basin.

The size of the pebbles is similar to that in the Folkestone Beds Formation to the north and reworking of the older pebbly sandstones is probable.

Fittleworth Station (TQ 007 181), Burton School (SU 974 173) and Duncton (SU 961 175), Sussex

The pebble bed at the base of the Gault Clay Formation at Fittleworth Station, Burton School and Duncton is similar in appearance. The bed was described by Kirkaldy (1935) and a short description was also given by Casey (1961). The bed has recently been described by Anderson (1986).

Description: The pebble bed at the base of the Gault Clay Formation in West Sussex is 0.1-0.3m thick and is composed of small pebbles, less than 10mm in length. The pebbles are of quartz and dark chert, with minor quantities of ironstone (Sect. 4.2.3.3). The bed has a planar base and overlies cross-stratified sandstones of the Folkestone Beds Formation. The upper surface of the bed is similarly

sharp and is overlain by mudstones (Pl. 4-6). The bed in West Sussex differs from that at Aldersnapp Farm, being cemented by microcrystalline goethite. Phosphates and glauconite are absent from the bed in which quartz and feldspar sand grains are fractured and partially replaced.

Interpretation: Compositionally the pebble suite is similar to that at Aldersnapp Farm and reworking of detritus from the top of the Folkestone Beds Formation is likely.

The goethite matrix to the pebble bed is clearly authigenic in origin since it is aggressively replacive towards detrital grains. The general scarcity of goethite ooids in the bed makes it distinct from the other Lower Greensand Group ironstones in England of marine origin and it is improbable that the iron cementation is of early diagenetic origin. The goethite is possibly the oxidation product of pyrite cement, but this has not been confirmed during the present study. The restriction of the goethite matrix to the horizon immediately below the mudstones of the Gault Clay Formation implies that ionic concentrations causing cementation resulted from dewatering of the mudstones (cf. Curtis, 1978).

The compositional difference in the matrix of the bed has important implications for the environment of deposition. A phosphate-cemented pebble bed at Aldersnapp Farm implies open marine depositional conditions with slow sedimentation rates. The absence of such a matrix in West Sussex possibly enabled cementation of the pebble bed by pyrite following burial. It is likely, therefore, that early burial conditions in the West Sussex area were not suitable for phosphate formation. Kirkaldy (1935) suggested that the bed occurred on a high and this conclusion has been reiterated by Anderson (1986). It is possible that the deposition was in well-oxygenated waters unsuitable for phosphate formation.

2.2.4 The Oxfordshire and Wiltshire area

The area between the Vale of Wardour and Oxford lies to the west of the Weald Basin and to the north of the Central Channel Basin (Sect. 1.5). Included in the Oxfordshire-Wiltshire area are a number

of outliers of Lower Cretaceous strata (Arkell, 1947b; Casey & Bristow, 1964). The marine sediments of Aptian and Albian age were deposited in the Pewsey and Mere Basins, western extensions of the Weald Basin. Faunal and sedimentological indicators suggest that the margins of these basins existed relatively short distances to the northwest (Middlemiss, 1962b; Bridges, 1982).

Pebble beds of Late Jurassic and Early Cretaceous age have been studied in the area. A combination of the scarcity of exposures and the limited original extent of some units has prevented detailed lateral studies of a single horizon. The horizons examined include those of the Lower and Upper Lydite Beds, the Lower Greensand Group and the Gault Clay Formation. Pebble beds of the Corallian Group were studied, but the pebble assemblages have not been examined in detail.

2.2.4.1 The basal Swindon Clay pebble bed (pallasioides Zone): Swindon, Wiltshire (SU 150 830)

The pebble bed at the base of the Swindon Clay is occasionally exposed in cuttings and has been reported between Wiltshire and Buckinghamshire (Arkell, 1947b). Pebbles were collected from this horizon in a small excavation at Swindon. The section was described by Chatwin & Pringle (1922) and Arkell (1947b).

Description: The section of the Swindon Clay is now largely overgrown, but a pebble bed was exposed in a small cutting at the time of study.

Pebbles are scattered throughout a brown argillaceous sandstone, 0.30-0.35m thick. The base of the bed is sharp and the bed overlies a glauconitic sandstone without clasts and passes up into a shelly mudstone with abundant Nanogyra. The top of the shell bed was not observed. Small pebbles and granules are present in low abundance in the shell bed but are concentrated towards its base. The pebbles are rarely greater than 10mm in length and are composed of dark chert and quartz (Sect. 4.3.4.1).

Interpretation: The fauna of the shelly mudstone indicates that the pebble bed is of marine origin. The poor sorting of the pebble bed

possibly results from bioturbation. Pebbles at the base of the shell bed are likely to represent the basal unit to a coquina, but the poor exposure prevents further interpretation.

In the section described by Chatwin & Pringle (1922), the Lower Lydite Bed was noted at the base of the Swindon Clay where it overlies the "Exogyra" nana Bed. The horizon sampled is at the base of a shell bed and is therefore unlikely to be the Lower Lydite Bed. Inversion of this section by slumping does not appear to have occurred and the clasts were probably in the Pectinatus Sands, below the "Exogyra" nana Bed.

2.2.4.2 The Upper Lydite Bed (glaucolithus Zone)

The Upper Lydite bed at the base of the Portland Group is better exposed than the Lower Lydite Bed and outcrops between the Vale of Wardour in the south and Buckinghamshire in the north. The horizon has been sampled at two localities. Descriptions of the pebble bed at a number of localities were made by Arkell (1933a, 1947b).

Swindon, Wiltshire (SU 152 831)

Descriptions of the locality were made by Chatwin & Pringle (1922), Arkell (1933a, 1947b) and Wimbledon (1976).

Description: The pebble bed at the base of the Portland Group in this exposure is conspicuous. It contains pebbles of chert, phosphorite and quartz (Sect. 4.2.4.2) in a fine-grained bioclastic sandstone with calcareous cement (Pl. 5-1). The bed has a planar base above the Swindon Clay and passes upward into bioclastic sandstones without pebbles.

The pebble suite consists of chert clasts, up to 25mm in length and slightly larger phosphorite pebbles, up to 35mm long. The quartz and chert pebbles are subrounded to rounded, bladed to compact-bladed. Phosphorite clasts are angular to subrounded and of a variety of shapes. Casts of bioclasts are common, particularly the bivalves Pleuromya and Protocardia. Rod-like structures, possibly burrow-fills, are common; teeth and bone are also found.

PLATE 5

WILTSHIRE, OXFORDSHIRE AND BEDFORDSHIRE

WILTSHIRE, OXFORDSHIRE AND BEDFORDSHIRE

5-1. Basal surface of the Upper Lydite Bed, Swindon, Wiltshire. The pebbles are predominantly of phosphorite, but include Carboniferous shelf chert pebbles.

5-2. Goethite-cemented very coarse-grained skeletal grainstones with scattered pebbles in the Faringdon Sponge Gravel, Wicklesham Pit, Faringdon, Oxfordshire. Lens cap diameter: 50mm. View to the northeast.

5-3. Reticulate iron-cemented pebbly sandstones in the Seend Ironsand at Seend, Wiltshire. Hammer length: 0.32m. View to the south.

5-4. Cross-stratified pebbly sandstones, Seend Ironsand, Seend, Wiltshire. Hammer length: 0.32m. View to the south.

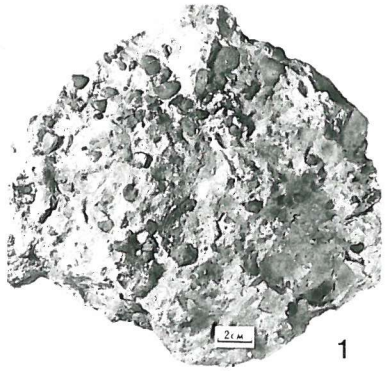
5-5. Small-scale "herring-bone" cross-stratification in the Woburn Sands at Double Arches Sandpit, Leighton Buzzard, Bedfordshire. Small pebbles are concentrated on the bottom sets. Lens cap diameter: 50mm. View to the south.

5-6. Large-scale cross-stratified sandstones of the Woburn Sands (middle ground) overlain by the Gault Clay Formation (top). Billington Crossing Sandpit, Leighton Buzzard, Bedfordshire. Truck for scale. View to the southeast.

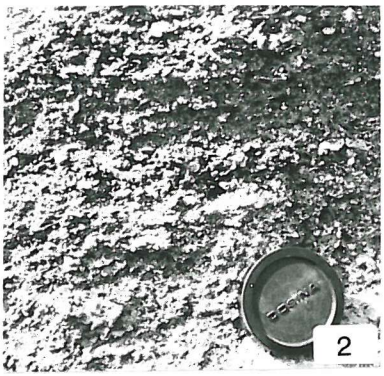
5-7. Cross-stratified very coarse-grained skeletal grainstones in the Faringdon Sponge Gravel, Wicklesham Pit, Oxfordshire. Hammer length: 0.32m. View to the northeast.

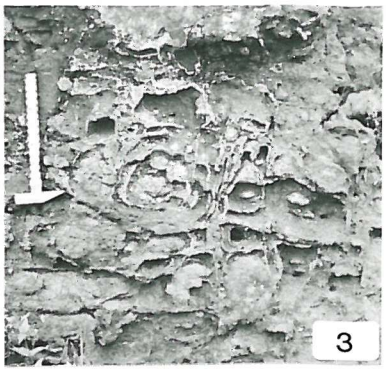
5-8. Two isolated pebbly cross-sets at the base of the Gault Clay Formation overlying clean sandstones of the Woburn Sands at Double Arches Sandpit, Leighton Buzzard, Bedfordshire. Hammer length: 0.32m. View to the northwest.

5-9. Cross-stratified pebbly-set at the base of the Gault Clay Formation on a planar erosion surface above the Woburn Sands. Double Arches Sandpit, Leighton Buzzard, Bedfordshire. Hammer length: 0.32m. View to the northwest.



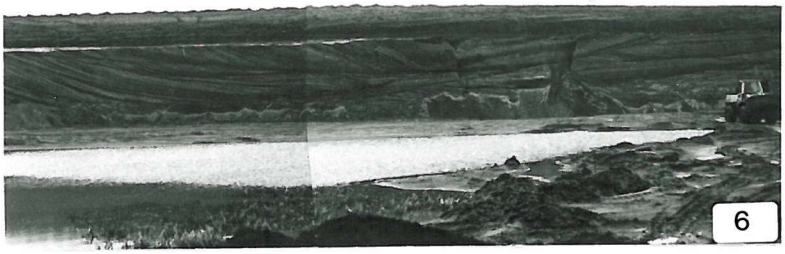
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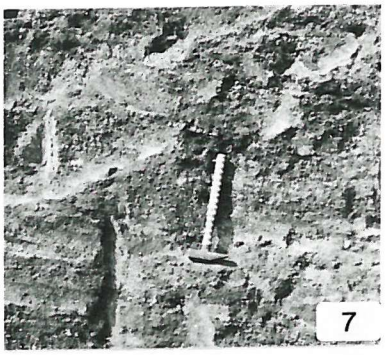

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PLATE 5

Interpretation: The pebble bed at the base of the Portland Group is a lag deposit containing both mature extrabasinal detritus and locally derived intrabasinal material. The phosphorite clasts have undergone only slight abrasion and are unlikely to have been transported far from their source. The formation of a basal gravel over a disconformity is typical of strand-line deposits (Clifton, 1967). It was suggested by Casey (1963) that the Upper Lydite Beds were produced during a major shoreline-retreat phase.

Littleworth Brick Pit, Oxford (SP 589 055)

The brick pit at Littleworth is now disused and, although much of the section is obscured by slipping, the Upper Lydite Bed is exposed. The section was described by Neaverson (1925); Pringle (1926); Arkell (1943, 1947b) and McKerrow & Kennedy (1973).

Description: The pebble bed exposed at the top of the section is 0.10-0.15m thick and rests with a sharp contact on fine-grained calcareous sandstones. It is overlain by glauconitic sandy limestones with scattered pebbles. The pebbles are predominantly of black chert, with some quartz and sandstone clasts. Phosphorite pebbles are rare. The average pebble size is 15-20mm, but clasts up to 55mm in length have been collected.

Interpretation: The poor exposure prevents precise interpretation of the environment of deposition. The size of the clasts is unusually large for shelf deposits (cf. Sect. 2.2.3.1) and they are more similar in size to strand-line pebbles.

2.2.4.3 The Lower Greensand Group

Remnants of the Lower Greensand Group are preserved between the Vale of Wardour and Oxford in small outliers extending beyond the outcrop of the Gault Clay Formation. The exposures are isolated and commonly elongated northwest-southeast. The present outcrop pattern probably reflects the position of original structural lows, some of which also existed during Late Jurassic times (Arkell, 1933a, 1939a, 1947b).

The Lower Greensand Group has been examined at three localities;

Seend, near Devizes, Faringdon and at Hurst Hill, near Oxford. The deposits are all of differing ages (Casey, 1961) and each is lithologically distinct.

2.2.4.3a Faringdon Sponge Gravel (nutfieldiensis Zone): Wicklesham Pit, Faringdon, Oxfordshire (SU 294 943)

The Faringdon Sponge Gravel is well exposed in pits around the village of Faringdon and has been examined at one locality. The Lower Greensand Group of the Faringdon district was separated by Arkell (1947b) into the following divisions:

4. Sands with chert and ironstone
3. Sandy clays
2. Red Gravel
1. Yellow Gravel

} Sponge Gravel

Detailed descriptions of the Faringdon Sponge Gravel and the overlying sands were made by Austen (1850), Sharpe (1854) and Meyer (1864). Later studies were made by Melville (1943), Arkell (1943) and Casey (1961). A detailed sedimentological and palaeontological investigation was carried out by Krantz (1972). Wilson (1986) described the encrusting, nesting and boring fauna of the Red Gravel. Investigations into the provenance of the coarse-grained detritus have been limited, but comments were made by the authors above. The descriptions of clasts given by Wilson (1986) are inconsistent with those made during this study. It is probable that Wilson preferentially described encrusted lithotypes.

Pebbles are present in both the Yellow and Red Gravel, but are more abundant in the latter. A pebble bed exists at the base of the Red Gravel and it was from this and the overlying horizons that pebbles were sampled (Pl. 5-2).

Description: Pebbles were present in two rock types. These are:

1. massive, poorly-sorted, pebbly coarse-grained bioclastic sandstones. These beds are 0.25-1.00m thick, clast-supported,

with a matrix of coarse- to very coarse-grained shell debris. The shell debris is composed of brachiopods, bivalves (especially oysters), echinoid plates and spines, bryozoa and calcareous sponges. The sandstones are unstratified or have low-angle to horizontal stratification.

The pebble suite is trimodal. Details of the suite are given in Section 4.2.4.3. The three types of phenoclast are:

a. limestones and pale-coloured cherts, 20-350mm in length (average, 30-40mm),
b. dark chert and white quartz, and
c. black phosphorite clasts.

a. Limestone pebbles include bioclastic and oolitic packstones and wackestones and calcite-cemented sandstones. Clasts of limestone are rounded to well-rounded, bladed to platy in shape, commonly have bivalve borings and are encrusted by bryozoa and serpulids. Calcareous sand-filled perisphinctid ammonite whorls and rolled scleractinid corals are also found. The pale chert pebbles are white to brown and rounded to very angular.

b. Quartz and dark chert rounded and non-encrusted pebbles, 10-25mm in length.

c. Phosphorite clasts which are up to 50mm in length, subrounded to well rounded and include rolled bone fragments and ammonite and bivalve casts. Preservation of the ammonite casts is poor, but they appear to be of perisphinctid forms. The bivalves are more readily identifiable and include specimens of Pleuromya and Protocardia.

2. very coarse to medium-grade bioclastic sandstones (Pl. 5-2). The sandstones are similar to those described above, but contain fewer pebbles and calcareous sponges. The pebbles are predominantly from the quartz and dark chert subsuite but are smaller than those in the massive pebbly bioclastic sandstones. The sandstones are trough cross-stratified, with sets 0.2-0.3m thick (Pl. 5-7).

Interpretation: The bioclasts of the Sponge Gravel are both rounded

and angular. Bivalves and brachiopods are predominantly disarticulated, but the degree of abrasion of the valves suggests that they were not subjected to prolonged attrition. The shelly sandstones are unlikely to have been deposited in an area of persistent high-energy conditions and therefore they are unlikely to be shoreface deposits. Sponges and bryozoa are not found in life-position. Krantz (1972) interpreted the fauna as being a hardground assemblage, transported prior to deposition.

The pebble beds are stratified deposits with low-angle sets which suggests that they were gravel banks or bars, accreting laterally. The sands were probably deposited as migrating dunes (Krantz, 1972).

2.2.4.3b Seend Ironsand (nutfieldiensis Zone): Seend, Wiltshire (ST 937 600)

Ferruginous and sideritic sandstones in the Lower Greensand Group outcrop at a number of localities in Wiltshire, Oxfordshire and Bedfordshire (Casey, 1961; Casey & Bristow, 1964), but exposure is limited. Samples were collected from the Seend Ironsand at one locality.

The Seend Ironsand are exposed in a disused sandpit in the village of Seend. The sands were described by Cunningham (1850), Jukes-Browne (1892, 1905) and Barron (1957).

Description: In the pit, 2m of reddish-brown ferruginous sandstones are exposed (Pls. 5-3, 5-4). The sandstones are cross-stratified with tabular sets up to 1.35m thick (Pl. 5-4). Reverse-inclined sets, 0.05-0.10m thick, were also recognised.

Pebbles are scattered on the foresets and bottomsets of the sandstones and are up to 12mm in length. Rounded, bladed quartz and dark chert pebbles predominate (Sect. 4.2.4.4). The sandstones contain scattered bioclasts.

Interpretation: The sands were transported as megaripples, probably forming part of a sandwave complex. Bimodal current indicators imply that tidal currents were the probable mechanism of transportation.

High iron contents in shallow marine sands were suggested to imply local fluvial influence by Brookfield (1973a) and Teyssen (1984). It is probable that the ironsands were deposited in a nearshore area on the margins of the Wessex Basin, with a local fluvial influence.

2.2.4.3c Hurst Hill Sands (nutfieldiensis Zone to jacobi Zone): Hurst Hill, Oxford (SP 476 042)

These sandstones have not been given a formal name, but probably represent equivalents of the Red Sands of Uffington described by Casey (1961). The sandstones were examined at one locality near Oxford. The locality at Hurst Hill was described by Pringle (1926) and Arkell (1947b, p.161) when the Lower Greensand Group was exposed above the Kimmeridge Clay Formation in the Charley Brick pit. The site is now disused and the section largely obscured.

Description: Samples were taken from a small excavation at the top of the former pit and pebbles were extracted from goethite-cemented quartz sandstones. Sedimentary structures were not observed. The pebbles are concentrated in laminae and scattered throughout the sandstones. Clasts are small (less than 8mm in length) and predominantly of quartz with minor amounts of dark chert (Sect. 4.2.4.5). Pebbles are rounded to subrounded and compact to bladed in shape.

Interpretation: It is not possible to ascertain the environment of deposition from the present exposure. Arkell (1947b) described the sandstones as cross-stratified, with large sets inclined to the southwest. It is probable that the deposit is part of a tidal-sand complex similar to those of the Lower Greensand Group of Seend and the Weald.

2.2.4.4 The Gault Clay Formation (dentatus Zone): Haredene Woods, Wiltshire (ST 964 290)

As in other parts of southern England, the Gault Clay Formation in Wiltshire oversteps the Lower Greensand Group. The basal beds of this formation are rarely exposed, but samples have been collected

from a site in the Vale of Wardour.

Description: The exposure of the base of the Gault Clay Formation is largely obscured by slumping, but pebbles were collected from a stream section. The clasts occur in ferruginous sandstones and are rounded to subrounded, bladed and composed of quartz and dark chert (Sect. 4.2.4.6). Clasts are up to 30mm in length but are on average less than 20mm long.

Interpretation: The pebble bed appears to be a lag deposit, but the poor exposure inhibits interpretation.

2.2.5 The Bedfordshire-Cambridgeshire area

The area between Leighton Buzzard, Bedfordshire and Ely, Cambridgeshire contains a thin sequence of Lower Cretaceous rocks (Table 1.7). A number of diastems exist in the sequence (Rawson et al., 1978) and are commonly marked by phosphorite nodule beds or pebble beds (Casey, 1961). Exposure is limited but samples of the pebble beds in the Woburn Sands and the Gault Clay Formation were collected.

2.2.5.1 The Woburn Sands (jacobi Zone to tardefurcata Zone)

The Woburn Sands are of Late Aptian to Early Albian age (Casey, 1961; Rawson et al; 1978) and are correlated with the Folkestone Beds Formation of the Weald area. Aspects of the sedimentology of the Woburn Sands have been described by Schwarzacher (1953) and Buck (1985, 1987) and a summary of the palaeoenvironmental setting was given by Bridges (1982). The sands have been shown to be a sandwave complex (Nio, 1976), with current indicators implying dominant southerly currents (Schwarzacher, 1953; Narayan, 1963; J.R.L.Allen, 1982). The deposits are in general of sand-grade material, but pebbles and granules are found locally.

Haddenham, Cambridgeshire (TL 469 755)

This sandpit was described by Worssam & Taylor (1969), but has since become disused and is now largely overgrown.

Description: A section, 1m thick, of brown ferruginous sandstones is

exposed at the top of the old pit. The sandstones are medium-grained with clay laminae. Scattered pebbles and granules are present in subhorizontal laminae. The pebbles are up to 5mm in length and are principally of dark chert and quartz (Sect. 4.2.5.1). Phosphorite and ironstone clasts are absent. The cross-stratified sandstones described by Worssam & Taylor (1969) are no longer exposed.

Interpretation: The pebbles are concentrated in thin lags and were probably separated from the surrounding sands by winnowing. The variation in grain size of the sediment indicates that current conditions were probably pulsatory. There is no evidence for these being strand-line gravels and their presence in sands deposited under tidal conditions (Nio, 1976) suggests similar conditions of deposition.

Billington Crossing (SP 931 240), Double Arches (SP 940 288) and Tiddensfoot (SP 913 236) Sandpits, Leighton Buzzard, Bedfordshire

The sandpits at Leighton Buzzard have been the venue for a number of Geologists' Association meetings in the past and the description of the junction with the Gault Clay Formation in a selection of the pits is given by Owen (1972).

Description: The Woburn Sands at Leighton Buzzard consist of medium to coarse-grained quartz sandstones of quartz with varying quantities of oolitic goethite. The sandstones are locally pebbly, with clasts of dark chert and ironstone predominating (Sect. 4.2.5.1). Quartz pebbles are present but are not abundant. The phenoclasts are up to 15mm in length, but more commonly are less than 8mm long. The quartz and chert clasts are rounded and compact to bladed. The ironstones are subrounded to subangular and platy.

Pebbles were found in two types of bed:

1. large-scale cross-stratified sandstones, and
2. small-scale cross-stratified sandstones.

1. large-scale cross-stratified sandstones. The pebbles are present on the foresets and bottomsets of 1-5m thick tabular cross-sets of medium to coarse-grained sandstones. Beds of this type were exposed in the Billington Crossing Sandpit at Leighton Buzzard

(Pl. 5-6). Pebbles are as described above, but may be as large as 15mm in length.

2. small-scale cross-stratified sandstones. These units are present at the top of the Woburn Sands in the Double Arches and Tiddensfoot Pits. Pebbles are less common in these sandstones, than in those with large-scale cross sets, but granules may be present. The sandstones are cross-stratified, with small sets up to 40mm thick. Sets dipping in opposite orientations (herring-bone cosets) are common (Pl. 5-5). Pebbles and granules are concentrated as lags at the base of sets and are less than 8mm in diameter.

These bedding units correspond to the two facies recognised by Nio (1976) and are similar to the Folkestone Beds Formation described from Huntingford Bridge and Moorhouse in the Weald (Sect. 2.2.3.1b).

Interpretation: The pebbly sands of the Woburn Sands closely resemble those of the Folkestone Beds Formation in the Weald. The associated characteristics suggest that both sand sequences were deposited under the influence of tidal currents. The sandstones of the Woburn Sands were interpreted as deposits of sandwave complexes by de Raaf & Boersma (1971) and Buck (1985), similar to those described from the southern North Sea (Houbolt, 1968). The large-scale sets probably formed part of "Class I" type sandwaves (Fig. 2.4a) described by J.R.L.Allen (1980).

The abundance of bidirectional current indicators in the sands with small-scale structures is probably evidence of greater parity in the strength of the flood and ebb currents. The structures are similar to the complex cross-bedded cosets described by Dalrymple (1984) and possibly formed part of a "Class VI" sandwave (J.R.L.Allen, 1980; Fig. 2.4a).

Transportation of pebbles across the shelf probably occurred in association with the migration of sand bodies. The predominance of southerly-dipping sets (Schwarzacher, 1953; J.R.L. Allen, 1982) suggests a northern source for the detritus. Rounding and maturity of the siliceous clasts indicates that reworking from older pebble beds is probable.

2.2.5.2 The Gault Clay Formation (tardefurcata Zone to mammillatum Zone)

The base of the Gault Clay Formation is exposed in sandpits at Leighton Buzzard (Sect. 2.2.5.1). A selection of the pits was described in detail by Owen (1972). The junction beds between the Woburn Sands and the Gault Clay Formation were sampled in two pits, Billington Crossing and Double Arches.

Double Arches Sandpit, Leighton Buzzard, Bedfordshire (SP 940 288)

Description: The contact between the Woburn Sands and the overlying muddy and pebbly sandstones at the base of the Gault Clay Formation is sharp, with a planar erosion surface at the base. The Woburn Sands are composed of small-scale cosets with scattered small pebbles. The basal beds of the Gault Clay Formation are pebbly sandstones with a matrix of glauconitic sand. Small isolated cross-stratified pebble sets are present above the erosion surface (Pls. 5-8, 5-9). The sets are asymmetrical, 0.10-0.15m thick, have a matrix of coarse-grained glauconitic sand and are draped by dark mudstones. The framework pebbles are 10-20mm in length and predominantly of dark chert and white quartz.

Interpretation: The pebbles are found in planar and cross-stratified sets. The latter probably resulted from the migration of pebble megaripples. The draping of the sets by mud indicates variable current conditions, probably with periodic winnowing of the sediment and the subsequent settling of fines.

The sharp base to the pebbly cross-sets and the equally sharp tops suggest that they were deposited during a short-lived catastrophic event. The glauconitic sand matrix suggests that deposition occurred in the marine environment. It is more probable that the pebble beds were produced by wave or storm-induced processes with periodic reworking during a period of general quiescence. Pebbly megaripples of similar size and shape were described by Yorath et al. (1979) and Forbes & Boyd (1987) and were also considered to result from storm swells.

The clasts in the basal Gault Clay Formation are slightly

coarser grained than those present in the Woburn Sands, but it is probable that they were largely reworked from the underlying beds.

Billington Crossing Sandpit, Leighton Buzzard, Bedfordshire (SP 931 240)

Description: The pebbles in the junction beds are small, on average less than 8mm in length, and are composed of quartz and dark chert (Sect. 4.2.5.1). Clasts are rounded to subrounded and bladed in shape. The pebbles are present in thin beds, 0.05-0.10m thick or scattered throughout muddy sandstones. Cementation of the pebble beds by goethite is common. The pebbles are supported by matrices of muddy glauconitic sandstones, with evidence of bioturbation. Beige or white nodules of phosphate are common and some are studded with small pebbles and granules.

Interpretation: The pebbly sandstones at the base of the Gault Clay Formation are concentrate deposits, probably produced by slow deposition rates and continual reworking. The presence of phosphorite nodules and glauconitic sandstones were considered by Johnson (1978) to be typical of sediment-starved shelf sedimentary rocks. The poor sorting of the beds indicates variable energy conditions with periodic winnowing of the fine-grained detritus. The similarity in the composition and clast-range of the Woburn Sands and the Gault Clay Formation pebble suites suggests that reworking of the older pebbly sandstones is likely to have occurred.

2.2.6 The East Midlands area

The East Midlands area (East Midlands Shelf) extends from the Market Weighton High in the north to the Anglo-Brabant Massif in the south (Sect. 1.5). To the east, the shelf extends into the southern North Sea, where its eastern margin is defined by the Dowsing fault. The western limit of the area is uncertain as a result of post-Cretaceous erosion.

During Early Cretaceous times, marine sandstones, mudstones, ironstones and argillaceous limestones were deposited on the East Midlands Shelf. Breaks in sedimentation were frequent and towards the basin margins were probably prolonged. The diastems are commonly

marked by phosphate nodule beds or pebble beds and three of the latter have been sampled. The Mid-Spilsby Nodule Bed and the basal Claxby Ironstone Formation pebble bed were both sampled at one locality. The Carstone was sampled in three areas. The stratigraphical terminology of Kelly & Rawson (1983) has been adopted for the Upper Jurassic and Lower Cretaceous rocks of the East Midlands in this study.

2.2.6.1 The Mid-Spilsby Nodule Bed (icenii Zone): Donington-on-Bain, Lincolnshire (TF 245 822)

The concentration of pebbles at the base of the Upper Spilsby Sandstone Member has been sampled in central Lincolnshire, but the Clixby pebble bed in north Lincolnshire is possibly of similar age (Sect. 2.2.6.4).

The section exposed in the disused railway cutting at Donington was described by Kelly & Rawson (1983) and in more detail by Kelly (1984). Exposed in the cutting are parts of the Lower and Upper Spilsby Sandstone Members and the Claxby Ironstone Formation. The basal Claxby Ironstone Formation pebble bed was not exposed at the time of examination, but the Mid-Spilsby Nodule Bed was sampled.

Description: The Mid-Spilsby Nodule Bed is a thin concentrate of black chert pebbles, with lesser quantities of white quartz and brown phosphate pebbles (Sect. 4.2.6.1). The bed is 0.15-0.20m thick and rests on a sharp, planar erosion surface above the Lower Spilsby Sandstone Member (Pl. 6-9). The siliceous pebbles are rounded, bladed to compact-bladed and up to 17mm in length. The pebble bed has a fine to medium sand-grade matrix.

The Lower Spilsby Sandstone Member is composed of massive glauconitic sandstones up to 1m thick, which contain scattered pebbles and granules. The pebbles are predominantly of dark chert and are generally less than 8mm in length. The Upper Spilsby Sandstone Member is similar in appearance to the lower unit, but contains fewer pebbles.

Primary traction structures were not recognised in either of the sandstone units, which are both massively bedded and mottled.

PLATE 6

NORFOLK AND LINCOLNSHIRE

PLATE 6
NORFOLK AND LINCOLNSHIRE

6-1. The unconformity between the Kimmeridge Clay Formation (A) and the Carstone Member (B). The Carstone Member is overlain by the Hunstanton [Red Chalk] Member (C) and Ferriby Chalk (D). South Ferriby, Humberside. The Carstone Member is 0.7m thick. View to the west.

6-2. The contact between the Carstone Member (A), Hunstanton [Red Chalk] Member (B) and Ferriby Chalk (C) at Hunstanton, Norfolk. The Red Chalk is 1.5m thick. View to the eastsoutheast.

6-3. The Carstone Member overlain by nodular weathered Hunstanton [Red Chalk] Member, Nettleton Bottom, Lincolnshire. Hammer length: 0.32m. The pebbly sandstones of the Carstone Member at the base of the section grade upwards into sandy conglomerates and pebble beds. View to the east.

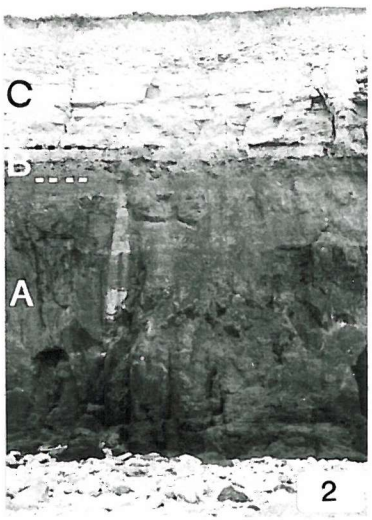
6-4. Pebbly ferruginous sandstones at the top of the Carstone Member, Nettleton Bottom, Lincolnshire. Lens cap diameter: 50mm. View to the east.

6-5. The disconformable contact between the Lower Spilsby Sandstone Member (A) and the Claxby Ironstone Formation (C) at Woods Hill, Nettleton, Lincolnshire. A thin conglomerate (B) overlies the unconformity. Hammer length: 0.32m. View to the northeast.

6-6. The basal Claxby Ironstone Formation pebble bed (B) overlying the Lower Spilsby Sandstone (A) and beneath the Clixby Ironstone Formation (C). Woods Hill, Nettleton, Lincolnshire. Hammer length: 0.32m. View to the east.

6-7. Clixby pebble bed infilling an erosion hollow in the Lower Spilsby Sandstone Member at Clixby, Lincolnshire. Hammer length: 0.32m. View to the southeast.

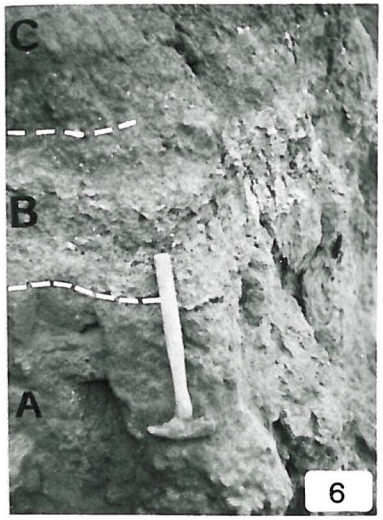
















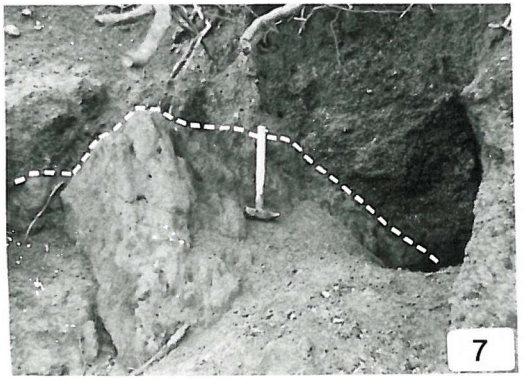


PLATE 6

6-8. The contact between the Lower Spilsby Sandstone Member and the Clixby pebble bed, Clixby, Lincolnshire. Hammer length: 0.32m. View to the northnortheast.

6-9. Mid-Spilsby Nodule Bed, Donington-on-Bain, Lincolnshire. Hammer length: 0.32m. The bed is a concentration of extrabasinal siliceous pebbles and intrabasinal phosphorites. View to the northeast.

Clay-lined burrows are preserved locally.

Interpretation: The pebble bed is a winnowed lag. The similarity in size of pebbles in the pebble bed and those in the underlying sandstones implies that the concentration of pebbles resulted from a break in sedimentation and erosion of the Lower Spilsby Sandstone Member. The sandstones are probably of shallow marine origin but in the absence of sedimentary structures little may be deduced. The lack of structure probably results in part from bioturbation. However, the preservation of bed boundaries suggests that the sandstones were probably never internally stratified.

Laterally, in Lincolnshire, the pebble bed horizon is marked by phosphate nodules and is considered to have been produced during a transgressive phase (Casey, 1963). At the basin margin the pebble bed is possibly a strand-line deposit, but reworking of the underlying pebbly sandstone probably occurred on the shelf.

2.2.6.2 The Claxby Ironstone Formation (Paratollia Zone): Woods Hill Sandpit, Nettleton, Lincolnshire (TF 108 994)

The pebble bed at the base of the Claxby Ironstone Formation was sampled at one locality in northern Lincolnshire. The section was described by Casey (1973) and by Kelly (1984). The pit is partially filled but the contact between the Spilsby Sandstone Formation and Claxby Ironstone Formation is still exposed (Pl. 6-5). The pebble bed at the base of the Claxby Ironstone Formation was sampled.

Description: The pebble bed is 0.2-0.3m thick and composed of chert and scattered quartz pebbles (Pl. 6-6). The pebbles are rounded to well-rounded and up to 20mm in length. Belemnites and disarticulated bivalves are present in the bed. The pebble bed has a matrix sand of goethitic ooids and quartz and is cemented by micritic ferroan calcite. The surface separating the pebble bed from the underlying sandstone is sharp and undulatory. Pebbles fill borings extending down into the underlying sandstone. The upper contact to the pebble bed is transitional, with a decrease in the number of pebbles and increase in the proportion of goethitic sandstone.

The Spilsby Sandstone Formation is composed of coarse-grained

glauconitic sandstones partially cemented by carbonate. Scattered pebbles are found in the sands. Overlying the pebble bed is a ferruginous arenite (Claxby Ironstone Formation) composed predominantly of goethitic ooids with mudstone and micrite laminae. Belemnites and bivalves are common in the ironstone.

Interpretation: The pebble bed rests on an erosion surface overlying the Lower Spilsby Sandstone Member (Kelly & Rawson, 1983). Bivalves and belemnites in the ironstones indicate a marine origin. Oolitic ironstones are commonly considered to form in estuarine or lagoonal environments where fluvial input results in high iron concentrations (Brookfield, 1971; Teyssen, 1984).

The pebble bed is a basal lag deposit and is similar to basal beds interpreted as strand-line lags by Clifton (1967). The lack of comminuted shelly debris indicates that pebbles were unlikely to have been deposited on the upper shoreface and were possibly winnowed subsequent to deposition. It is possible that the pebbles were not reworked through a strand-line and were winnowed on the sea floor.

Reworking of the pebbles from the Spilsby Sandstone Formation and particularly from the Mid-Spilsby Nodule Bed is probable. There is no evidence for an influx of fresh detritus into the basin at this locality.

2.2.6.3 The Carstone Member (*tardefurcata* Zone to *mammillatum* Zone)

The Carstone Member of the East Midlands was examined at six localities and sampled at three. The sandstones attain their greatest thickness in north Norfolk, where 17.8m is present in the North Creake borehole (Kent, 1947), and thin to the south (Gallois & Morter, 1982) and to the north (Rawson & Riley, 1982).

Hunstanton, Norfolk (TF 674 418)

The Hunstanton section was described by Larwood (1961) and reveals the Carstone Member, Hunstanton [Red Chalk] Member and the overlying white Ferriby Chalk.

Description: The Carstone Member is composed of pebbly ferruginous

sandstones with pebble beds towards the top of the unit. In the exposed section in the cliff at Hunstanton (Pl. 6-2), the lowest 6m of the Carstone Member are of ferruginous sandstones containing small cross-sets with pebble and granule lags. The sets are 0.05-0.10m thick and include both planar and trough sets. Pebble lags are common on the foresets and bottomsets. The clasts are up to 5mm in length.

Two pebble beds, 0.20-0.35m thick, are present at the top of the section. The pebble beds are clast-supported, with medium-grained ferruginous sand matrix. The sand matrix includes abundant goethite ooids and granular flakes of ironstone.

Overlying the upper pebble bed is a yellowish orange, marly sandstone with clay laminae and scattered pebbles. This bed passes upward into nodular bioclastic packstones and wackestones of the Hunstanton Member. The basal limestones are red to pink in colour, with scattered goethite grains and small pebbles. Belemnites and fragmented inoceramids are common at the base of the Hunstanton Member.

The pebble beds consist of clasts, up to 40mm in length, composed of dark brown or black chert, quartz, phosphorite and ironstone (Sect. 4.2.6.3). The pebbles are rounded to subrounded, except for the ironstones which are angular to subangular.

Interpretation: The poor sorting of the Carstone Member sandstones and the range of grain sizes indicates that they were deposited in an environment in which energy conditions were variable. This feature is uncharacteristic of most strand-line gravels (Clifton et al., 1971; Leithold & Bourgeois, 1984).

The general upward-coarsening trend in the unit is reminiscent of offshore sand bars or ridges described on the North Atlantic shelf east of the U.S.A. by Swift et al. (1973). Similar structures have also been noted in the Lower Carboniferous rocks of southern Ireland by Cotter (1985), who recognised three pebbly bedding structures:

1. swaley cross-stratification in pebbly sandstones (dispersed granules and pebbles),
2. tabular, thin pebble beds (concentrated conglomerates), and

3. individual beds of pebbles interspersed in rippled muddy sandstones and mudstones.

The pebble beds towards the top of the Carstone Member are similar to Cotter's concentrated conglomerates and the pebbly sandstones below are possibly of the dispersed pebble type. However, the cross-stratification in the Carstone Member was not readily defined and could not be verified as swaley.

The pebbles of the Carstone Member differ from those of the older Cretaceous pebble beds in the area and reworking of older beds was not the principal source of detritus.

Nettleton Bottom Chalk Pit, Lincolnshire (TF 126 982)

In the disused chalk pit at Nettleton, a small section of the Carstone and Hunstanton Members is exposed. The pit was examined by Penny & Rawson (1968).

Description: The section exposes 3m of the Carstone Member (Pl. 6-3). The deposit is of ferruginous pebbly sandstones, cemented by goethite with a reticulate habit. The sandstones of the lowest part of the section are coarse-sand to granule grade and contain scattered pebbles, up to 5mm in length (Pl. 6-4). They are overlain by a pebble bed with a fine-grained sand matrix. Pebbles are of rounded, dark chert and quartz up to 30mm in length, subrounded phosphorite clasts, up to 40mm long and angular to subrounded ironstones, less than 30mm in length (Sect. 4.2.6.3). The cherts are commonly brown or red in colour, are weathered and have a porous texture. The uppermost bed in the Carstone Member is a ferruginous sandstone with calcareous mud matrix and scattered pebbles. This bed passes up into the Hunstanton Member.

Interpretation: The Carstone Member at this locality is similar in appearance to the same horizon at Hunstanton. The lack of sorting in the pebbly sandstones is inconsistent with the characteristics of tidal-sandwave or shore-line deposits. The poor sorting of the rocks and the general coarsening upward trend is consistent with offshore bar deposits (e.g. Swift et al., 1973). The transition into the Hunstanton Member suggests bar abandonment.

South Ferriby Quarry, Humberside (SE 204 994)

A description of the Carstone Member at South Ferriby was given by Kelly & Rawson (1983). Wood & Smith (1978) studied the Chalk of this pit and gave a brief description of the underlying sequence.

Description: The quarry provides good exposure of the Carstone Member, 0.71m thick and the disconformity above Kimmeridge Clay Formation (Pl. 6-1). The Carstone Member is separable into three divisions: the lowest is a black muddy sandstone with abundant pebbles, which grades upward into pale red marly sandstone with small pebbles. The highest division is a red marly sandstone with few pebbles which fines upwards into the red skeletal packstone with sparse siliceous pebbles and granules at the base of the Hunstanton Member.

The pebbles of the Carstone Member are up to 15mm in length and are composed of dark chert, quartz, ironstone and phosphorite (Sect. 4.2.6.3). Pebbles of phosphorite are more common in the lower part of the unit.

Interpretation: The Carstone Member at this locality is thinner than to the south and appears to be a concentrated lag deposit. The size of the clasts is smaller to the south. Again there is a distinct variation in the grain sizes of the sediments. This suggests that episodic winnowing occurred with accumulation of fines during times of quiescence.

The scarcity of extrabasinal pebbles in the Carstone Member at this locality and the thinning of the unit northward across the Market Weighton High (Kent, 1980) suggests that it was deposited on a shoal remote from a major source of coarse-grained detritus.

2.2.6.4 The Clixby pebble bed, Clixby Lincolnshire (TA 103 044)

This location and the surrounding area was described by Kelly & Rawson (1983).

Description: The pebble bed exposed is from 0.2-1.2m thick and

composed of small pebbles up to 15mm in diameter. Black chert is the primary component, with minor quantities of white quartz (Sect. 4.2.6.5). Ironstone and phosphorite clasts were not recognised. Pebbles are set in a matrix of quartz sand, weakly cemented by goethite (Pl. 6.8).

The upper contact of the pebble bed is not exposed, but the lower surface is deeply incised and overlies a pebbly glauconitic sandstone (Pl. 6-7), similar to the Lower Spilsby Sandstone Member at Donington and Woods Hill, Nettleton. Below the base of the pebble bed, pockets of pebbles with a muddy matrix are present in the sandstones. The pockets are 30-40mm in diameter and resemble burrows. The pebble bed thickens into a hollow, of which only one margin is exposed.

Interpretation: The pebble bed at Clixby is a lag deposit infilling an erosion hollow. The overlying strata were not exposed and the deposit cannot be dated. The pebble bed differs from those of the Carstone Member since it contains very few phosphorite or ironstone pebbles. The lack of flint pebbles suggests that the bed is not a Pleistocene deposit. The thickness of the bed and the composition of the pebble suite is similar to those of the Mid-Spilsby Nodule Bed and the Claxby Ironstone Formation.

2.2.7 The Normandy area

The Aptian and Albian pebble beds of Normandy have been studied at a number of locations on the coast, both to the south and the north of the Seine Estuary. The mid-Cretaceous transgression resulted in a westward overstep of Cretaceous rocks across faulted and folded older Mesozoic strata in Normandy, as in Dorset. Sandstones of Aptian age rest on the Kimmeridge Clay Formation in the Bas de Caux region, but to the west the basal Cretaceous rocks are of Albian age.

To the north of the Seine the Lower Cretaceous sequence thickens and pebble beds are present at a number of horizons in the Sables Ferrugineux and Poudingue Ferrugineux. The present study was limited to coastal outcrops where exposure is good but locally obscured by slips.

2.2.7.1 The Gault Clay Formation (*dentatus* Zone): Vaches-Noire, between Villers-sur-Mer and Houlgate

To the south of the River Seine the basal beds of the Cretaceous System (Middle Albian) include a pebble lag. This horizon was sampled at one locality. The section at this locality is described by Doré *et al.* (1977).

Description: This section exposes mudstones, limestones and ironstones of Late Callovian to Late Oxfordian age, overlain unconformably by mudstones and muddy sandstones of the Gault Clay Formation (Middle Albian). The Gault Clay Formatiom overlies Late Oxfordian bioclastic packstones and the basal bed is of pebbly, glauconitic sandstone, 1.2m thick. The unconformity surface is planar, without boring or encrusting of the underlying limestone. The pebbles occur in impersistent laminae or scattered in bioturbated glauconitic sandstones. Phosphorite nodules are present 1.0m above the unconformity.

Clasts are small, averaging 10-15mm in length, but are occasionally up to 30mm long. The pebble assemblage is dominated by quartz, with lesser amounts of sandstone and chert (Sect. 4.2.7.1). Pebbles are generally bladed to compact and rounded. Angular chert pebbles, up to 25mm in length are present in the suite.

Interpretation: The pebble bed at the base of the Cretaceous sequence resembles a winnowed lag deposit. The presence of glauconite-rich sandstones with phosphorite nodules indicates that the pebble bed was probably deposited on a marine shelf with limited terrigenous input (*e.g.* Odin & Matter, 1981; Heckel, 1977). Mixing of the pebbles and sand probably resulted from bioturbation and episodic reworking.

The thin pebble lag is similar to strand-line ravinement deposits, but it is probable that the pebbles were reworked in an offshore environment. Belderson & Stride (1966) described a bed of gravel that had been stranded in the English Channel southwest of England following the Holocene transgression. It is possible that the basal Gault Clay Formation pebble bed was formed in a similar manner.

2.2.7.2 The Sables Ferrugineux and Poudingue Ferrugineux pebble beds (*jacobi* Zone to *dentatus* Zone): Cap de Hève, Cauville, Octeville and St. Jouin

The sections of the Lower Cretaceous strata on the Bas de Caux were described by Destombes (1958), Owen (1971a), Juignet *et al.* (1973), Doré *et al.* (1977) and Breton (1981). The Poudingue Ferrugineux and Sables Ferrugineux were described in detail by Juignet *et al.* (1973) and the provenance and the depositional environment of the Lower Cretaceous sedimentary rocks was interpreted. The Poudingue Ferrugineux thickens to the north and the number of pebble beds decreases. The contact between the Poudingue Ferrugineux and Sables Ferrugineux was examined at four localities, Cap de Hève, Octeville, Cauville and St. Jouin.

Description: The contact between the Sable Ferrugineux and Poudingue Ferrugineux was exposed in low cliffs, just above sea-level (Pl. 3-7). The Sables Ferrugineux are yellow, goethite-cemented, medium- to coarse-grained sandstones with granule and pebble lags. The sandstones are trough cross-stratified, with sets 0.1-0.2m thick. Pebbles and granule lags occur on the foresets and at the bases of the troughs. Bioturbation of the sandstones is common, with a predominance of vertical sand-filled burrows. The pebbles in the sandstones are small, rounded and less than 5mm in length. Quartz is the main pebble component.

The Poudingue Ferrugineux is composed of muddy sandstones with shells. The sandstones are highly bioturbated. Some horizons contain scattered pebbles and pebbles are also present in thin pebble beds. Stratification is rarely observed. The sandstones contain variable amounts of glauconite and phosphorite nodules are common. The contact with the underlying clean sandstones of the Sables Ferrugineux is sharp.

The pebbles of the Poudingue Ferrugineux are up to 12mm in length. Clasts are composed predominantly of rounded to subrounded quartz, with minor amounts of chert and sandstone (Sect. 4.2.7.1). Brown angular cherts are present in very small quantities.

Interpretation: The clean coarse-grained sandstones of the Sables Ferrugineux were probably deposited under moderately high-energy conditions. The absence of any indicators of bimodal palaeo-currents and variable current energy suggest that tidal currents were of limited effect in the area of deposition. The bioturbated sands with small-scale cross-sets are more reminiscent of lower shoreface deposits described by McCubbin (1982).

The poorly-sorted sandstones and mudstones of the Poudingue Ferrugineux were deposited under variable energy conditions, with episodic winnowing and concentration of coarse-grained detritus. The grain size of the clasts suggests that tidal currents are unlikely to have been the mode of transportation.

Juignet et al. (1973) suggested that the pebble beds of the Poudingue Ferrugineux were the product of influxes of detritus onto the shelf by strong currents. Rip-currents or downwelling currents produced during storm events or from river discharge possibly resulted in sediment transportation onto the shelf.

CHAPTER III
PETROGRAPHICAL DESCRIPTIONS OF THE PHENOCLASTS

3.1 GENERAL

The present study has been carried out on pebble beds and pebbly sands of Middle Oxfordian to Middle Albian age in southern Britain and Normandy. Regional and stratigraphical variations in the suites are recognised, but in many areas the suites are compositionally similar. To avoid unnecessary repetition, the general phenoclast microlithofacies types (lithotypes) are described without reference to the horizons from which they were taken. The compositions of the pebble suites are described in detail in Chapter IV.

Earlier investigations have been made of many of the pebble beds studied. For most horizons, descriptions were limited and little attempt was made to ascertain the source of the detritus; detailed studies were made in a number of cases (Sect. 1.4). Few detailed petrographical studies have been conducted and those of relevance are Wells & Gossling (1947) for the Lower Greensand Group of west Kent; P.Allen (1949, 1960, 1961, 1967a, 1972) for the Hastings Beds Group in the Weald and the Wessex Formation in Dorset; Rastall (1919, 1930) for the Hunstanton [Red Chalk] and Carstone Members in the East Midlands; Versey & Carter (1926) for the Carstone Member in the East Midlands and Ingham (1929) for the Spilsby Sandstone Formation in Lincolnshire.

3.1.1 Petrographical classifications

It has been necessary to define strictly the terminology used in the petrographic descriptions. Pebble sphericities were calculated using the method defined by Sneed & Folk (1958) and Dobkin & Folk (1970). Diagrams are presented in Appendix II (Fig. ii.ii). Estimates of roundness were made using the optical chart of Powers (1953; App. II, Fig. ii.ib). Particle size has been classified using a modified Udden-Wentworth scale (App. II, Fig. ii.ia). Phenoclast colour has been defined using the American Geological Society color chart (Godard et al., 1948). Colour descriptions and reference codes are taken from this publication. Classifications have been developed or chosen for the descriptions of chert, limestone and sandstone clasts.

3.1.1.1 Petrographic textural classifications

Chert phenoclasts are some of the most useful lithotypes for the identification of detrital source areas. The majority of the cherts are silicified limestones (Sect. 3.2) and it has proved possible to adapt limestone terminology (Folk, 1959, 1962; Dunham, 1962) to classify silicified textures.

The classification scheme of Folk (1959, 1962) separates limestone components into two groups; allochems (detrital and organic carbonate grains) and orthochems (cements and matrix). A limestone is therefore defined by its dominant allochem grain type and its dominant orthochem component. Cherts may thus be considered as silicified varieties of such limestones. However, the classification implies the presence of one hundred per cent pore-filling carbonate cement or matrix. The Folk classification also has mineralogical connotations, since it separates limestones into those with micrite (lime-mud) matrices and those with sparite (coarsely-crystalline carbonate) cements. Many cherts are the replacements of micritic limestones, but replacements of sparry carbonate cements are rare in the detrital suites studied. Hence, although Folk's classification may be adapted for chert description, it is not ideal.

The limestone classification of Dunham (1962) is based principally on the definition of limestone fabric and grain-contact relationships. If the primary fabric is preserved, the classification may be used regardless of the diagenetic state of the limestone. Dunham's classification may be used as an indicator of the energy of depositional environment, but does not take into account the effects of organic activity following deposition or diagenetic alteration of primary fabrics. This classification has no compositional connotations and does not assume the presence of pore-filling phases. If the effects of silicification have not destroyed the original limestone fabric, the classification may be readily adapted to describe cherts. For consistency, Dunham's classification (App. II; Fig. ii.iii), has also been used for the description of limestone, phosphorite and ironstone clasts.

3.1.1.2 Petrographic compositional classifications

1. Sandstones: sandstone textures may be classified using the terminology of Dunham (1962). Siliciclastic rocks may also be classified compositionally by the abundance of the main detrital components. The principal detrital grain types in most sandstones are quartz, feldspar and lithic fragments. A number of sandstone classifications based on these principal components have been developed. For this project, the classifications of Crook (1960) and Dott (1964) have been combined (App. II, Fig. ii.iv).

2. Cherts: petrographical classifications of chert need not be restricted to the primary fabrics of the lithoclasts (Sect. 3.1.1.1). The replacement and cement fabrics associated with silicification also need to be defined. A variety of chert classifications have been developed. Wilson (1966), adapting the work of Sosman (1927) and Walker (1962), made the distinction between siliceous replacements and siliceous cements and defined five categories: 1. microcrystalline quartz, 2. lutecite, 3. chalcedony, 4. mosaic quartz, and 5. chalcedonic overlay. The first four categories are common replacement textures. Mosaic quartz, chalcedony and chalcedonic overlay also form cements.

Chert-fabric definitions have also been developed from studies of evaporites, in particular by Folk & Pittman (1971), whose classification is based on earlier works and indicates the presence of five types of silica: 1. megaquartz, 2. microquartz, 3. lutecite, 4. quartzine (length-slow chalcedony), and 5. chalcedonite (length-fast chalcedony). Similar fabrics have also been identified in silicified limestones and deep-sea cherts (Keene, 1983) and in particular in replaced bioclasts (Jacka, 1974; Schmitt & Boyd, 1981). The similarity of the silicification fabrics in limestones, evaporites and bioclasts permits the use of a single silica classification: microquartz (Fig. 3.1a; Pls. 7-2, 7-5), chalcedony (length-fast and length-slow; Fig. 3.1a; Pls. 7-2, 7-3, 7-6, 7-7, 8-1) and lutecite (Fig. 3.1a; Pl. 8-2) are common to both limestone and evaporite classifications. Megaquartz as defined by Folk & Pittman (1971) consists of crystals greater than 20μm in diameter (Fig. 3.1b; Pls. 7-1, 7-4, 8-3), which is synonymous with Wilson's mosaic quartz.

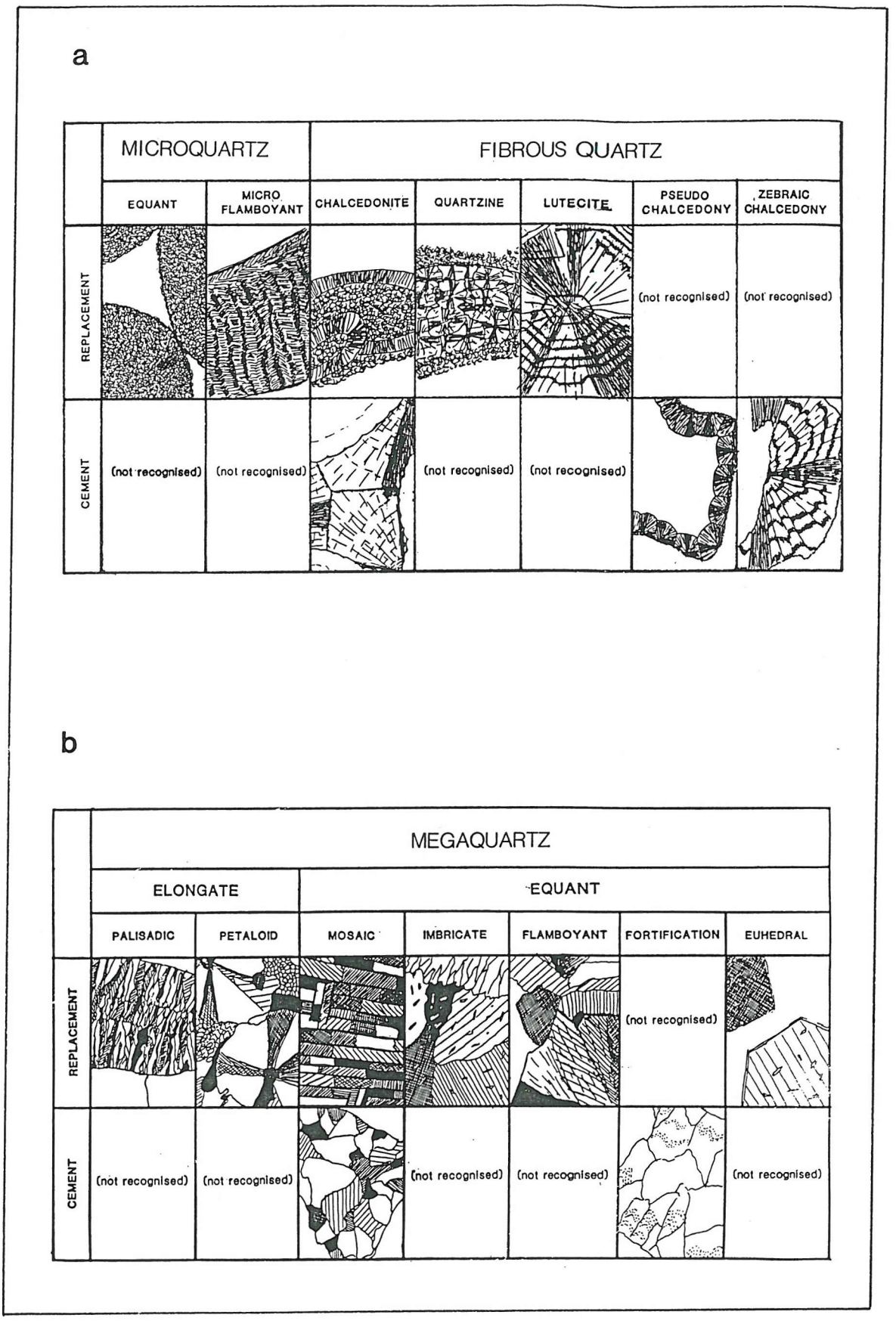


Figure 3.1 Classification of microquartz and fibrous quartz (a) and megaquartz (b) fabrics (in part after Arbey, 1980).

PLATE 7

SILICA FABRICS

PLATE 7
SILICA FABRICS

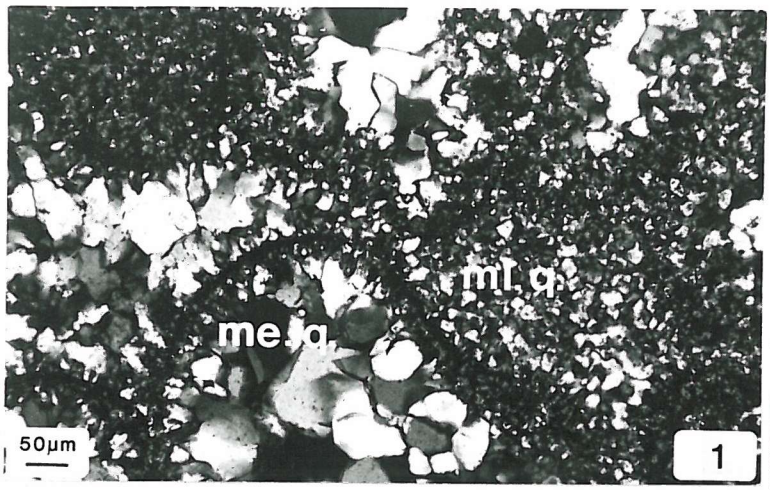
7-1. Mosaic megaquartz interparticle cement (me.q, left-centre) in an oolitic chert. The megaquartz also cements dissolution cavities in ooids (bottom-centre). Note the microcrystalline (mi.q) replacement of some ooids (top-left and right-centre).
Thin-section photomicrograph, cross-polarized light.
Pebble: Coarse Quartz Grit, Wessex Formation, St. Oswald's Bay, Dorset.
Source: Winspit Member, Portland Limestone Formation, probably from the South Dorset High.

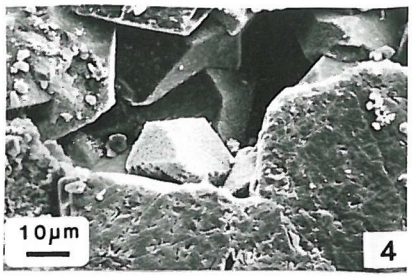
7-2. Pseudochalcedony (pc) lining a pore, filled by spherulitic chalcedonite (sc). Note the equant microquartz replacement (mi.q.) of a micrite precursor.
Thin-section photomicrograph, cross-polarized light.
Chert nodule: Cherty Freshwater Member, Purbeck Formation, Stair Hole, Dorset.

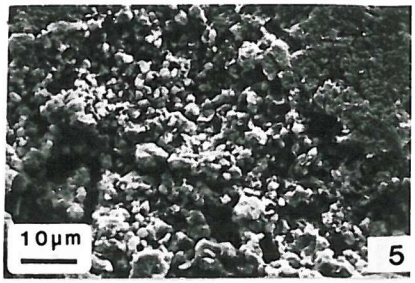
7-3. Chalcedonite replacement of an endothyrid foraminifer. The fibrous silica fabric is the replacement of the original calcite test.
Thin-section photomicrograph, cross-polarized light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

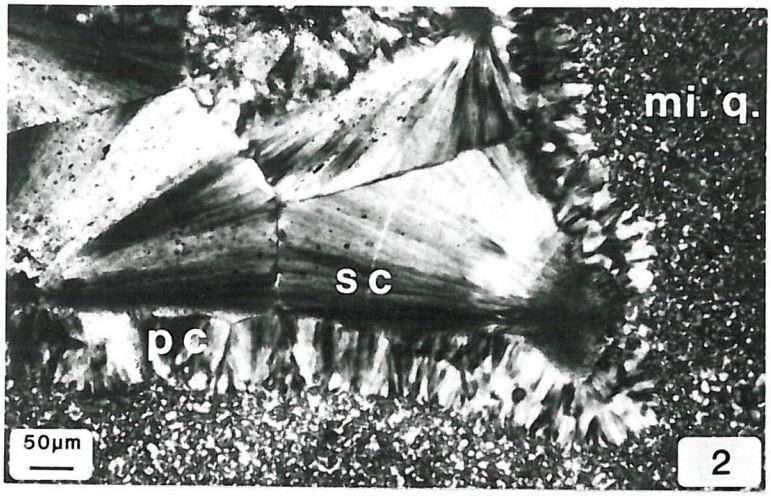
7-4. Euhedral pore-lining megaquartz.
Etched polished sample, S.E.M. photomicrograph.
Chert nodule: Portland Limestone Formation, Dorset.

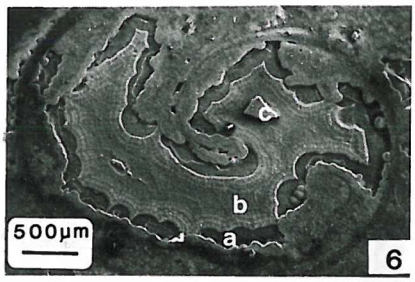
7-5. Equant microquartz, probably the replacement of a micrite precursor.
Etched polished sample, S.E.M. photomicrograph.
Chert nodule: Portland Limestone Formation, Dorset.

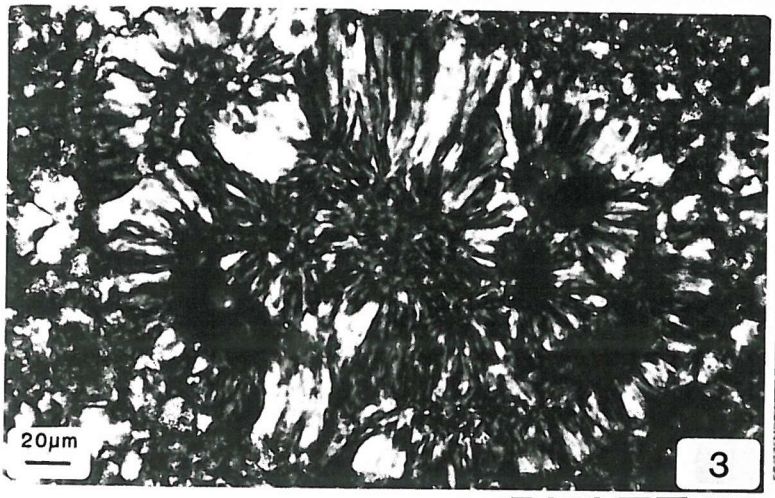

mi. q.
me. q.
50µm
1

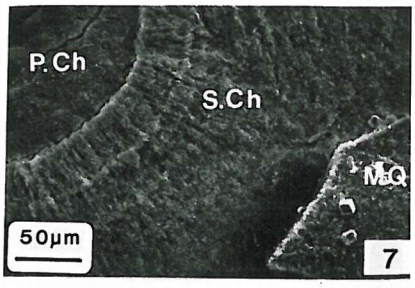

10µm
4


10µm
5


mi. q.
s c
p c
50µm
2


c
b
a
500µm
6


20µm
3


P.Ch
S.Ch
MeQ
50µm
7

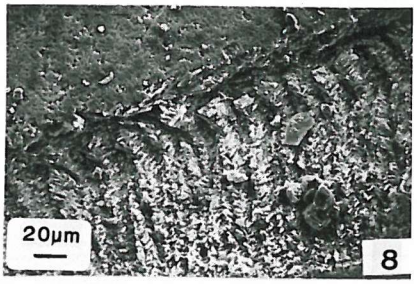

20µm
8

PLATE 7

7-6. Silica cements filling a gastropod body chamber. The chamber is lined by spherulitic pseudochalcedony (a) and is largely filled by spherulitic chalcedonite (b). The central part of the chamber is cemented by mosaic megaquartz (c).
Etched polished sample, S.E.M. photomicrograph.
Chert nodule: Cherty Freshwater Member, Purbeck Formation, Stair Hole, Dorset.

7-7. Etched silica cements. The fibrous pseudochalcedony (P.Ch) and spherulitic chalcedonite (S.Ch) are more readily etched by hydrofluoric acid than mosaic megaquartz (MQ).
Etched polished sample, S.E.M. photomicrograph.
Chert nodule: Cherty Freshwater Member, Purbeck Formation, Stair Hole, Dorset.

7-8. Chalcedonic silica replacement of a bivalve. Note the cross-lamellae structure (originally aragonite) preserved by the replacement silica.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Gault Clay Formation, Holworth House, Dorset.
Source: Cherty Freshwater Member, Purbeck Formation, probably from the South Dorset High.

PLATE 8

SILICA FABRICS

PLATE 8
SILICA FABRICS

8-1. Pore-filling zebraic chalcedony cement. Note the poorly developed pseudochalcedony cement at the margins of this pore. The chert is a sandy bioclastic packstone.
Thin-section photomicrograph, cross-polarized light.
Chert nodule: Portland Limestone Formation, Dorset.

8-2. Spherulitic lutecite with concentric inclusion trails. Note the oblique extinction of the lutecite.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed RC1, Ferruginous Sands Formation, Redcliff, Isle of Wight.
Source: Basal Purbeck Formation, probably from the Isle of Wight High.

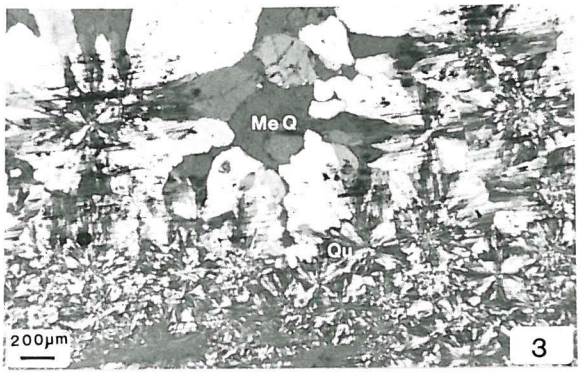
8-3. Spherulitic quartzine (Qu) replacing wood. The quartzine grades into mosaic megaquartz (MeQ).
Thin-section photomicrograph, cross-polarized light (sensitive tint).
Silicified wood: Basal Purbeck Formation, Osmington Mills, Dorset.

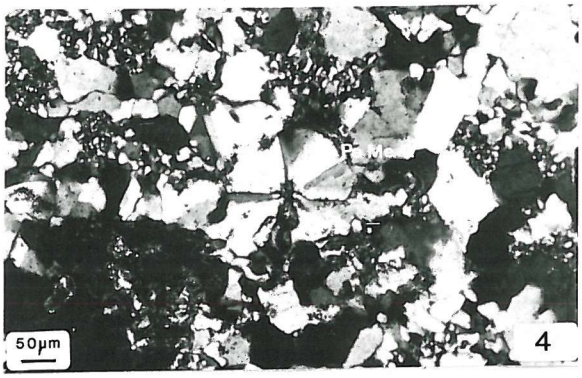
8-4. Petaloid megaquartz (Pe.Me.Q). Note the patches of microcrystalline quartz at the margins of the megaquartz spherulites.
Thin-section photomicrograph, cross-polarized light.
Pebble: Coarse Quartz Grit, Wessex Formation, Dorset (Durdle Door).
Source: Probably silicified volcanics, Cornubia or Armorica.

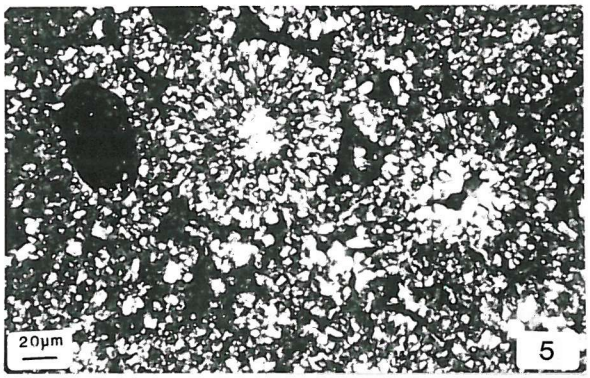
8-5. Microflamboyant microquartz replacement of ooids. Note the megaquartz replacement/cement at the ooid cores.
Thin-section photomicrograph, cross-polarized light.
Pebble: Coarse Quartz Grit, Wessex Formation, St. Oswald's Bay, Dorset.
Source: Winspit Member, Portland Limestone Formation, probably from the South Dorset High.











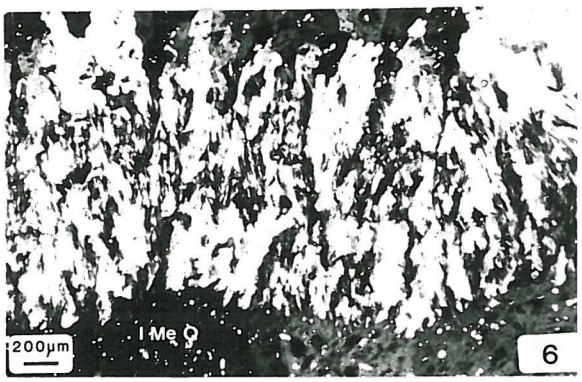


PLATE 8

8-6. Palisadic (centre) and imbricate (top and bottom) megaquartz after anhydrite. Note the anhydrite relics in the imbricate megaquartz (bottom centre).

Thin-section photomicrograph, cross-polarized light.

Silicified evaporite nodule: Triassic, Mercian Mudstone Group, Worminster Sleight, near North Wootton, Somerset.

Chalcedonic overlay (Fig. 3.1a; Pls. 7-2, 7-6, 7-7), as defined by Wilson (1966), has no counterpart in the Folk & Pittman (1971) classification, but is the same as the pseudo-chalcedony of Arbey (1980). The varieties of megaquartz: mosaic (Pls. 7-1, 8-3), petaloid (Pl. 8-4), imbricate (Pl. 8-6) and palisadic (Pl. 8-6), recognised by Arbey (1980; Fig. 3.1b) are refinements of earlier classifications by Folk & Pittman (1971), McBride & Folk (1977) and Milliken (1979).

The silicified evaporite classification of Arbey (1980) is probably the most comprehensive yet developed and may be used for most types of siliceous replacement and cement. An adapted version of Arbey's classification is given in Figure 3.1. Length-fast chalcedony is referred to as chalcedonite (Folk & Pittman, 1971; Arbey, 1980) to distinguish it from chalcedony, which is commonly used for fibrous silica irrespective of optical orientation.

3.2 PHENOCLAST LITHOTYPES

The principal phenoclast lithotypes identified are separable into fifteen groups. The petrographical characteristics and provenance indicators of the phenoclast lithotypes are discussed below.

3.2.1 Silicified limestone phenoclasts

Fifteen types of silicified limestone have been defined during this study. Petrographical and palaeontological indicators imply their derivation from limestones similar to those exposed in southern Britain and northern France.

3.2.1.1 Silicified bivalve and *Pachastrella* packstones and grainstones

Description: Very pale orange (10.YR.8/2) to dark yellowish orange (10.YR.6/6) or occasionally greyish black (N2) cherts. The clasts are angular to well rounded, bladed to elongate in shape and up to

90mm in length. The variations in phenoclast colour and chert texture relate to weathering of the clasts in the pebble beds. In some examples, weathering was so extreme as to destroy the cohesion between the silicified allochems in the clasts. These cherts are termed rotten and unbroken Pachastrella antiqua spicules and fragments of the bivalve Plicatula echinoides have been collected from such pebbles. More commonly the cherts are coherent and the fauna can only be recognized by acid etching and microscopy.

Four main varieties of these silicified bioclastic cherts are recognised:

1. Fine-grained bivalve packstones: these clasts are composed of angular shell fragments which are equant or slightly elongate, with fractured edges. The fragment-morphology indicates that they are probably broken bivalves. The grains are replaced by equant microquartz which does not preserve the shell fabric. Coarse-grained shell detritus is rare in this phenoclast lithotype.

2. Coarse-grained bivalve and sponge spicule grainstones: pebbles of this lithotype are composed of large bivalve and Pachastrella spicule fragments. Ooids are present in some of the clasts. The cements are typically of chalcedonic silica or more rarely of mosaic megaquartz. Some bioclastic grainstones are poorly washed and contain microquartz-replaced sediment in pore throats.

3. Coarse-grained bivalve and sponge spicule packstones: these cherts contain bivalve and Pachastrella fragments in microquartz matrices. Echinoderm, bryozoa and foraminifera fragments are also present in the cherts (Pls. 9-1, 9-2). Grains of quartz sand are rare. The matrix of the silicified packstones is of equant microquartz, with chalcedonite or mosaic megaquartz filling small pores (Pl. 8-1).

4. Silicified gastropod packstones: silicified gastropods, probably Aptyxiella portlandica, have been found in pebbles of bioclastic chert (Pl. 9-3). One clast contains two Aptyxiella tests in a Rhaxella and Pachastrella spicule packstone, with a microquartz matrix. Ooids are absent from this clast, but a minor amount of

PLATE 9

PORTLAND LIMESTONE FORMATION CHERT FABRICS

PLATE 9

PORTLAND LIMESTONE FORMATION CHERT FABRICS

9-1. Silicified bivalve packstone. The large bivalve fragment (centre) is uncompacted and the replacement megaquartz preserves the original shell fabric.
Thin-section photomicrograph, plane-polarized light.
Pebble: Gault Clay Formation, St. Oswald's Bay, Dorset.
Source: Portland Limestone Formation, probably from the South Dorset High.

9-2. Silicified sponge-spicule packstone. The comminuted Pachastrella antiqua spicules are replaced by chalcedonic silica. Note the opaque inclusions in the axial canals of the spicules.
Thin-section photomicrograph, plane-polarised light.
Chert nodule: Portland Limestone Formation, Dorset.

9-3. Silicified bioclastic packstone with a turreted gastropod, probably Aptyxiella portlandica. Note the finely crystalline megaquartz replacement of the gastropod test and the coarser mosaic megaquartz chamber cement. The groundmass (bottom centre) contains megaquartz casts of Rhaxella (Rh) spicules.
Thin-section photomicrograph, cross-polarized light.
Pebble: Coarse Quartz Grit, Wessex Formation, Stair Hole, Dorset.
Source: Portland Limestone Formation (possibly from the Winspit Member), probably from the South Dorset High.

9-4. Oolitic grainstone in which the ooids are replaced by microquartz and are cemented by pseudochalcedony and spherulitic chalcedonite (centre left). Megaquartz also cements the ooids locally (top centre).
Thin-section photomicrograph, cross-polarized light.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Winspit Member, Portland Limestone Formation, probably from the South Dorset High.

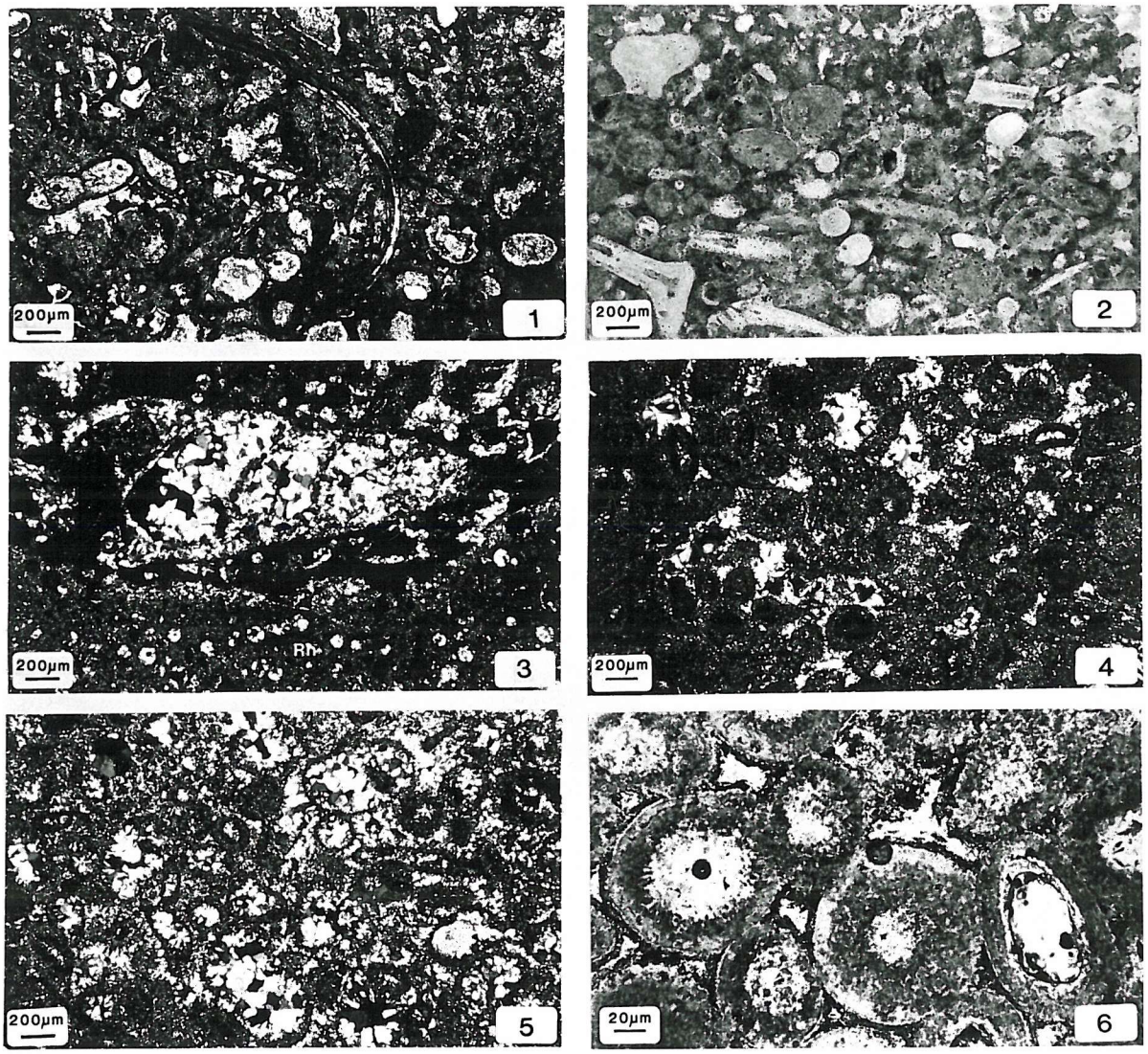


PLATE 9

9-5. Silicified oolitic grainstone. Ooid rims are replaced by microquartz but the cores are of megaquartz which appears to be a cement. The ooids are cemented by equant mosaic megaquartz. Thin-section photomicrograph, cross-polarized light.

Pebble: Coarse Quartz Grit, Wessex Formation, St. Oswald's Bay, Dorset.

Source: Winspit Member, Portland Limestone Formation, probably from the South Dorset High.

9-6. Silicified ooids, marginally replaced by microquartz, with their cores composed of colourless megaquartz.
Thin-section photomicrograph, cross-polarized light.

Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.

Source: Winspit Member, Portland Limestone Formation, probably from the South Dorset High.

bivalve debris is present. The gastropods are replaced by flamboyant megaquartz with a ghost fabric outlined by carbonate inclusions. The chambers are infilled with megaquartz. The infill and replacement appear to have formed simultaneously, the former passing into the latter without obvious discontinuity.

Bioclast fabrics in the coarse-grained packstones and grainstones are similar, as is their faunal assemblage. The tetraxon spicules of the sponge Pachastrella antiqua range in size from 0.5-5.0mm. Replacement of Pachastrella spicules is typically by flamboyant megaquartz. In some examples, the quartz extinction fans across the grain in a similar manner to chalcedony. The crystallites of quartz are elongated perpendicular to the spicule wall. Axial canals, present in each spine, are generally preserved by the replacement. Where the canal is preserved it is typically as a dusty trail of opaque inclusions in megaquartz or a cement of chalcedonic silica. Overwidening of the canals is observed in some examples, but bored spicules, common in modern sponges (Duncan, 1881; Land, 1976), have not been recognised.

Pachastrella spicules composed of mosaic megaquartz with no central canal are common, especially in cherts with megaquartz ooids (Sect. 3.2.1.2). The quartz of the spicule is interpreted as a pore-filling cement. Spicules with blocky megaquartz rims and spherulitic chalcedonite cores are found. The megaquartz is possibly a replacement; the chalcedony contains no inclusions, has no preferred orientation and appears to be a pore-filling cement. Occasionally megaquartz is present at the centre of such spicules and is a late-stage cement.

Silicified bivalves are common in these bioclastic cherts and a variety of siliceous replacement textures are observed. The form of silicification was related to the shell fabric and probably also the position of the bioclast relative to the chert core. Larger bivalve fragments are commonly replaced by more than one silica fabric. Replacement by flamboyant megaquartz is common and may be distinguished from pore-filling cement by its undulose extinction and the presence of calcite inclusions. The shell texture is also outlined by inclusions in spherulitic chalcedony, megaquartz or microflamboyant microquartz. Microquartz replacements are typically

bladed, length-fast and commonly preserve the nacreous, cross-lamella or heterogeneous texture of aragonitic mollusc shells (Pls. 7-8, 15-3). Silicification occurred prior to aragonite solution and predated calcite cementation.

In some clasts and at the rims of chert nodules, thin bivalve fragments are composed of fibrous chalcedonite which does not preserve the shell structure. The chalcedony is nucleated on the bioclast margins and projects towards the grain centre, forming central compromise sutures. In chert nodules similar silica fabrics pass into blocky calcite cements. This form of silicification probably occurred simultaneously with dissolution of the carbonate, in zones where silica saturation was insufficient to replace calcite directly, but sufficient to cause rapid silica nucleation and chalcedony formation.

Mosaic quartz cements are present in bivalve moulds in some cherts. Chalcedonic cements are rarely found.

Discussion: The clasts of this lithotype are varied but contain faunal and petrographical characteristics that may be matched with those of Jurassic rocks of shallow marine facies. Derivation of the clasts was from fully silicified limestones with few carbonate inclusions preserved. In Britain, well-developed cherts are known in the exposed marine Jurassic rocks only in the Corallian Group of Yorkshire (Wilson, 1939) and the Portland Limestone Formation in southern England (Raisin, 1903; Wilson, 1966). The Corallian Group in southern England is not known to have well-silicified limestones.

The pebbles and cobbles of these lithotypes have been collected from Lower Cretaceous pebble beds in Dorset and the Lower Greensand Group of the Isle of Wight. Only the Portland Limestone Formation contains significant quantities of chert in this area and is the probable source. The presence of an example of the Portlandian bivalve Plicatula echinoides and a possible example of the gastropod Aptyxiella portlandica in pebbles supports a Portland Limestone Formation source.

The fine-grained bioclastic cherts contain few identifiable fossil fragments other than comminuted bivalves. Limestones of

fine-grained shelly debris are present in the Dungy Head and Dancing Ledge Members of the Portland Limestone Formation and may be silicified (Townson, 1975). Similar limestones are also found in the Purbeck Formation and such a source cannot be discounted. The abundance of identifiable Portland Limestone Formation clasts and the scarcity of Purbeck Formation detritus in the same pebble beds (Sect. 4.2.1.5) suggest that derivation from the older limestones is more probable.

Silicification in the coarse-grained bioclastic packstones and grainstones occurred prior to the dissolution or neomorphism of aragonitic shells but following partial compaction of the limestones. Coarse-grained bioclastic cherts in the Portland Limestone Formation were shown by Townson (1975) to be restricted to the Winspit Member and to be of greater abundance in the east of Dorset (Isle of Purbeck) than in the west. The association of bioclastic cherts with oolitic cherts however, indicates that they are likely to have been derived from the swell areas (Fig. 3.2) defined by Townson (1975).

Aptyxiella portlandica is a large turreted gastropod, common in the Winspit Member from the northern part of the Isle of Portland and in the junction beds between the limestones of Portland and Purbeck facies in the south Midlands (Sylvester-Bradley, 1940). Specimens have also been identified from the top of the Winspit Member at Poxwell (West, 1975) and at the Fossil Forest. The gastropods probably existed in shallow marine areas adjacent to shoals or the shoreline (Townson, 1971).

3.2.1.2 Silicified ooid and bivalve grainstones and packstones

Description: Very light grey (N8) to greyish yellow (5.Y.8/4) and occasionally pale pink (5.RP.8/2) pebbles and cobbles. The clasts are angular to subangular, bladed to elongate and 30-200mm in length. Rare examples of less weathered black (N1) and dark grey (N3) cherts are occasionally found. Weathering of the clasts produces a powdery and porcellanous texture and causes the clasts to disintegrate on extraction from the pebble bed. Ooids and bioclasts commonly project from the clast surface or have been plucked, leaving small pits.

The ooids range in size from 250-400μm and are bladed to

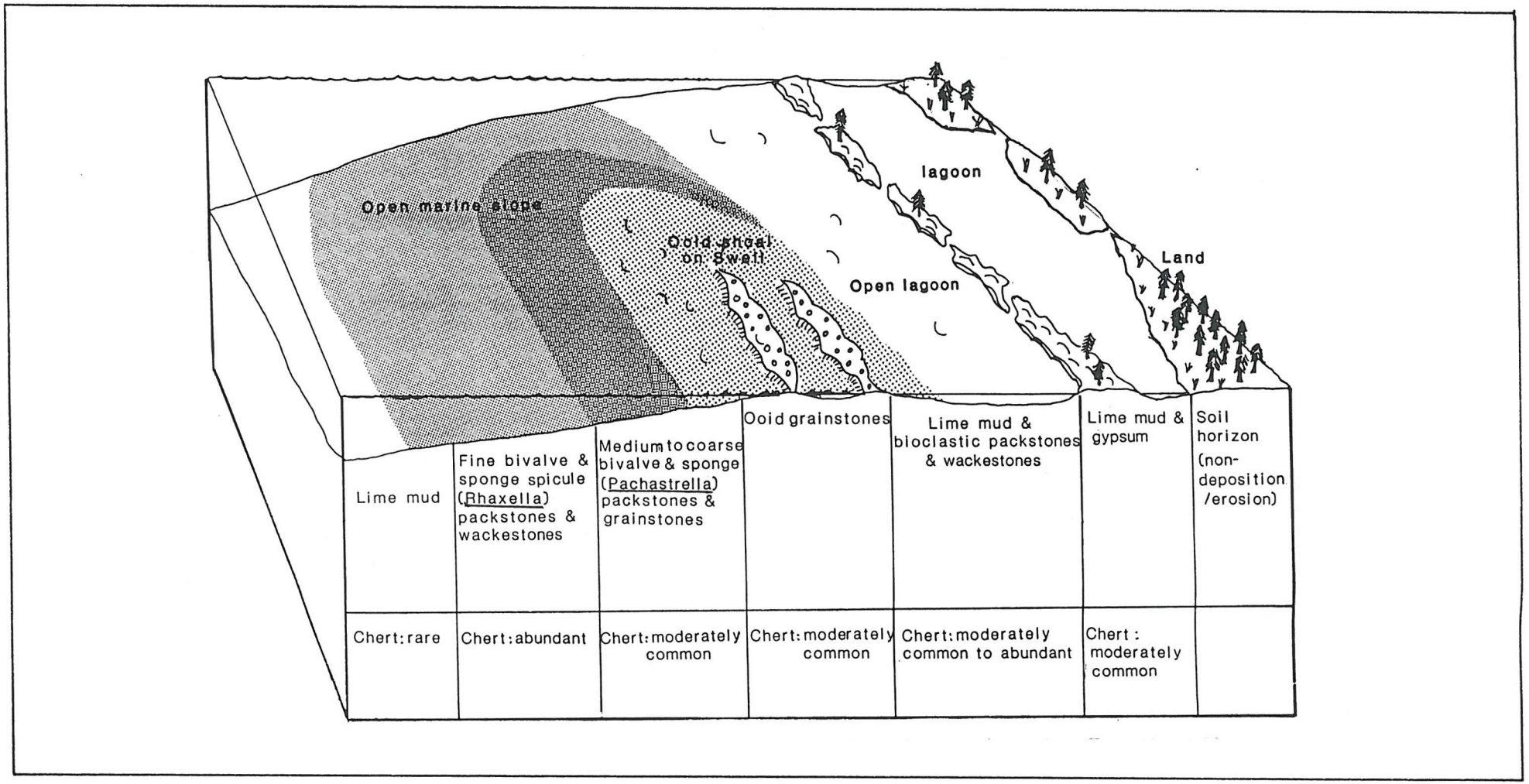


Figure 3.2 Hypothetical model showing the depositional environments of the Portland Limestone and basal Purbeck Formations and the abundance of chert in the associated lithofacies groups (in part after Townson, 1975).

compact-bladed. Nuclei are rarely identifiable but oolitic coatings are observed on quartz sand grains and rounded bioclasts. Sand in the cherts is scarce and is of medium to fine-grained angular quartz. Bioclasts are common, especially bivalves and Pachastrella antiqua spicules. Echinoderm and foraminifera debris and Rhaxella spicules are less abundant.

Replacement of the ooids is by microquartz and megaquartz. Equant microquartz replacement of entire ooids has occurred (Pl. 9-4), but more commonly ooid rims are replaced by microquartz and the cores by mosaic megaquartz (Pls. 8-5, 9-6). Inclusions of carbonate in the quartz replacements are rare, but concentric fabrics are preserved as trails of opaque inclusions in the microquartz. Clasts are found in which mosaic megaquartz replaced most of the ooids and there is only a monogranular layer of microquartz at the ooid margins (Pl. 9-5). The most common form of ooid replacement is an equant microquartz rim, a half to a third of the grain radius in thickness, surrounding a core of mosaic megaquartz (Pl. 9-6). The microquartz contains minute inclusions orientated in trails concentric to the ooid margin.

Quartz sand grain nuclei surrounded by megaquartz are present at the centres of some ooids, but dropped nuclei, as are found in dissolved aragonitic ooids (Wilkinson et al., 1985; Strasser, 1986), are not present. It is therefore probable that the megaquartz is a replacement. In other examples the megaquartz is free from inclusions and has a mosaic texture. This bears close resemblance to pore-filling cements described by Wilson (1966) and Orme (1974). The absence of inclusions or traces of former fabric prevent clear distinction between cement and replacement quartz in such clasts.

Clasts of oolitic grainstone are common locally and a few silicified oolitic packstones have been collected. The matrix of the packstones is composed of microquartz, less than 10μm in diameter, with pinpoint or undulose extinction. The quartz preserves no trace of former texture.

Cements in the oolitic cherts are of two types:

1. pseudo-chalcedony, chalcedonite and megaquartz (Pls. 7-6, 7-7; chalcedony-megaquartz cement),

2. mosaic megaquartz (Pls. 7-1, 8-3).

The chalcedony-megaquartz cements are commonly associated with ooids replaced by microquartz. Initial cementation is by a thin isopachous rim of pseudo-chalcedony, 20-30μm thick, which is succeeded by spherulites of chalcedonite. The chalcedonite commonly fills the pore space, but any remnant pore-space is cemented by mosaic megaquartz. In the detrital clasts, rare examples of coarsely crystalline calcite spar succeeding the chalcedonic cements occur, but silica cements postdating calcite cementation do not.

Mosaic megaquartz cements are nucleated on the surfaces of the ooids and other allochems and are elongated perpendicular to the pore margins. Towards the pore centre the quartz is equant. Carbonate inclusions are not present and there is no evidence that this is a replacement texture.

Bioclasts are replaced by various silica fabrics. The shells of bivalves are commonly replaced by imbricate or flamboyant megaquartz with minute carbonate inclusions. The original fabric of the shell is indicated by trails of inclusions or more commonly by the orientation and extinction pattern of the quartz. Replacement by length-fast microflamboyant microquartz occurred in such a manner as to mimic the original carbonate fabrics. Bivalve clasts composed of spherulitic chalcedonite are present. The chalcedonite is orientated perpendicular to the shell walls. It contains no inclusions and its orientation bears no relationship to the primary shell fabric. This might be interpreted as a pore fill, but the fabric differs from that of the chalcedonic cements.

Pachastrella spicules of megaquartz are common in the oolitic cherts. Chalcedony replacement of spicules is less common, but chalcedonite or megaquartz cements in axial canals are present. Spicules with pyrite-filled canals are present in the cherts. Spicules without canals are composed of mosaic megaquartz or spherulitic chalcedonite, both of which are nucleated at the grain margins.

Discussion: The clasts are replaced bioclastic and oolitic grainstones and packstones. Silicification of the limestones is

complete and few carbonate inclusions are preserved. There is no clear distinction between the ooid fabric-types and it is probable that the differences result from the silicification process. Microquartz replacement of ooids and the associated chalcedonic cements imply that ambient porewaters were supersaturated with respect to silica and hence caused rapid replacement. In contrast, the megaquartz replacements and cements probably formed when silica concentrations were lower and nucleation rates less rapid.

The fauna, in particular the sponge spicules Pachastrella and Rhaxella, indicate that the clasts are of Jurassic origin. Oolitic cherts in the British Jurassic are known from the Portland Limestone Formation of Dorset (Raisin, 1903; Arkell, 1947a; Wilson, 1966) and from the Corallian Group of Yorkshire (Wilson, 1939). Partially silicified oolite clasts of probable Corallian origin are found in the south Midlands (Sects. 3.2.6.1, 4.2.4.3), but Corallian oolitic cherts are not found in the south of England.

The absence of brachiopods and the scarcity of echinoderms and foraminifera is a characteristic of limestones in the Portland Group (Townson, 1971), but not of Corallian Group limestones. This suite of clasts was collected from the Wessex and Gault Clay Formations of Dorset. The detrital source, therefore, was probably the Portland Limestone Formation.

The Winspit Member of the Portland Limestone Formation is both oolitic and chert-bearing in the Lulworth and Portland areas of Dorset (Arkell, 1947a). Townson (1975) identified oolitic packstones only in the Lulworth region, but similar facies probably existed in association with other oolite shoals in the area.

The fabrics of these silicified ooids are similar to the high-energy, aragonitic (type 1) ooids described by Strasser (1986). Megaquartz at the cores of ooids may, therefore, result from cementation of pores following partial dissolution of aragonite.

3.2.1.3 Silicified Rhaxella packstones and wackestones

Description: Light grey (N7) to greyish orange (10.YR.7/4) bioclastic packstones and wackestones. The colour of the clasts is

the result of weathering. The clasts are greyish orange to moderate yellowish brown (10.YR.5/4) at the surface, light grey to dark grey (N3) at the core. The thickness of the weathered rim varies from 1-15mm. The clasts are subangular to subrounded, bladed to compact-platy and 4-450mm in length.

These cherts are composed of reniform-shaped spicules of the sponge Rhaxella, 100-150μm long. The spicules are set in a matrix of equant microquartz (Pl. 10-1) and occur in association with Pachastrella spicules, bivalve fragments and occasionally echinoderm plates and foraminifera. Bioclasts in the Rhaxella cherts have similar fabrics to those described in the bivalve cherts (Sect. 3.2.1.1) and the two types of chert detritus are commonly found together. Ooids are rare in the Rhaxella cherts.

Flamboyant megaquartz or microflamboyant microquartz replaces many spicule rims, but the cores of the spicules are composed of mosaic megaquartz or spherulitic chalcedonite. The mosaic megaquartz has uniform extinction and both it and the spherulitic chalcedonite are nucleated on the siliceous rim and project towards the spicule centre. The rim phases are interpreted as replacements and the mosaic megaquartz and chalcedonite are cements.

Discussion: The clast shape indicates that the Rhaxella chert is locally derived. It is found in association with identifiable Portlandian clasts in the pebble beds of Dorset and the Isle of Wight and is almost certainly of similar origin. Rhaxella cherts are common in the Portland Limestone Formation of Dorset, especially in the Dungy Head and Dancing Ledge Members. Tentative identifications of Rhaxella cherts from the Carstone Member in the East Midlands have been made and these are possibly from Corallian Group sources.

3.2.1.4 Silicified peloidal and Rhaxella packstones

Description: Pale yellowish orange (10.YR.8/6) to very pale orange (10.YR.8/2) chert pebbles. The clasts are subangular, bladed to compact-bladed, and 15-30mm in length.

PLATE 10

PORTLAND LIMESTONE FORMATION, PURBECK FORMATION AND CARBONIFEROUS SHELF CHERT FABRICS

PLATE 10

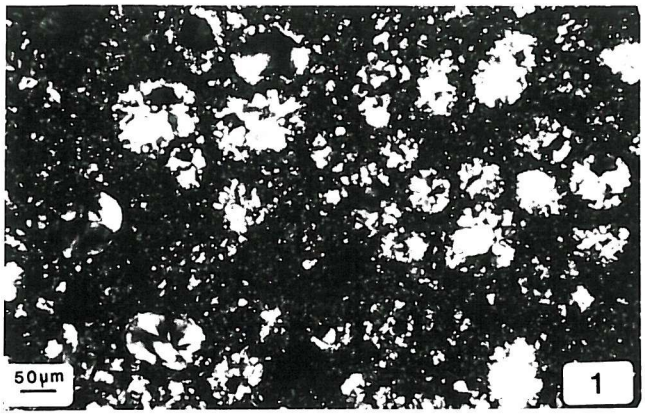
PORTLAND LIMESTONE FORMATION, PURBECK FORMATION AND CARBONIFEROUS SHELF CHERT FABRICS

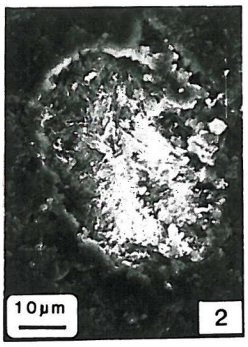
10-1. Rhaxella packstone. The reniform spicules (top left) are replaced by equant microquartz with chalcedonite (top centre, bottom left) and megaquartz (top left) cavity cements.
Thin-section photomicrograph, cross-polarized light.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Dungy Head or Dancing Ledge Member, Portland Limestone Formation, probably from the South Dorset High.

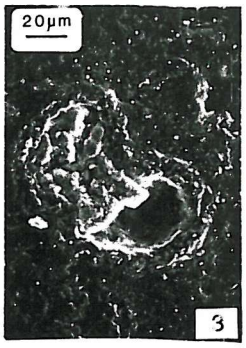
10-2. Chalcedony cement infilling the centre of a Rhaxella spicule.
Etched polished sample, S.E.M. photomicrograph.
Chert nodule: Portland Limestone Formation, Dorset.

10-3. Rhaxella spicule. The spicule wall is replaced by finely crystalline megaquartz and the spicule core is partially cemented by blocky megaquartz.
Etched polished sample, S.E.M. photomicrograph.
Chert nodule: Portland Limestone Formation, Dorset.

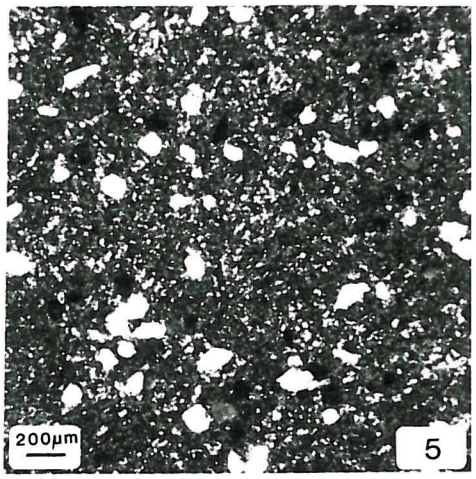
10-4. Bioclastic packstone with ostracods (Os; centre right), bivalves (centre right) and charophytes (Ch; centre and centre top). The bioclasts are set in a matrix of microquartz.
Thin-section photomicrograph, plane-polarized light.
Pebble: Gault Clay Formation, Holworth House, Dorset.
Source: Cherty Freshwater Member, Purbeck Formation, probably from the South Dorset High.

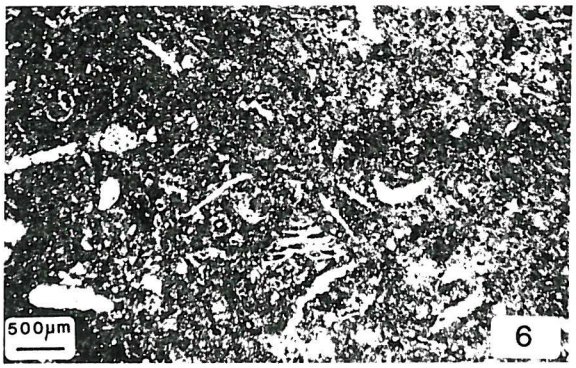












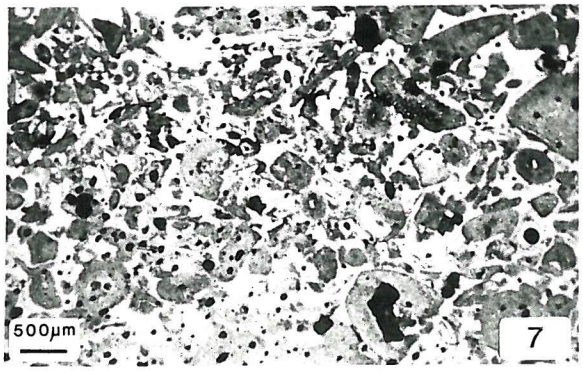


PLATE 10

10-5. Sandy pellet packstone in which the microquartz pellets are indistinct in the microquartz matrix. The pellets are of similar size as the detrital sand which is composed principally of quartz.

Thin-section photomicrograph, cross-polarized light.

Pebble: Faringdon Sponge Gravel, Wicklesham Pit, Faringdon, Oxfordshire.

Source: Corallian Group limestones.

10-6. Bioclastic wackestone. Silicified crinoids, brachiopods, bryozoa and foraminifera in a microquartz matrix. Note the Tetrataxid foraminifer (cf. Tetrataxis conica; centre).

Thin-section photomicrograph, cross-polarized light.

Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.

Source: Carboniferous limestone, probably from the Welsh or Anglo-Brabant Massifs.

10-7. Bioclastic grainstone composed predominantly of crinoid plates but with scattered foraminifera and brachiopod fragments. The grainstone has a megaquartz cement.

Thin-section photomicrograph, plane-polarized light.

Pebble: Carstone Member, Hunstanton, Norfolk.

Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

The cherts are composed of sub-spherical grains (peloids; c.400μm in diameter) and bioclasts set in a matrix of microquartz. The fauna is dominated by bivalves and Rhaxella spicules, with some Pachastrella spicules and echinoderm plates. Sand grains are absent.

Replacement of the peloids is by megaquartz, with undulose extinction and calcite inclusions at the grain margins, and grading into inclusion-free quartz with uniform extinction at the grain centres. The inclusions in the outer layer are not orientated and there is no evidence of concentric sheaths.

Discussion: Cherts with Rhaxella spicules are found in the Portland Limestone Formation and Corallian Group in England (Wilson, 1966) and in the Bajocian, Bathonian and Oxfordian limestones in northern France. The morphology of the clasts indicates that the source was close to the site of deposition and that transportation had not been great. The chert pebbles are found in the "Unio" Member of the Purbeck Formation at Friar Waddon, Dorset. This locality occurs adjacent to an area of Cretaceous uplift which caused local erosion of Upper Jurassic strata (House, 1961). The source is, therefore, probably the Portland Limestone Formation or Corallian Group limestones. The scarcity of Corallian Group cherts in Dorset indicates that derivation from a Portland Limestone Formation source is more probable.

The siliceous replacement of the peloids is similar to that seen in some oolitic cherts (Sect. 3.2.1.2). However, the grains are less rounded than the ooids and there is no evidence for a tangential fabric at the margins of the grains. The clasts also differ from the oolites in the Portland Limestone Formation in the greater proportion of Rhaxella spicules and the replaced lime mudstone matrix. The mud matrix and the presence of Rhaxella spicules in the cherts indicates relatively quiet conditions of deposition for the limestones. The probable sources are the rocks of Western Basin Portland limestone facies in Dorset (Fig. 3.2; Townson, 1975). The peloids are either poorly preserved ooids, rounded intraclasts or algal nodules. The state of preservation, however, precludes a more specific identification. These grains superficially resemble the type 2 and 3 ooids of Strasser (1986).

3.2.1.5 Silicified charophyte, ostracod and gastropod packstones

Description: Sparse clasts of moderate brown (5.YR.3/4) to moderate yellowish brown (10.YR.5/4) bioclastic chert. The pebbles are subrounded to rounded, bladed and 10-40mm in length.

Chert clasts of this variety contain shelly debris set in matrices of microquartz. The bioclasts include articulated and disarticulated ostracod valves, bivalves, gastropods, monaxon sponge spicules and charophyte oogonia and stem fragments (Pl. 10-4). Cavities in the chert are cemented by spherulitic chalcedonite. Pseudo-chalcedony cements are not commonly developed, but small spherulites may exist at the cavity margins.

The bivalves are replaced by microflamboyant microquartz (Pls. 7-8, 15-3) or flamboyant megaquartz, both preserving the original shell fabric. Ostracods and thin-walled gastropod shells have been replaced by chalcedonite, orientated perpendicular to the shell wall. Charophytes are replaced by flamboyant or imbricate megaquartz, packed with calcite inclusions. The sparse spicules present in the cherts are replaced by microflamboyant microquartz. The spicules are 10μm in diameter and approximately 300μm in length. Axial canals are preserved in some examples.

Discussion: The fauna of these clasts is quite distinct. The presence of charophytes, ostracods and gastropods indicates that the source limestones were probably of freshwater or brackish origin. Monaxon spicules are found in Carboniferous cherts (Hinde, 1912), but these spicules resemble in size and structure elements of Spongilla purbeckensis. Cherts containing ostracods, charophytes and gastropods are present in both the lower and middle Purbeck Formation (West, 1961; Barker et al., 1975; Clements, 1969; El-Shahat & West, 1983). The spicules of Spongilla purbeckensis have only been observed in cherts in the Cherty Freshwater Member of the middle Purbeck Formation (El-Shahat, 1977). The Purbeck Formation contains the only known extensively silicified Jurassic lagoonal limestones in the Britain and they are almost certainly the source of the detrital clasts.

3.2.1.6 Silicified sandy pellet packstones

Description: Greyish orange (10.YR.7/4) to pale yellowish orange (10.YR.8/6) microcrystalline cherts. Occasional examples of moderate brown (5.YR.3/4) cherts of this group have also been found. The clasts are subrounded to rounded, bladed and 20-160mm in length. Clast-texture varies from porcellanous to glassy. The phenoclasts are encrusted with serpulids and bryozoa, but are not bored.

The cherts are composed of quartz sand, small pellets and bioclasts set in matrices of equant microquartz (Pl. 10-5). The pellet-like grains are 100-150μm in length and ovoid in shape. They are composed of microquartz. The sand is of fine- to very fine-grained quartz, but includes minor amounts of partially altered glauconite (less than 5%). Quartz overgrowths are present on some sand grains. Bioclasts, principally bivalves, are abraded and partially silicified or unsilicified. At the margins of some pebbles, the bioclasts are composed of poikilotopic calcite which extends into the matrix.

Discussion: The fauna of the cherts is not distinctive, but the predominance of bivalves and the scarcity of brachiopods, echinoderms and bryozoa indicate that the source was probably of Jurassic rather than Carboniferous age. The Portland Limestone Formation or Corallian Group are the most likely sources.

The pebbles and cobbles were collected from the Faringdon Sponge Gravel at Faringdon and were found in association with limestone and chert clasts of probable Jurassic origin. Derivation from limestones of the Portland Group is possible, but silicification of limestones in the southern Midlands is not known. Corallian Group rocks are locally silicified in this area (Wilson, 1966; Milodowski & Wilmot, 1984) and this is the more probable source.

3.2.1.7 Silicified bioclastic pellet packstones

Description: Greyish yellow (5.Y.8/4) to pale yellowish orange (10.YR.8/6) clasts of bioclastic chert. The clasts are commonly weathered and may have very pale orange (10.YR.8/2) to yellowish grey (5.Y.8/1) cores. The staining of the surface is 2-3mm thick, but the

chert is weathered throughout. Clasts vary in shape from bladed to platy, are subangular to rounded and 20-120mm in length.

Clasts of this group are texturally similar to the sandy pellet cherts (Sect. 3.2.1.6) but have a lower quartz sand and a greater bioclast content. The pellets are composed of equant microquartz and are set in matrices of coarsely crystalline microquartz. The dominant bioclastic components in the cherts are broken and whole Pachastrella spicules, foraminifera and Rhaxella spicules. Bivalves and echinoderm plates are rare. Pachastrella spicules are replaced by flamboyant megaquartz, which preserves the axial canals as trails of opaque inclusions. Foraminifera were possibly micritized prior to replacement by microquartz. Calcite inclusions in the bioclasts are common and non-silicified grains are present in the matrices.

Discussion: The bioclastic pellet cherts are texturally immature, containing many carbonate relics. Their faunal content indicates that the clasts are of Jurassic origin. Rhaxella spicules are common in the Corallian Group and Portland Limestone Formation and either could be a source. The moderate abundance of foraminifera and echinoderms in the clasts is not typical of Portland Limestone Formation and therefore a Corallian Group source is more probable. The clasts were collected from the Faringdon Sponge Gravel (Sect. 2.2.4.3a). Coarse-grained bioclastic limestones are present in the Corallian Group of the southern Midlands in the Coral Rag and "Trigonia" beds and are the probable source rocks.

3.2.1.8 Silicified crinoidal packstones, wackestones and grainstones

Description: Clasts in this diverse suite contain a varied silicified fauna and flora, but have similar clast-morphology and silicification fabrics. The colour of the pebbles is related to the host lithotype and the effects of clast weathering. Unweathered clasts and clasts in limestones are predominantly greyish black (N2) to brownish black (5.YR.2/1). In ferruginous sands and mudstones, clasts commonly weather brownish black (5.YR.2/1) to dark yellowish brown (10.YR.4/2). Clasts in ferruginous sands are particularly susceptible to alteration. Weathering produces a porous fabric

(tripolite; Keller, 1978). In pebbles such as these, the surfaces remain smooth and chatter marks are still discernible. Weathered pebbles are pale in colour or are iron-stained (very pale orange; 10.YR.8/2 to moderate red; 5.R.4/6). Examples of weathered chert clasts have been described by Krumbein (1942), Curry (1963), Folk (1974) and Shanmugam (1985), who suggested that tripolitization occurred as a result of weathering in acidic groundwater. Clasts of chert with black exteriors are occasionally found to be red internally. The pebbles are similar to the silicified algal foraminiferal, coral, cephalopod and bryozoan limestones and silicified limestones with debris of ostracods, brachiopods and echinoderms of P.Allen (1961; p.273, 275, 279-280) and the cherts with organic remains of Wells & Gossling (1947; p.207-208).

The cherts are silicified fine- to medium-grained bioclastic packstones or wackestones (Pls. 10-6, 11-2, 11-5, 12-1). Bioclastic mudstones are moderately abundant, but grainstones are rare (Pl. 10-7). Two principal faunal groups exist:

1. a crinoid-bryozoa assemblage (Pl. 10-7), which also includes brachiopods, endothyrid foraminifera and calcareous algae,
2. an ostracod, foraminifera, bryozoa and calcareous algae assemblage (Pl. 12-1).

Crinoid and brachiopod fragments are not excluded from the second group but occur in lower abundance. Petrographic fabrics are similar in the two groups.

The matrices of the cherts are typically equant microquartz of uniform crystallite size. Megaquartz and chalcedonic cements are found, the former being the more common in grainstones. Spherulites of chalcedonite are present in small cavities, such as body chambers in foraminifera tests and between ostracod valves.

Rhombohedral shaped pseudomorphs (rhombic pseudomorphs), moulds (rhombic moulds) and dolomite/ankerite rhombohedra are present in the bioclastic cherts. The rhombs are typically concentrated in the matrices, but may cross-cut bioclasts (Pl. 12-1). Rhombs cutting siliceous cements are very rare. Replaced rhombs are composed of flamboyant or microflamboyant microquartz and rarely contain carbonate inclusions. Rhombohedral moulds are most common at

PLATE 11

CARBONIFEROUS SHELF CHERT FABRICS

PLATE 11

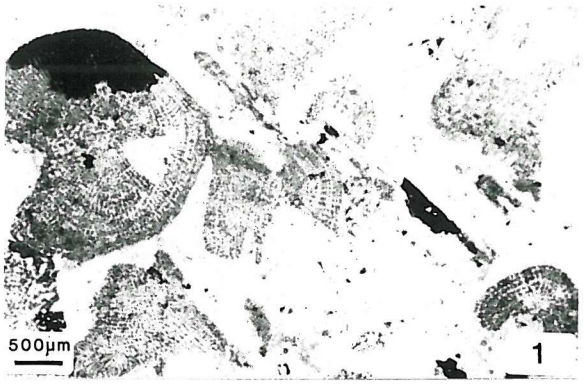
CARBONIFEROUS SHELF CHERT FABRICS

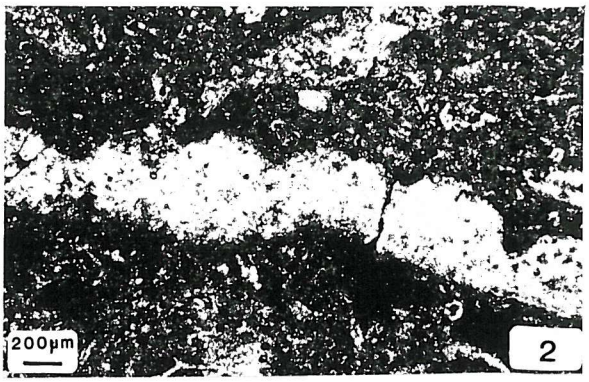
11-1. Silicified crinoidal grainstone. Microquartz replacement of the crinoid plates preserves their stereome structure. The bioclasts are cemented by colourless mosaic megaquartz. Geothite alteration preferentially affects the microquartz of the crinoid plates (top left).
Thin-section photomicrograph, plane-polarized light.
Pebble: Carstone Member, Hunstanton, Norfolk.
Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

11-2. Silicified bioclastic packstone with a large brachiopod fragment. The shell is replaced by microflamboyant microquartz and contains minute carbonate inclusions.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

11-3. Silicified fenestellid bryozoan in a microquartz matrix with finely comminuted shell debris.
Etched sample photomicrograph, reflected light.
Pebble: Upper Lydite Bed, Littleworth, Oxfordshire.
Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

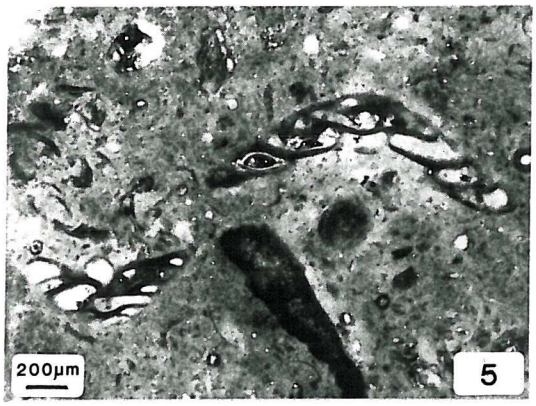
11-4. Silicified foraminiferal and crinoidal grainstone. The endothyrid foraminifera and crinoid plates are cemented by colourless megaquartz.
Thin-section photomicrograph, plane-polarized light.
Pebble: Carstone Member, Hunstanton, Norfolk.
Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

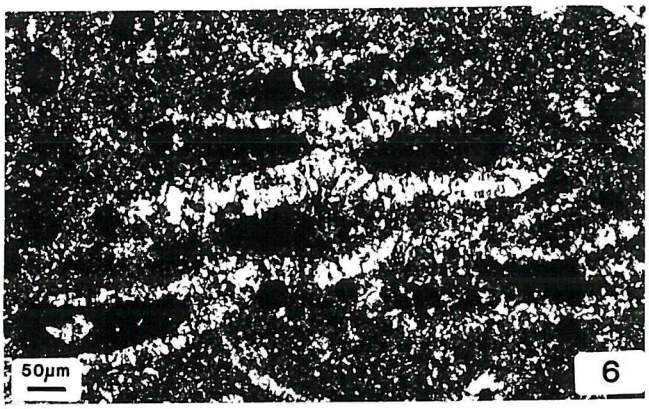












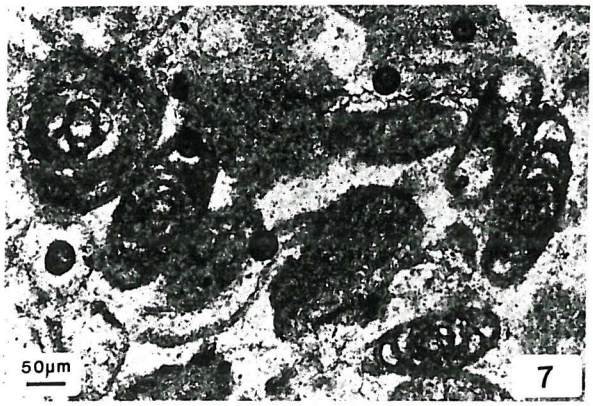




PLATE 11

11-5. Silicified foraminiferal wackestone. The two tetrataxid foraminifera (Tetrataxis cf. conica and Tetrataxis cf. pressula) are in a matrix of microquartz with finely comminuted shelly debris.
Etched polished sample photomicrograph, reflected light.
Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

11-6. Silicified tetrataxid foraminifer (Tetrataxis cf. conica). The foraminifer is replaced by palisadic quartz probably after a fibrous calcite precursor. The chambers are cemented by chalcedony which has been preferentially stained during weathering.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

11-7. Silicified endothyrid foraminifera. The foraminifera are replaced by microquartz and the chambers are cemented by megaquartz.
Thin-section photomicrograph, plane-polarized light.
Pebble: Carstone Member, Hunstanton, Norfolk.
Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

11-8. Silicified foraminifer in a bioclastic packstone.
Etched polished sample, photomicrograph, reflected light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Carboniferous limestone, probably from the Anglo-Brabant Massif.

clast-margins and are present in cherts with either silicified or carbonate rhombs. Rhombic moulds may be filled with glauconite or goethite. Glauconite is also found in thin veinlets extending from the clast surface.

The silicification fabrics of the six main bioclast types are described below.

1. Crinoid and echinoderm plates: silicified crinoidal grainstones are rarely preserved as detrital clasts, but packstones with echinoderm plates are common. The grainstones have siliceous cements of mosaic megaquartz. Crinoidal packstone and wackestone pebbles commonly contain allochem grains with a bimodal size distribution. A fine-grained sand component is composed of assorted bioclasts, whereas a coarser grained fraction is made up of crinoid plates (up to 2mm in diameter) and brachiopod fragments.

Replacement of echinoderms is by a variety of silica types. The most common replacements are flamboyant or imbricate megaquartz and microflamboyant microquartz. Megaquartz replacements are pseudomosaic and are occasionally packed with oriented calcite inclusions. The microquartz and chalcedony replacements are both length-fast and commonly extinguish uniformly. In a number of examples, microquartz has replaced the ossicle margins, but the centres of these are replaced by megaquartz or chalcedony. All three silicification fabrics sometimes preserve the stereome structure (Pl. 11-1). The stereome is filled by minute opaque inclusions or microquartz.

Echinoderm plates of unorientated mosaic megaquartz, without inclusions and unfilled cavities at the centres of the echinoderm grains are found in some cherts. The mosaic megaquartz fabric appears to be the result of dissolution of the crinoid carbonate and cementation of the resulting mouldic porosity.

2. Bryozoa: clasts of silicified bioclastic packstone and wackestone frequently contain fragments of bryozoa. The most common bryozoa recognized in the pebbles are fenestellids from which two or three fenestrules remain intact. Occasional examples of larger bryozoan fragments are found (Pl. 11-3), but even these are partially

fragmented and identification is not possible. Replacement of the laminate calcite fabric of the bryozoa (Bathurst, 1975) is by microflamboyant microquartz, orientated parallel to the fenestrule walls. Modern bryozoa are normally composed of either high-magnesium calcite or aragonite or both, and ancient types are assumed to have had similar compositions. There is, however, no evidence of dissolution of bryozoa tests prior to silicification.

The fragments of bryozoa are commonly associated with crinoid ossicles, brachiopod fragments and in some cases endothyrid foraminifera.

3. Brachiopods: brachiopods frequently prove resistant to silicification in chert nodules (Newell et al., 1953), but may be preferentially silicified in a limestone (Jacka, 1974; Schmitt & Boyd, 1981; Holdaway & Clayton, 1982; Brunton, 1984). Individual specimens of brachiopods have not been found as detrital clasts, but the comminuted remains of these organisms are present in pebbles of bioclastic chert.

Brachiopods occur disarticulated, broken and occasionally rounded. Fragments are 100-3000μm in length, but are rarely thick (100-400μm). Silicified brachiopod fragments are replaced by three forms of silica:

a. microflamboyant microquartz orientated parallel to the shell length (Pl. 11-2). Carbonate inclusions aligned sub-parallel to the shell length may be present in the silica. Punctae or pseudopunctae are recognised in some fragments. The replacements appear to consist of the secondary calcite layer of the brachiopods; preservation of the prismatic layer is rarely observed.
b. fibrous chalcedonite orientated perpendicular to the shell wall. The fibres project towards the grain centre from one or both margins of the shell. The chalcedony is free from inclusions and has uniform extinction. Evidence for this texture being a replacement is limited. The chalcedony does not preserve the shell structure and contains no inclusions. However, it differs from the cement fabrics of the chert.
c. imbricate or flamboyant megaquartz. The quartz has a pseudo-mosaic fabric, undulose extinction and may contain

inclusions aligned parallel to the clast-length.

Hollow brachiopod spines comprise a significant proportion of the bioclast component in some cherts. Spines are up to 100μm in diameter. Replacement is by microflamboyant microquartz orientated tangentially to the spine-margin. Filling of the spine-centre is by micrite and fine bioclastic debris.

4. Foraminifera: foraminifera are moderately abundant in the bioclastic chert pebbles and provide the best means of dating the clasts. They are readily visible on etched pebble surfaces and a variety of genera have been recognised; these include Endothyra, Tetrataxis, Howchinia, Valvulinella and Omphalotus (Pls. 10-4, 10-5, 10-6, 10-8). In thin-section, the foraminifera are less easily distinguished.

Foraminiferal cherts are commonly packstones and wackestones but an example of a bimodal grainstone, with crinoids and endothyrids, has been collected (Pl. 11-4). Endothyrids are the most common group of foraminifera found and are present in association with crinoids and bryozoa. Tetrataxids are more common in fine-grained cherts with lesser amounts of crinoid debris (Pl. 10-6).

Replacement of the foraminifera is commonly by chalcedonite orientated perpendicular to the test walls (Pl. 11-6). In exceptional examples, the granular outer layer of some tetrataxids is preserved as microquartz. Several of the smaller endothyrids are replaced by microquartz, with no preferred orientation (Pl. 11-7). This is possibly the replacement of microgranular calcite of micritized tests.

5. Ostracods: ostracods are common in the dark bioclastic chert pebbles. The shells are seen only in cross-section and identification to a generic level has not proved possible. The tests are normally disarticulated but occasional articulated specimens are present (Pl. 12-1). Replacement of the ostracod tests is by length-fast chalcedony or blocky microquartz, both elongated perpendicular to the shell surface. Ostracod debris is found in

PLATE 12

CARBONIFEROUS SHELF CHERT FABRICS

PLATE 12

CARBONIFEROUS SHELF CHERT FABRICS

12-1. Silicified ostracod and dasycladacean algae packstone. The articulated ostracod valves (top left) are replaced by chalcedonite and the body-chamber is cemented by spherulitic chalcedonite. Replacement of the dasycladacean algae (bottom right; possibly Nanopora) is by microquartz. Note the goethite-replaced rhombic pseudomorph after dolomite, which cross-cuts the upper ostracod valve and the inner chalcedonic cement.

Thin-section photomicrograph, plane-polarized light.

Pebble: Pebble bed RC5, Carstone Member, Redcliff, Isle of Wight.

Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

12-2. The dissolution contact between a ooid grainstone (top) and a pellet packstone (bottom). The grainstone is cemented by blocky megaquartz which is not the replacement of a calcite cement.

Thin-section photomicrograph, cross-polarized light.

Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.

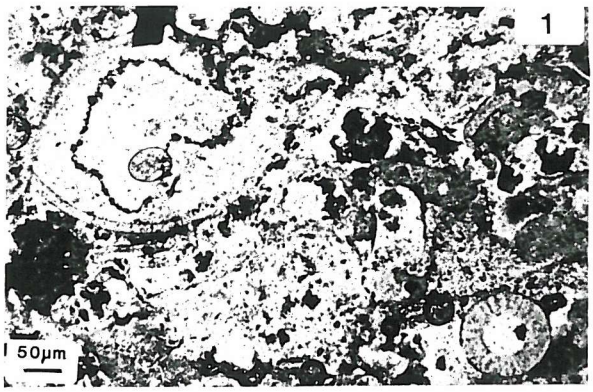
Source: Carboniferous limestones, probably from the Welsh or the Anglo-Brabant Massifs.

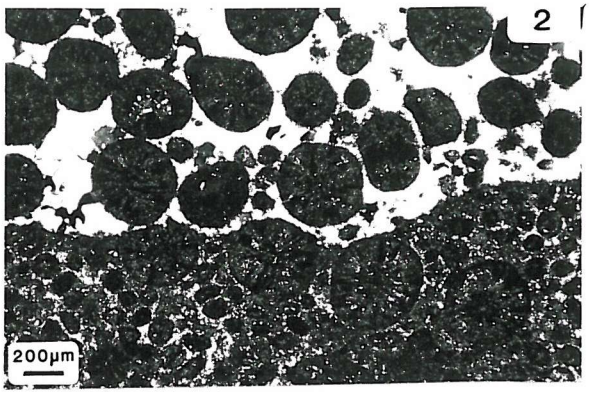
12-3. Silicified ooid grainstone. The ooids are replaced by microquartz which preserves both radial and tangential fabrics. The ooids are cemented by layers of chalcedonite (pseudochalcedony). Note that the margins of the ooids are stained by goethite.

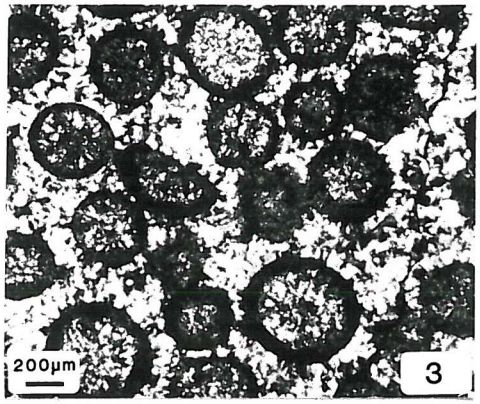
Thin-section photomicrograph, cross-polarized light.

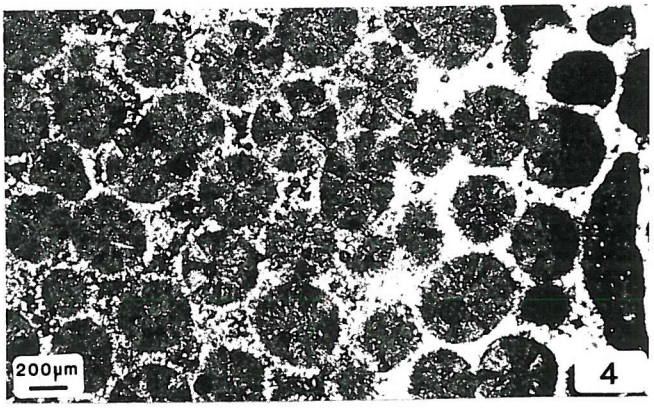
Pebble: Folkestone Beds Formation, Chilworth, Surrey.

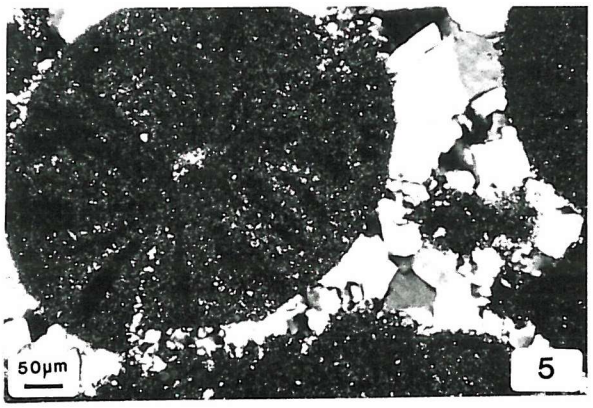
Source: Carboniferous limestone or Upper Jurassic pebble bed, probably from the Anglo-Brabant Massif.













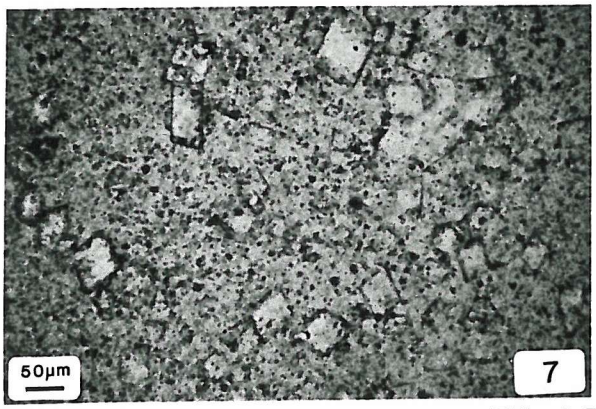




PLATE 12

12-4. Silicified ooid grainstone in which the ooids are replaced by microquartz. The ooids are cemented by flamboyant megaquartz in the central and left area and by mosaic megaquartz in the area to the right.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or Anglo-Brabant Massifs.

12-5. Silicified ooid replaced by microquartz which preserves a radial fabric. Note the pre-megaquartz cementation fractures parallel to the radial fabric and the displacement of the fragments.
Thin-section photomicrograph, cross-polarized light.
Pebble: Carstone Member, Rock, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or Anglo-Brabant Massifs.

12-6. Laminated chert with a chalcedonite and megaquartz-cemented pore (fenestra?). The chert is unfossiliferous but contains rhombic pseudomorphs.
Thin-section photomicrograph, plane-polarized light.
Pebble: Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or Anglo-Brabant Massifs.

12-7. Silicified pseudomorphs after dolomite in a microquartz matrix. The pseudomorphs are composed of flamboyant megaquartz.
Thin-section photomicrograph, plane-polarized light.
Pebble: Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or Anglo-Brabant Massifs.

12-8. Silicified pseudomorphs after dolomite in a matrix of equant microquartz.

Thin-section photomicrograph, plane-polarized light.

Pebble: Faringdon Sponge Gravel, Wicklesham Pit, Faringdon, Oxfordshire.

Source: Carboniferous limestone, probably from the Welsh or Anglo-Brabant Massifs.

association with crinoids and brachiopods but is more commonly present in fine-grained bioclastic packstones and wackestones with foraminifera, calcareous algae and sponge spicules.

6. Calcareous algae: several of the pebbles of chert with ostracods, foraminifera and rare crinoids contain small hollow spherical bodies. The spheres possess few characteristic features and are possibly calcispheres. They differ in size and appearance from radiolaria, being smaller and composed of microflamboyant microquartz orientated tangentially to the test wall. The test thickness, 10-30μm, and the absence of elongate sections indicate that the clasts are not brachiopod spines.

Segmented bioclasts, 100-125μm in diameter and with hollow centres have been noted in one chert clast (PI. 12-1). The bioclasts are replaced by length-fast microflamboyant microquartz. The central cavities of the grains are filled by spherulitic chaledonite without inclusions. The bioclasts are dasycladacean algae and resemble the genera Nanopora described by Wood (1964) from the Asbian-Brigantian strata of Yorkshire and the Avon Gorge. The algal tubules were broken prior to deposition in a bioclastic packstone. The packstone also contains foraminifera and ostracods.

Discussion: The fauna of the dark bioclastic cherts is distinctly different from the weathered bivalve and spicular cherts (Sects. 3.2.1.1 to 3.2.1.7). The dominance of crinoids and brachiopods in the faunal assemblages indicate that the cherts are of silicified Palaeozoic marine limestones. Silicified shallow marine limestones in the Palaeozoic rocks of Britain are limited. The Durness Dolomite Formation contains chert nodules but does not possess the diverse fauna present in the pebble suites. Extensive silicification is not known in the Ordovician and Silurian limestones of Britain. In contrast, Carboniferous strata contains silicified marine limestones at several horizons (North Wales, Sargent, 1923; Yorkshire, Wells, 1955; Hey, 1956; Derbyshire, Orme, 1974). The identifiable foraminifera in the clasts indicate that some of the cherts are of Carboniferous origin and this is supported by the abundance of fenestellid bryozoa, brachiopods and crinoids. Hexactinellid and monaxon spicules are more common than tetraxinellid spicules and this also distinguishes these cherts from those of Jurassic origin.

The association of crinoids and bryozoa is common in bioclastic packstones, the allochems typically being comminuted but normally unrounded. This indicates limited sorting of the sediment but with generally quiet water conditions. Rocks deposited under similar conditions have been reported from a number of Carboniferous sequences (e.g. Lees, 1961, 1964; Wilson, 1975; Lees et al., 1985).

In the Carboniferous limestones of Britain, bioclastic cherts are common. The Black Rock and Penmaen Burrows Limestones (Hastarian) are cherty in the Mendips and South Wales. The Hotwells Limestone (Asbian) of the Mendips is chert-bearing (Green & Welch, 1965), as are the Brigantian limestones of the North Crop in South Wales (Robinson, 1935). In Derbyshire, cherts are found in the Monsal Dale and Eyam Limestones (Brigantian; Smith et al., 1967; Frost & Smart, 1979). The cherts in the partially dolomitized Carboniferous limestones of North Wales are of Pendlian age and also contain silicified bioclasts (Sargent, 1923). The limestones of Yorkshire contain silicified bioclastic limestone horizons above the Little Limestone and the Crow Limestones (Pendlian; Wells, 1955; Hey, 1956). Cherts are also present in the older Yoredale limestones such as the Simonstone and Middle Limestones (Brigantian; Izzidien, 1984; Cousins, 1977). The widespread distribution of bioclastic cherts in the Carboniferous rocks of England and Wales precludes the precise identification of the source area.

The association of ostracods, foraminifera and calcareous algae possibly indicates a more restricted environment of deposition. The Caswell Bay Mudstone of South Wales and the Clifton Down Limestone of the Mendips have a similar fauna. However, chert in the latter does not closely resemble the chert in the detrital suite. Similar facies are known from the northern margin of the Welsh Massif (Gray, 1982) and possibly existed in other sheltered areas. The presence of crinoid and brachiopod fragments in these cherts suggests that the waters were of normal marine salinities.

The bioclast replacement fabrics in the cherts suggest that silicification occurred prior to carbonate neomorphism or inversion. Evidence of compaction is normally limited and pre-silicification carbonate cements have not been found. Crinoids and brachiopods are

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frequently less well silicified than the other bioclasts and may contain carbonate inclusions. The mosaic megaquartz of some crinoid ossicles appears to be a cement fabric, formed following the dissolution of the bioclasts. Silicification of Carboniferous limestones in Derbyshire was considered by Orme (1974) to have occurred at an early stage after burial. In the Simonstone Limestone of Yorkshire, however, Izzidien (1984) noted that silicification followed compaction and the formation of ferroan calcite and dolomite. Chert clasts of the second type do not appear to have survived in the pebble assemblage.

Silicification subsequent to dolomitization is observed in a number of the chert pebbles. Partial or total dolomitization of Carboniferous limestones is common and it has been proposed that it resulted during regressive phases when hypersaline groundwaters were refluxed through unlithified or partially lithified carbonate sediments (Ramsbottom, 1973, 1978; Hird et al., 1987).

The glauconite in the cherts is a late-stage feature occurring after erosion when the pebbles were in the marine environment. The presence of chert pebbles with glauconite in the non-marine Hastings Beds Group (P.Allen, 1960; P.Allen et al., 1964) suggests that glauconitized pebbles were reworked from older pebble beds.

3.2.1.9 Silicified oolitic grainstones and packstones

Description: Pebbles of silicified oolite form a small but distinctive group of clasts in many of the pebble beds studied. The clasts vary in colour; unweathered pebbles are black (N1) or brownish black (5.YR.2/1) but weathered clasts are paler (moderate brown; 5.YR.3/4 to very pale orange; 10.YR.8/2). The clasts are rounded to subrounded and bladed to compact in shape. Oolitic chert pebbles are up to 35mm in length. These pebbles are similar to the silicified oolitic limestones of P.Allen (1961; p.277-278, 281) and the oolitic cherts of Wells & Gossling (1947; p.204-206).

At the pebble margins, ooids are dissected but in some clasts the cut ooids are slightly elevated above the matrix. Examples in which the matrix is more resistant are also found and in such cases the ooids are plucked, leaving small pits.

The majority of the oolites are silicified grainstones; silicified packstones are rare. These pebbles can be separated into three types, with intermediates existing between each. One packstone phenoclast type and two grainstone phenoclast types are recognised:

1. Silicified oolitic grainstones with megaquartz cement: the ooids of which are 300-500μm in diameter and compact to bladed-compact in shape. Replacement of the ooids is by equant or microflamboyant microquartz. The ooids rarely contain identifiable nuclei but some are composed of slightly coarser-crystalline microquartz at their cores. A tangential fabric (Pls. 12-2, 12-4, 12-5) in the ooids is preserved by the silicification and is best developed at the ooid rims.

   The matrices are of mosaic megaquartz (Pl. 12-5). Early palisadic or fortification-like megaquartz cements formed before mosaic megaquartz cements in some clasts. The early quartz cements are elongated perpendicular to the grain margins and have undulose fanning extinction. Chalcedonic cements are rare and silicified carbonate cements are absent.

2. Silicified oolitic grainstones with chalcedonic silica cements: are composed of microflamboyant microquartz ooids cemented by chalcedony. A tangential fabric is preserved in some ooids but radial fabrics are more common. The radial fabric is produced by pigmentation of microquartz (Pl. 12-5) or elongation of microquartz crystallites perpendicular to the ooid margins. The microquartz crystallites are 2-3μm in length.

   The oolite cement is composed of one or more layers of pseudo-chalcedony with spherulitic chalcedonite filling the remaining pore space. Occasionally, final cementation was by equant megaquartz (Pl. 12-3).

3. Silicified oolitic packstones: the ooids of which resemble those of the grainstones, possessing both tangential and radial fabrics but are set in matrices of microquartz. Pre-silicification carbonate replacement, a feature not observed in the oolitic grainstones, occurred prior to silicification in some packstones.

This phase formed as isolated euhedral rhombohedra, 30-50μm in length and they are probably after dolomite or ankerite. The rhombs are replaced by undulose megaquartz with few carbonate inclusions. Rhombohedra are commonly found concentrated in the matrix and occasionally in the outer layers of the ooids.

Bioclasts and quartz grains are conspicuously absent from all three varieties of oolitic chert. Gradations between the types of oolitic grainstone exist and in some examples both varieties of silica cement are present in different parts of a clast. In such a case, the boundary between the two cement types is sharp (Pl. 12-4).

Broken ooids are present in some chert clasts, especially those containing ooids with radial fabrics (Pls. 12-3, 12-5). Examples of broken ooids with younger oolitic sheaths are noted in some clasts and fracturing occurred both before (Pl. 12-3) and after deposition (Pl. 12-5). The ooids of this variety commonly broke tangentially, not parallel to the radial fabric. Clasts in which the fracturing of the ooids occurred subsequent to burial contain broken grains with minor displacement of the fragments (Pl. 12-5). Fractures of this type are found to parallel the radial fabric. Quartz cement infills the interstices between broken grains and was not affected by the fracturing. Elongate grain contacts and interpenetration of grains is observed in some clasts but is uncommon.

Discussion: Most of the skeletal remains present in these cherts are comminuted and rounded and in some cases have oolitic coatings. The type of preservation precludes certain identification of the bioclasts.

The two cement types in the silicified oolites appear to be the result of localized conditions in the chert nodule and are unlikely to be diagnostic of a source area. A similar feature was also observed in the oolitic chert clasts derived from the Portland Limestone Formation (Sect. 3.2.1.2).

Broken ooids are not common but possibly provide an indication of the original mineral-composition of the ooids. It has been suggested that breakage of ooids is more common in ooids with a primary radial fabric (Halley, 1977). The radial fabric results in

weakness of the grains to attrition and compaction. Ooids with radial fabrics of low-magnesium calcite are widespread in the geological record but in modern environments, ooids with radial fabrics are restricted in distribution and are more common in quiet water hypersaline environments (Sandberg, 1975; Halley, 1977; Strasser, 1986). Modern marine ooids usually have tangential fabrics and are composed of aragonite. In contrast, many ancient ooids with radial and tangential calcite fabrics may be shown to have been deposited in high-energy environments. It was therefore initially assumed that the ancient ooids were originally composed of aragonite and had undergone neomorphism. However, the preservation of a fine structure in the radial fabric of such ooids suggests that neomorphism was unlikely to have occurred. The inversion of aragonitic ooids is considered to have resulted in ooids of sparry calcite (Tucker, 1984; Wilkinson et al., 1985; Strasser, 1986) which preserve little trace of the original fine-scale structure. It is suggested, therefore, that ooids with a radial texture were primarily calcitic (Wilkinson et al., 1985).

The silicified ooids with radial and tangential fabrics therefore have two possible origins. They may have been formed by the replacement of either aragonite or calcite with tangential fabrics. The tendency for aragonite to dissolve, especially when brought in contact with freshwater, would suggest that ooids of such a composition would also undergo dissolution. Such an effect would result in the formation of moulds after ooids and, possibly, dropped nuclei (e.g. Carozzi, 1963; Tucker 1984). In contrast, calcite ooids would be more stable, possibly undergoing inversion from high to low-magnesium calcite but not forming moulds.

Dissolution moulds after ooids are not recognised in the chert pebbles with radial and tangential fabrics. This, and the absence of replaced carbonate cements in the cherts, implies that silicification occurred at an early stage. The grains are not replaced aragonitic ooids. They were probably composed of calcite.

Oolites are present in a number of Palaeozoic and Mesozoic carbonate sequences in Britain and the surrounding region but silicified oolites are very rare. Chert pebbles in the Torridon Group of Scotland contain spherical bodies resembling oolites (Wells,

1947; Williams, 1969). Partially silicified ooids have been noted from the Bonahaven Formation (Dalradian Supergroup) in northwest Scotland by Fairchild (1985). Oolitic cherts have been described by Swett (1965) from the Durness Dolomite Formation. However, the distance of northwest Scotland from the area of deposition suggests that these are improbable sources.

The limestones of Jurassic age contain oolitic cherts in the Corallian Group of Yorkshire (Wilson, 1939) and the Portland Limestone Formation of Dorset (Wilson, 1966; Raisin, 1903). The Jurassic oolitic cherts are distinctive, typically containing quartz sand grains, bivalves and tetraxinellid sponge spicules. In this study, Portland and Corallian Group oolitic cherts have been compared with these chert pebbles and found to have distinctly different silicification fabrics.

Descriptions of Carboniferous chert with ooids are not common. The Brigantian limestones of the North Crop, South Wales are noted to contain cherty oolitic limestones (Robinson, 1935) and Holkerian limestones in the Ebbsfleet borehole, Kent are reported to be siliceous (Strahan, 1912). Carboniferous oolitic limestones are largely restricted to the basins south of the Welsh and Anglo-Brabant Massifs (St. George's Land), with minor occurrences in south Derbyshire and in the Northumberland Trough.

Where unaltered oolitic chert pebbles are present in beds containing identifiable Carboniferous chert detritus, the clast-shape and roundness are similar. The oolitic cherts were therefore probably derived from Carboniferous limestones. The southern margins of the Welsh and Anglo-Brabant Massifs (St. George's Land) were the most probable source areas.

3.2.1.10 Silicified lime mudstones with rhombic pseudomorphs

Description: Brownish black (5.YR.2/1) to greyish orange (10.YR.7/4) pebbles of microcrystalline chert with minute rhombic pseudomorphs. The clasts are subrounded to well-rounded, compact-bladed to bladed. Pebble surfaces have chatter marks and are polished. The features

used to define this group of clasts are:

1. the presence of rhomb-shaped pseudomorphs or moulds in microcrystalline siliceous matrices,
2. the absence of allochems and sedimentary lamination.

In the rhomb-bearing chert pebbles, megaquartz and chalcedonite-filled pores are common and some clasts have a mottled texture. Chert pebbles with bioclasts (Sect. 3.2.1.8), intraclasts (Sect. 3.2.1.14), pellets (Sect. 3.2.1.15), ooids (Sect. 3.2.1.9) and parallel lamination (Sect. 3.2.1.11) may all contain silicified or rarely unsilicified rhombic pseudomorphs. These pebbles were not included in the rhombic chert group for the compositional analysis (Chap. IV), but the processes of formation of the rhombs in all the cherts were probably similar. These pebbles are similar to the silicified rhombohedral (dolomitic) limestones of P.Allen (1961; p.278, 281) and the rhomb-bearing cherts of Wells & Gossling (1947; p.208-211).

The pebbles are composed of equant microquartz, typically without a fabric. Irregular-shaped, frequently elongate cavities present in a high proportion of the clasts, are filled with pseudo-chalcedony and spherulitic chalcedonite (Pl. 12-6). Megaquartz cavity cements are less common.

Alignment of rhombs is observed, but more commonly the rhombic grains are scattered randomly throughout the matrix. Rhomb-length ranges from 50-100μm and replacement is by a variety of siliceous fabrics. Replacement is typically by flamboyant megaquartz but in rare examples is by microflamboyant microquartz. In a number of the pebbles, the rhombs are not silicified and are either empty or composed of carbonate. Rhombic moulds are more common towards clast-margins and are filled with glauconite or goethite in some examples.

Rhombic pseudomorphs of two types are recognised:

1. small rhombs, 50-70μm in length (Pls. 12-7, 12-8), dispersed throughout the chert, commonly replacing the precursor of equant microquartz. Occasionally the silica replacement of the rhombs preserves the original zoning.
2. larger rhombs, often unsilicified or replaced by undulose

megaquartz. Rhombic voids of this type may also exist and in some examples are orientated in stringers cross-cutting all fabrics.

Discussion: The rhombs resemble those of carbonate replacements in limestones. Dolomite, ankerite (ferroan dolomite) and siderite all form crystals with rhombic habits, but siderite is not as common a limestone replacement as dolomite or ankerite. The rhombic pseudomorphs are often stained by goethite and this possibly indicates that in such examples, the primary carbonate was ferroan. Iron-stained pseudomorphs are possibly after ankerite or siderite. In many examples, however, staining occurred in the pebble beds and there is no evidence of ferroan carbonate precursors.

Dolomite is recognised in many of the cherts in the Carboniferous limestones in Britain, but is also known in cherts in the Lower Carboniferous basinal deposits of southwest England (Hinde & Fox, 1895) and the Durness Dolomite Formation of northwest Scotland (Swett, 1965). Dolomitization occurred in the Corallian Group limestones in Britain, where it typically predated silicification (Milodowski & Wilmot, 1984). Corallian Group cherts are not common and rarely contain appreciable amounts of dolomite, ankerite or siderite. Portland Limestone Formation and Purbeck Formation cherts are not known to contain rhombic pseudomorphs.

The source of the rhombic-pseudomorph cherts is probably Palaeozoic limestones. The chert pebbles do not have a high argillaceous content and are unlikely to have been derived from the basinal Carboniferous sequences of southwest England (Sect. 3.2.2). A Durness Dolomite Formation source is considered improbable because of the distance from the depositional site. The similarity of clast-shape and size between the rhombic cherts and Carboniferous bioclastic cherts, and the presence of rhombic pseudomorphs in the latter indicate that the two clast-types were probably derived from similar sources.

The rhombs are after early diagenetic replacements of the limestones, probably by dolomite or ankerite. The replacement was incomplete when silicification occurred. Chert-dolomite associations have been reported previously by several workers (Dapples, 1959; Dietrich et al., 1963; Swett, 1965; De Celles & Gutschick, 1983).

Dietrich et al. (1963) considered that silicification postdated initial dolomitization of the sediment but occurred before final dolomitization. A similar diagenetic history was recognised in the Durness Dolomite Formation by Swett (1965). Where silicification follows dolomitization, the dolomite rhombs are commonly resistant to replacement (Wise & Weaver, 1974) and may remain unsilicified.

In a number of the examples cited above, dolomitization and silicification occurred in lagoonal or intertidal sediments and both processes are considered to have occurred during early burial. The absence of silicified evaporites in the rhombic pseudomorph chert pebbles and the coarse size of the dolomite crystals indicates that sabkha dolomitization (e.g. Muir et al., 1980) was probably not the mechanism for the replacement of the chert precursors. Some cherts with rhombic pseudomorphs, such as the laminated (Sect. 3.2.1.11), mottled (Sect. 3.2.1.13), intraclastic (Sect. 3.2.1.14) and peloidal (Sect. 3.2.1.15) varieties were possibly derived from sabkha or intertidal sediments but this has not been confirmed. The bioclastic cherts with marine faunas are unlikely to have been affected by sabkha dolomitization. Groundwater mixing was considered by Badiozamani (1973) to produce laterally extensive stratiform dolomites and Ramsbottom (1973) and Hird et al. (1987) suggested that such a mechanism was of importance for the dolomitization of Carboniferous limestones in South Wales and conceivably was of importance in other areas. The groundwater mixing model for dolomitization has been criticised by Hardie (1987), who stressed the importance of burial temperature and burial time as controls on dolomitization. The chert phenoclast fabrics, however, indicate that silicification and dolomitization occurred at a relatively early stage after burial. Dolomitization (Badiozamani, 1973) and silicification (Knauth, 1979) may, therefore, be caused by groundwater mixing, although the mechanism is not understood fully.

3.2.1.11 Silicified laminated lime mudstones

Description: Brownish black (5.YR.2/1) to moderate yellowish brown (10.YR.5/4) microcrystalline cherts. The clasts are rounded to subrounded, platy to bladed and up to 35mm in length. The lamination

of the cherts is normally parallel to the L-I or I-S planes in the clasts. This was a controlling factor for clast-shape. Lamination is sub-parallel or rarely discordant.

The pebbles are composed of equant or microflamboyant microquartz, with laminae 100-1000μm thick. Laminae are produced by variations in crystallite-size or colour (Pl. 13-2). The laminae produced by variation in crystallite size have both sharp and graded contacts. The cherts commonly contain small rhombic pseudomorphs and silica-cemented cavities (Sect. 3.2.1.10). Occasionally the lamination results from alignment of rhombic pseudomorphs. The rhombs are composed of flamboyant megaquartz. The cavities in the cherts are cemented by layered spherulitic chalcedonite which nucleated at the cavity margins and occasionally passes into mosaic megaquartz (Pl. 13-2). Bioclasts are sparse in the silicified laminated lime mudstones but intraclasts and pellets are occasionally found.

Discussion: Pebbles of laminated microcrystalline chert are probably silicified lime or dolomitized muds. Clay and mica grains are not present in the chert and there is no preferred alignment of the groundmass. Planar fabrics created by silicification have not been recognised in other chert pebbles, but "zoning" of chert nodules is occasionally observed (e.g. Portland chert in the Dungy Head Member, Portland Limestone Formation at Poxwell and West Weare, Dorset). Similar fabrics in flint were described by Clayton (1984) and ascribed to weathering. Zoning rarely produces small-scale lamination similar to those identified in this type of chert pebble. The textures were probably inherited from the carbonate precursors.

The absence of bioclasts in many of the cherts of this variety precludes the definite identification of the source. The similarity in the clast-morphology to the bioclastic chert pebbles of Carboniferous origin (Sect. 3.2.1.8) and differences from the Jurassic chert pebbles (Sects. 3.2.1.1 to 3.2.1.7), suggests a Palaeozoic or Precambrian origin. However, the absence of phyllosilicate grains and metamorphic fabrics in the cherts probably precludes the Culm and Lower Palaeozoic cherts as sources for this detritus. The pebbles are therefore assumed to have been principally derived from Carboniferous limestones or dolomites.

PLATE 13

CARBONIFEROUS SHELF AND BASINAL CHERT FABRICS

PLATE 13

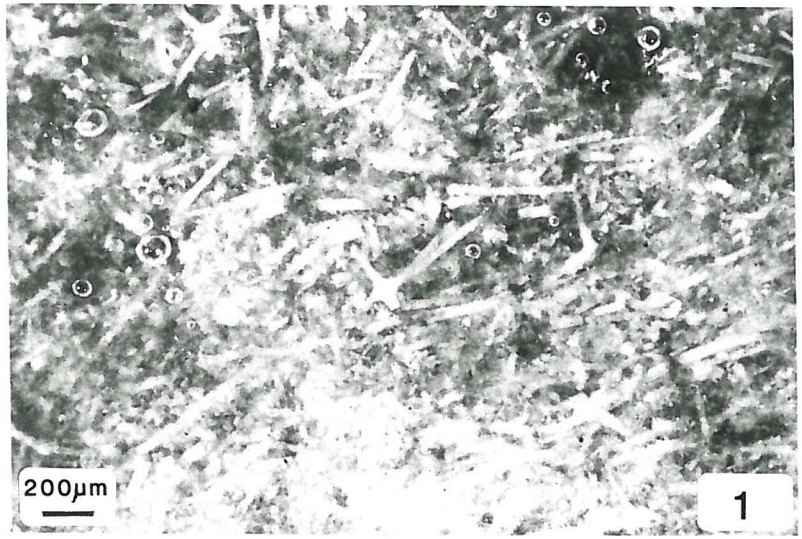
CARBONIFEROUS SHELF AND BASINAL CHERT FABRICS

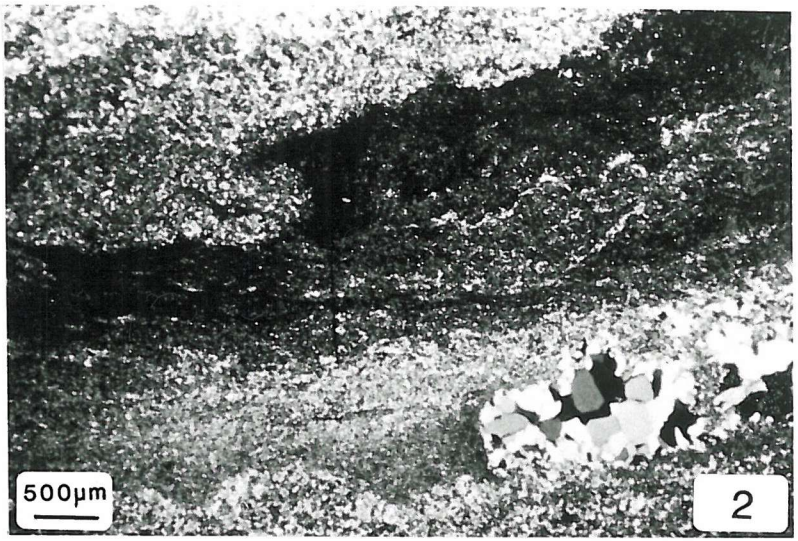
13-1. Sponge spiculite composed of chalcedonic spicules in a microquartz matrix. The bifurcating spicules are probably from a hexactinellid sponge. The spiculite contains no other identifiable bioclasts.
Etched polished sample photomicrograph, reflected light.
Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

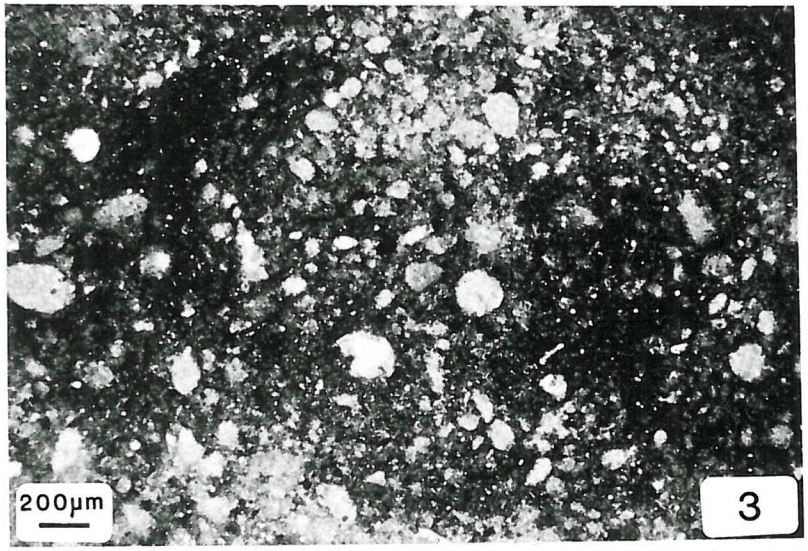
13-2. Laminated chert with a mosaic megaquartz-filled pore elongate parallel to the lamination (right). Lamination is due to variations in crystallite size and colouration due to goethite staining.
Thin-section photomicrograph, cross-polarized light.
Pebble: Gault Clay Formation, Haredene Woods, Wiltshire.
Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

13-3. Silicified peloidal packstone. The microquartz peloids are set in a matrix of darker goethite-stained microquartz.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed RC5, Carstone Member, Redcliff, Isle of Wight.
Source: Carboniferous limestone, probably from the Welsh or the Anglo-Brabant Massifs.

13-4. Silicified argillaceous mudstone with radiolaria. The radiolaria are replaced by chalcedonic silica which rarely preserves any internal structure.
Thin-section photomicrograph, plane-polarized light.
Pebble: Coarse Quartz Grit, Wessex Formation, Durdle Door promontory, Dorset.
Source: Chert Formation, probably from the Cornubian Massif.







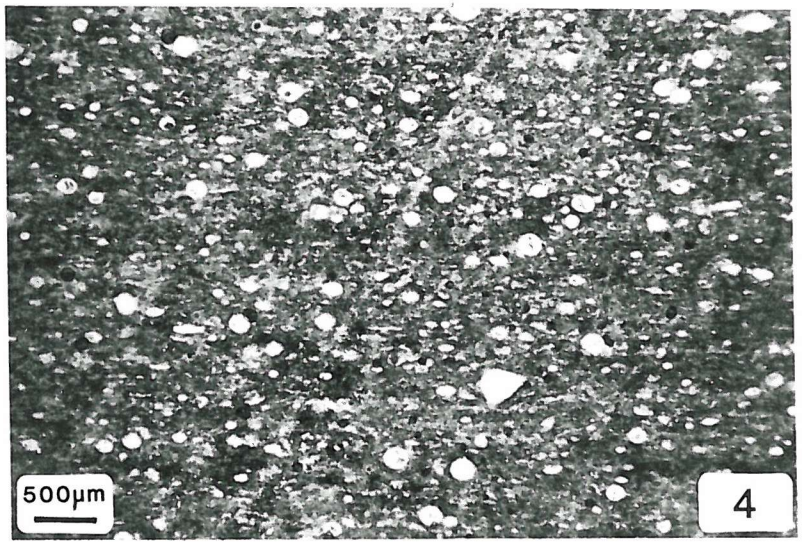


PLATE 13

The presence of lamination in lime or dolomitic mudstones indicates that bioturbation was restricted. Lamination is likely to be preserved if the environment of deposition is not suitable for burrowing or browsing organisms. This possibly resulted from anoxic bottom conditions or salinity restrictions. The former would be expected to produce dark, pyritic sediments which might contain planktonic organisms. Such a source does not appear to be appropriate for the type of laminated cherts found. In contrast, bioturbation of intertidal or subtidal muds in a lagoonal environment may be restricted by salinity controls. Intraclasts and pellets are expected in deposits from such environments.

The silicified rhombs resemble those of the rhombic-pseudomorph cherts (Sect. 3.2.1.10) and are probably after dolomite or ankerite. Dolomitization of lagoonal deposits may occur by sabkha (Muir et al., 1980) or groundwater-mixing (Badiozamani, 1973) processes. Hird et al. (1987) recognised both types of dolomitization in the Carboniferous limestones of South Wales.

The laminated cherts are probably silicified Carboniferous laminated lime or dolomitic muds and fine silts of a lagoonal origin. Suitable sources are likely to have existed on the marginal areas of the Welsh and Anglo-Brabant Massifs or in the Pennines area.

3.2.1.12 Silicified sponge spicule packstones

Description: Greyish black (N2) to moderate yellowish brown (10.YR.5/4) clasts of fine-grained bioclastic chert. Pebbles are rounded to subrounded, bladed to compact-bladed and 4-35mm in length. The surfaces of pebbles are polished, with arcuate chatter marks, 1-3mm in length. These pebbles are similar to the spicular cherts of P.Allen (1961, p.274, 279) and the cherts with organic remains of Wells & Gossling (1947, p.207).

Chert pebbles of this variety are composed of elongate spicules set in matrices of equant or flamboyant microquartz (Pl. 13-1). Monaxon, tetraxon and hexaxon spicules are recognised. In cross section, the spicules are circular and commonly axial canals are preserved. Spicule diameters are on average between 30-60μm, but may

be up to 100μm. The spicules are generally of a uniform size but occasionally a bimodal suite of spicule sizes is found. Other bioclasts are rarely present in the spicular cherts, but spicules are noted in some bioclastic cherts (Sect. 3.2.1.8).

The spicules are replaced by flamboyant megaquartz or microflamboyant microquartz. Inclusions in the quartz are rare, except for dust trails of goethite along the axes of the spicules. The spicules are typically replaced and quartz-cemented moulds are rare.

In thin-section, many of the spicules appear to be monaxon but this is probably an artefact of the sectioning procedure. Examples of "umbrella-like" spicules from hexactinellid sponges, possibly Hyalostelia, have been identified. The spicules in the detrital clasts are not easily identified but examples of Hyalostelia, Reniera and Geodites have been recognised.

Discussion: Cherts of this variety have been referred to as spiculites or spongolites (Land, 1976; P.Allen, 1961; Newells et al., 1953; Cavaroc & Ferm, 1968) because of the abundance of sponge spicules and absence of other bioclasts or allochems. The spicules are replaced by quartz without carbonate inclusions. This implies that they were originally composed of opaline silica but neomorphosed to megaquartz or chalcedony.

The alignment and concentration of the spicules in the chert clasts have three probable origins:

1. the clasts are from sediments deposited as mats of sponge spicules. These are known in Recent deposits and also in ancient rocks (Lane, 1981). Currents are considered to have caused spicule-alignment;
2. the clasts are silicified limestones in which sponges were the main biogenic detrital component. Lees et al. (1985) noted that sponges were capable of colonizing deeper water than calcareous algae and foraminifera;
3. the clasts are from sponge-anchoring structures composed of aligned spicules. Anchoring structures are found in Carboniferous cherts (Hinde, 1912) and are composed of elongate spicules with short appendages.

Bioclasts other than spicules might be expected in the first and second types of deposit but would be unlikely to be associated with the latter.

The spicules of these rounded, dark coloured pebbles are distinctly different in size, shape and mode of preservation from the spicules in the weathered, bioclastic cherts (Sects. 3.2.1.1, 3.2.1.3). The weathered cherts contain large tetraxinellid spicules, such as Pachastrella, in contrast to the dark cherts which are composed principally of hexactinellid spicules. Sponges identified have moderately long age ranges except for the genus Hyalostelia which is restricted to Palaeozoic rocks. Spicules have not been reported from the Durness Dolomite Formation cherts and although possibly present in the Lower Palaeozoic basinal sediments, they have not been noted in cherts. The Lower Carboniferous cherts of southwest England contain sponge spicules but these cherts are texturally distinct from the clasts described here. They typically include radiolaria and have a foliated groundmass. Spicular cherts are found in the Tournaisian, Visean and Namurian limestones in Britain and these are the probable source of the detrital clasts. Sponge spicules are found in a number of the marine limestones in the Carboniferous System, but it is not possible to define source locations.

3.2.1.13 Microquartz cherts with mottled textures

Description: Pebbles of microcrystalline chert with a mottled texture are blackish grey (N2) to dark yellowish brown (10.YR.4/2) in colour, rounded to subrounded, bladed to compact and up to 30mm in length. Surfaces of the pebbles are covered in small arcuate percussion pits. The pebbles are similar to the silicified clotted limestones of P.Allen (1961, p.276-277, 281).

The clasts are composed of equant microquartz, 1-15μm in diameter. Bioclasts, ooids and intraclasts are absent from the phenoclasts which have no clearly defined fabric. Crystallite size-variations result in a mottled or lumpy texture in the cherts (Pl. 13-3), but there are no stratification fabrics. Some clasts have a granular texture produced by peloids of microquartz set in

microcrystalline matrices. The peloids are 50-150μm in diameter, bladed in shape and are distinguished from the matrix by slight crystallite-size or colouration differences (Pl. 13-3).

Rhombic pseudomorphs are common in these clasts. The rhombs are 50-150μm long and replaced by flamboyant megaquartz. Rhombic cavities on the clast surfaces are occasionally filled with glauconite. Glauconite may also be present in thin veins, 10-20μm wide. Weathering of the glauconite resulted in the formation of goethite-filled cavities and staining of the clasts.

Discussion: Pebbles of this type do not contain bioclasts and identification of the source is therefore difficult. Shape, size and colour are the principal features of these clasts and provide indications of the clast-provenance. Clast-morphology distinguishes these chert pebbles from the weathered cherts (Sects. 3.2.1.1 to 3.2.1.7), but the pebbles resemble the bioclastic cherts with Carboniferous fauna and flora (Sect. 3.2.1.8). It is probable that the pebbles are of Palaeozoic origin. Cherts from the Lower Palaeozoic and Carboniferous basinal sediments commonly contain argillaceous matter and have well-developed fabrics. These clasts have neither and are likely to be derived from silicified Carboniferous shelf limestones.

3.2.1.14 Silicified intraclast packstones and grainstones

Description: Blackish grey (N2) to moderate yellowish brown (10.YR.5/4) clasts of silicified intraclast limestones. The chert pebbles are rounded to subrounded, bladed to compact-bladed and 4-35mm in length. Clasts are rarely weathered, having polished surfaces with chatter marks. These clasts are similar to the silicified limestone-sandstones and silicified pellet limestones of P.Allen (1961, p.275, 280).

The intraclastic chert pebbles are silicified calcarenites composed of rounded to subangular, commonly elongated, allochems of microquartz, 500-2000μm in length set in matrices of microquartz or chalcedony. The silicified intraclasts are generally in point contact. They are typically homogeneous or are occasionally composed of more coarsely crystalline quartz towards their centres.

Intraclasts with lumpy or peloidal textures are found but they do not contain bioclasts. Rounded brachiopod or bivalve fragments are present in the matrix in some cherts. A few of the intraclastic cherts also contain ooids with radial and tangential fabrics.

Rhomb-shaped pseudomorphs are present in both matrices and intraclasts but in some examples are restricted to the allochems. Replacement of the rhombs was by undulose megaquartz.

Discussion: These cherts are silicified intraclastic packstones and grainstones. The microquartz matrices in the cherts are probably the replacements of lime-mud sediment. Chalcedony appears to be a primary cement phase and there is no evidence of early calcite cements. The intraclasts were probably derived from lime mudstones, some of which had been partially dolomitized prior to reworking. The clotted texture of several intraclasts is possibly of algal origin.

The intraclastic cherts may be grouped by clast-morphology with the bioclastic cherts of Carboniferous origin and are distinct from the cherts of Purbeck and Portland limestones. These clasts were probably derived from Carboniferous limestones in the Anglo-Brabant, Welsh or Pennine areas.

3.2.1.15 Silicified pelletal packstones

Description: Greyish black (N2) to moderate yellow brown (10.YR/5/4) clasts of silicified calcarenite. The pebbles are rounded to subrounded, bladed to compact and 4-35mm in length. Weathered pebbles are brown in colour and slightly porcellanous. These pebbles are similar to the silicified pellet limestones and silicified limestone-sandstones of P.Allen (1961; p.275, 280).

The pebbles have peloidal and clotted textures caused by variations in the equant or microflamboyant microquartz crystallite size. The clasts are normally devoid of bioclasts. Peloids are 50-200μm in length, rounded, bladed in shape and are generally of uniform size (Pl. 12-2). They are grain-supported with interstitial microquartz or chalcedonic silica. The peloids are distinguished from the matrix by variations in colour and slight differences in the coarseness of the microquartz.

Rhombohedral pseudomorphs are present in some of these cherts. The rhombs are composed of megaquartz with undulose extinction and occassionally contain carbonate inclusions.

One of the pelletal packstone clasts collected also contains ooids and the contact with an overlying oolitic grainstone (Pl. 12-2). The ooids have both concentric and radial fabrics and are composed of microflamboyant microquartz.

Discussion: Clasts of this type are interpreted as pelletal cherts, but some pebbles bear close resemblance to intraclast (Sect. 3.2.1.14) and mottled (Sect. 3.2.1.13) cherts. The association of pellets with ooids indicates that the source rocks were probably of shallow marine or lagoonal origin.

The absence of bioclasts precludes the precise identification of the source limestones, but clast-morphology indicates that these cherts are related to the cherts with Carboniferous bioclasts (Sect. 3.2.1.8).

3.2.2 Radiolarian chert phenoclasts

Description: Black (N1) to light bluish grey (5.B.7/1) clasts of laminated chert with radiolaria. Quartz veining is common. The clasts are rounded to subrounded, bladed to elongate and 4-30mm in length. Weathering of the pebbles is rare and when altered the clasts are slightly paler in colour at the surface. Clasts similar to these are included in the other silicified limestones group of P.Allen (1961; p.278).

The cherts are composed of crypto- or microcrystalline quartz, with associated microcrystalline pyrite, chlorite and muscovite. The quartz and phyllosilicates are elongated parallel to the lamination. Allochems may form the framework of the chert or are supported in the siliceous matrix. Elongate grain contacts resulting from compaction are occasionally present and cross-cutting stylolites are also preserved in the pebbles.

The allochems are dominated by two types of bioclast:

1. spherical bodies 100-200μm in diameter, and
2. elongate spines 50-120μm in length and 10-20μm in width.

The former are radiolaria and occasionally preserve a fine internal lattice work and external spines. The elongate clasts contain few distinctive features, but in size and shape, are similar to sponge spicules. An algal body was identified in a clast of similar composition from a collection of pebble thin-sections on loan from Prof. P.Allen (University of Reading), but other bioclasts have not been found.

Radiolaria are poorly preserved in the clasts and their internal fabric rarely remains. Tests are composed of spherulitic chalcedonite or mosaic megaquartz, both of which nucleated at the clast-margins. The quartz of the latter has undulose extinction but no inclusions. The examples where the internal fabric of the test is preserved are those replaced by clear mosaic megaquartz. Spicules are composed of flamboyant megaquartz or chalcedonite.

Rhombic pseudomorphs of megaquartz and rhombic moulds are found in some pebbles. The pseudomorphs are 100-200μm in length and cross-cut both matrices and radiolaria tests. Cubic moulds present in these cherts are unfilled or filled with microcrystalline goethite.

Radiolaria tests are commonly flattened in the plane defined by the alignment of phyllosilicate grains and quartz crystallites. The spicules are orientated with their long axes in the same plane. Veins of quartz in the pebbles are commonly orientated perpendicular to this planar fabric. A number of phases of veining are recognised and some are associated with cubic moulds or pyrite crystals.

Discussion: The clasts are siliceous radiolarian packstones, wackestones and mudstones with high phyllosilicate contents. The plane of alignment of phyllosilicate minerals and spicules and flattening of radiolaria was probably a primary bedding feature, but with a weak metamorphic fabric superimposed.

The radiolarian chert pebbles differ in a number of respects

from silicified limestone clasts (Sect. 3.2.1). They have a high phyllosilicate content, contain euhedral pyrite or pseudomorphs after pyrite and have no significant benthonic fauna. They also have a foliated matrix and have quartz veins indicative of late-stage deformation.

The absence of a benthonic fauna indicates that either bottom conditions were unsuitable for life (stagnant/anaerobic) or water depths were too great. The presence of abundant pyrite in the cherts may support the former conclusion.

Radiolarian cherts are best known from deep sea sediments where terrigenous inputs are low and carbonates are absent due to their dissolution below the carbonate compensation depth (Kling, 1981). Oozes of radiolarian tests are commonly associated with oceanic crust and are occasionally preserved in obducted ophiolite complexes. Siliceous sediments may also result from blooms and mass mortality of organisms with siliceous tests.

Oceanic sediments are rarely preserved in the geological record. Few examples of oceanic crust or their associated sediments are found in Britain or the surrounding region and the known examples rarely contain radiolarian cherts. In Britain, radiolarian cherts are found in Carboniferous strata and the best development of such rocks are the Dinantian basinal deposits of southwest England (George et al., 1976; Hinde & Fox, 1895). Radiolarites were also reported in rocks of Pendlian age in South Wales by Dixon & Vaughan (1911) and radiolarian mudstones are known in the Edale Shales (Pendlian) of Derbyshire (Pulfrey, 1935; Holdsworth, 1964, 1966).

The presence of pressure-solution seams, quartz veins and foliation fabrics indicate that the clasts were derived from a deformed source area. The Lower Carboniferous rocks of Cornwall, Devon and southern Somerset, which were deformed during the Late Carboniferous to Early Permian Variscan Orogeny, are the most probable source.

Cherts in the Lower Carboniferous rocks of southwest England are

found on both limbs of the Devon synclinorium. Most of the cherts contain radiolaria (Hinde & Fox, 1895), but an exception is the chert of the Fire Beacon Formation, which outcrops near Boscastle, Cornwall (Freshney et al., 1972). The Lower Carboniferous strata in this area are highly deformed and it is probable that the cherts were recrystallized, thereby destroying the original fabric. The sources for radiolarian chert pebbles were probably in the less deformed eastern and northern parts of the Devon synclinorium.

3.2.3 Silicified evaporite phenoclasts

This group of clasts is distinguished by the presence of evaporite pseudomorphs or replaced evaporite textures. Many of the fabrics are similar to those in the silicified limestones (Sect. 3.2.1). However, there is generally little to suggest that the evaporites were calcitized or extensively dolomitized prior to silicification.

3.2.3.1 Silicified gypsiferous mudstones

Description: Greyish black (N2) when fresh, very light grey (N8) to very pale orange (10.YR.8/2) when weathered. The clasts are rounded to subangular, bladed to compact-bladed and 10-100mm in length. Internal lamination results in pebbles being friable.

The cherts are composed of lens-shaped pseudomorphs, 200-2000μm in length, set in matrices of equant or microflamboyant microquartz. Silicified lenticular crystals occur as isolated grains in microquartz matrices (Pls. 14-2, 14-4), as nodules, clusters or as a felted mass of chalcedony without distinct crystallite boundaries. In some clasts the lenticular crystals are aligned.

The lenticular crystals are pseudomorphed by lutecite, quartzine and megaquartz. Lutecite and quartzine are the most common replacements and occur as spherulites. Three fabrics are recognised:

1. quartzine orientated sub-parallel to the margins of the pseudomorphs,
2. spherulitic quartzine, nucleated on the pseudomorph-margins and passing into mosaic megaquartz towards the pseudomorph-centre (Pl. 14-2). The megaquartz is free from inclusions and is commonly

PLATE 14

SILICIFIED EVAPORITE AND WOOD FABRICS

PLATE 14

SILICIFIED EVAPORITE AND WOOD FABRICS

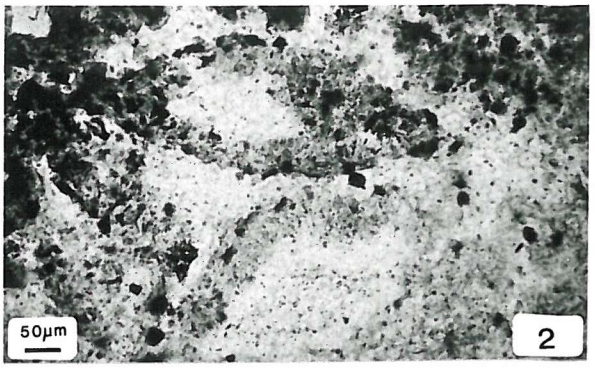
14-1. Spherulitic lutecite, probably after gypsum. The silica fabric does not bear close resemblance to identified evaporite fabrics.
Thin-section photomicrograph, plane-polarized light.
Pebble: Pebble bed RC1, Ferruginous Sands Formation, Redcliff, Isle of Wight.
Source: Basal Purbeck Formation, probably from the Isle of Wight High.

14-2. Quartzine (grey) lining a mould after gypsum which is infilled by clear megaquartz.
Thin-section photomicrograph, plane-polarized light.
Pebble: Gault Clay Formation, Aldersnapp Farm, Hampshire.
Source: Purbeck Formation, probably from the Isle of Wight High.

14-3. Silicified laminated, bioclastic mudstone. The gastropod shell is replaced by megaquartz which also cements the whorls. The equant and microflamboyant microquartz matrix includes pseudomorphs after gypsum. The fine crenulation of the lamination is reminiscent of a stromatolitic fabric.
Thin-section photomicrograph, cross-polarized light.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Purbeck Formation (possibly from the Soft Cap), probably from the South Dorset High.

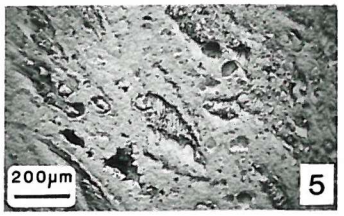
14-4. Silicified mudstone with lenticular pseudomorphs after gypsum. The chalcedonic replacement of the pseudomorphs has been etched preferentially by hydrofluoric acid.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Gault Clay Formation, Holworth House, Dorset.
Source: Basal Purbeck Formation, probably from the South Dorset High.

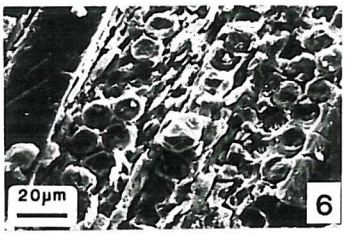

500µm
1

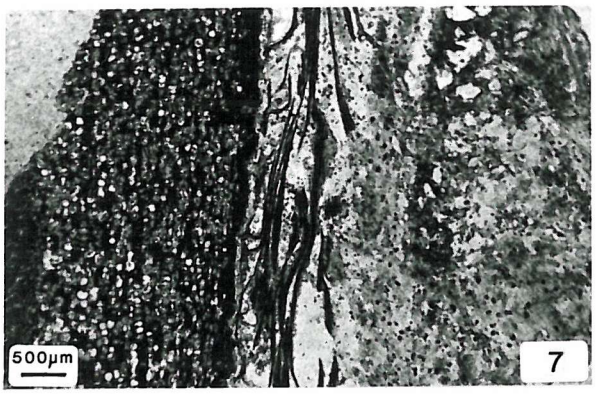

50µm
2

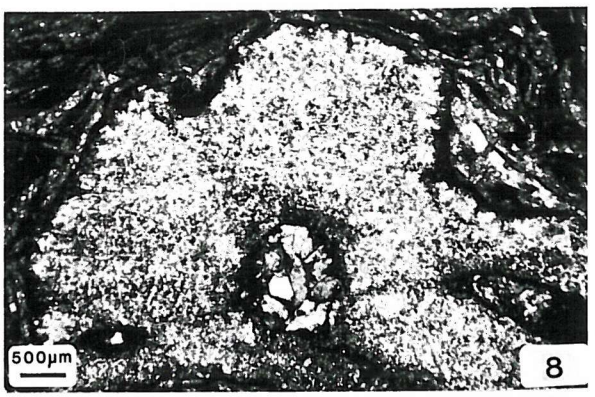

200µm
3

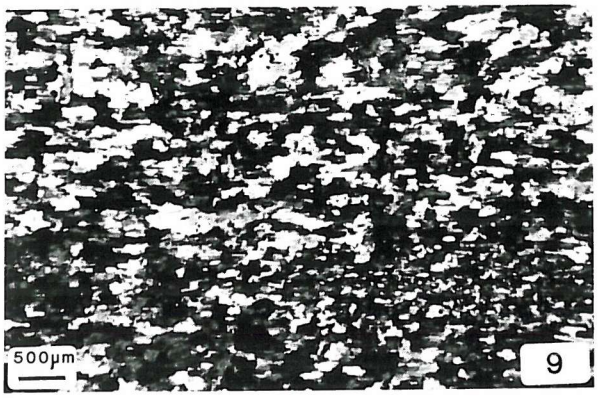

100µm
4


200µm
5


20µm
6


500µm
7


500µm
8


500µm
9

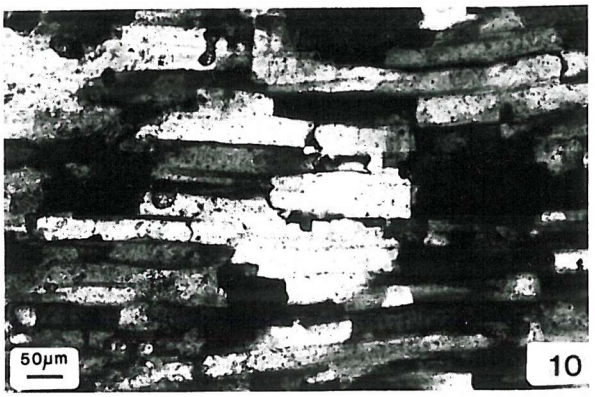

50µm
10

PLATE 14

14-5. Partially silicified wood with areas of well preserved cellular material (centre and top right). The remaining area is composed of microquartz and small cavities partially cemented by flamboyant megaquartz.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Middle Purbeck Formation, Worbarrow Tout, Dorset.
Source: Basal or middle Purbeck Formation, probably from the South Dorset High.

14-6. Silicified wood with megaquartz-filled lumina.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Coarse Quartz Grit, Wessex Formation, Durdle Door promontory, Dorset.
Source: Basal Purbeck Formation, probably from the South Dorset High.

14-7. Silicified wood largely replaced by microquartz. On the left, a cellular wood fabric is preserved, but in the centre the wood is largely replaced and preserves only a fine fibrous/cellular texture (probably shoot matter; J.E.Frances pers. comm.).
Thin-section photomicrograph, plane-polarised light.
Pebble: Scallop Member, Purbeck Formation, Worbarrow Tout, Dorset (Bed 153 of Ensom, 1985b).
Source: Basal or middle Purbeck Formation, probably from the South Dorset High.

14-8. Poorly preserved silicified wood. The wood is replaced by microflamboyant microquartz. Note the impregnation of the margins of the wood by pyrite and the crushed bivalves within the host limestone.
Thin-section photomicrograph, plane-polarized light.
Pebble: Cherty Freshwater Member, middle Purbeck Formation, Durlston Bay, Dorset (Bed DB 101 of Clements 1969).
Source: Basal or middle Purbeck Formation, probably from the South Dorset High.

14-9. Transverse section through silicified wood displaying the well preserved vascular structure. The wood, replaced by megaquartz, is probably of Dadoxylon.

Thin-section photomicrograph, cross-polarized light.

Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.

Source: Upper Carboniferous rocks, probably from the Welsh or the Anglo-Brabant Massifs.

14-10. Megaquartz replacement of wood. Note that the form of the silica fabric has been closely controlled by the wood texture and the sizes of the crystallites are similar to the thickness of the cells. Cell walls are preserved as dust trails of opaque inclusions.

Thin-section photomicrograph, cross-polarized light.

Pebble: Pebble bed CF2, Carstone Member, Rock, Isle of Wight.

Source: Upper Carboniferous rocks, probably from the Welsh or the Anglo-Brabant Massifs.

restricted to the thickest part of the pseudomorph,

3. lutecite, nucleated at the grain centre. The lutecite fibres are orientated sub-perpendicular to the grain margins.

Occasionally preserved in the pebbles are small nodular structures, 50-5000μm in diameter, composed of fine lenticular pseudomorphs and surrounded by equant or microflamboyant microquartz. These clusters of pseudomorphs are elongated parallel to the clast-lamination. In rare examples, the centres of the nodules are composed of mosaic megaquartz, the margins being replaced by chalcedonite. The surrounding microquartz is displaced by the formation of the nodules.

The replaced sediment associated with the silicified lenticular crystals is commonly composed of microquartz but examples of fine megaquartz aggregates with interstitial microquartz exist. Occasionally megaquartz crystals are hexagonal in form but do not appear to be the replacement of individual crystals.

Discussion: A variety of siliceous pseudomorphs after lenticular crystals have been identified in sedimentary rocks. Common carbonates such as dolomite, ankerite, siderite and calcite form rhombic crystals, as does the sulphate gypsum. Carbonate rhombs typically have the form of unit rhombohedra with straight or curved cleavage planes. The angle between the two good cleavages of the carbonate lattice is approximately 75°. In contrast, gypsum has one good and two poor cleavages. The resulting rhombs generally have curved edges and apical angles of approximately 66°. Lenticular gypsum crystals are therefore flatter and more elongated than carbonate rhombs.

The siliceous replacements of rhombic and lenticular crystals differ. Replacement of gypsum is commonly by quartzine (West, 1964; Folk & Pittman, 1971; Siedlecka, 1972, 1976; Tucker, 1976a; Arbey, 1980). Dolomite, the rhombic carbonate most frequently noted in cherts, is typically replaced by flamboyant or mosaic megaquartz. Chalcedonic replacements of dolomite are less common (Sect. 3.2.1.10).

The clasts of this group contain lenticular crystals,

pseudomorphed by silica, and closely resemble descriptions of replaced gypsum. The associated fabrics of the matrices, fine lamination, displacive nodular growths and absence of a shelly fauna, are all typical of evaporites.

Lutecite and quartzine, the common pseudomorphs in the pebbles, have been found in association with silicified evaporites by Folk & Pittman (1971) who considered that silicification of evaporites by lutecite or quartzine occurred in groundwaters with high concentrations of silica and high pH.

Potential sources of silicified evaporites are known in the Precambrian, Palaeozoic and Mesozoic rocks of Britain. Parnell (1985, 1986) described lenticular and stellate pseudomorphs in Devonian cherts from the Orcadian Basin which he interpreted as being after evaporites. Both gypsum and anhydrite are found in Dinantian limestones (Llewellyn & Stabbins, 1970; Bhatt, 1976) but few examples of silicified evaporites have been found. The Grande Brèche and Vesdre Dolostone Formation of Belgium is in part a calcitized and silicified evaporite sequence (Mamet et al., 1986; Rouchy et al., 1986; Swennen & Viaene, 1986). Silicified evaporites have also been reported in rocks of Visean age in Ireland (West et al., 1968) and are suggested to be present in the Lower Carboniferous rocks of southern England (Sonnenfeld, 1986). Permian and Triassic evaporites of Britain contain siliceous nodules or authigenic euhedral quartz but these are commonly of replaced anhydrite (Harrison, 1975; Tucker, 1976b). Calcite pseudomorphs after gypsum are found in Middle Jurassic deposits in the Inner Hebrides (Hudson, 1970; Andrews, 1986), but silicified examples have not been recognised. The Purbeck Formation in southern England is a sequence of lagoonal and sabkha sediments in which chert after evaporites is moderately common (West, 1964, 1975).

In the absence of characteristic bioclasts, estimates of the source of the silicified evaporite pebbles have been made by petrographic comparisons with possible source rocks. Identification of the source is also possible by the association with other datable phenoclasts in the suite.

The shape and size of the clasts in this group indicate that the

source was probably close to the site of deposition. The chert pebbles were found in the basal Gault Clay Formation pebble beds of east Dorset and east Hampshire and in the Ferruginous Sands Formation in the Isle of Wight. Pebbles in Dorset are associated with detritus from the Portland Limestone Formation. In the Isle of Wight and Hampshire, Portland Limestone Formation detritus is scarce, but Kimmeridge Clay Formation phosphorite and Carboniferous chert clasts are common. The pebbles are similar in appearance to the Portland cherts found to the west, but differ considerably from the Carboniferous cherts. The silica fabrics do not resemble those of Triassic evaporites. A Purbeck Formation source is therefore probable for these clasts.

The assignment of the silicified evaporites to the Purbeck Formation is possible in some examples by the presence of Classopollis and bisaccate pollen grains. Classopollis pollen ranges throughout the Jurassic System (small amounts occur in some Portland Limestone Formation cherts at Ringstead), but it is particularly abundant in the lagoonal and terrestrial deposits of the Purbeck Formation (Francis, 1983a; Hunt, 1986).

3.2.3.2 Silicified gypsiferous and stromatolitic mudstones

Description: A clast of very pale orange (10.YR.8/2) to very light grey (N8) laminated chert with lenticular pseudomorphs and small gastropods has been collected (3.G.8/4). The clast was rounded, bladed and approximately 50mm in length.

The thin lamination, which is preserved by aligned opaque inclusions and organic filaments, is gently crenulated, domed and drapes gastropod shells. Pseudomorphed lenticular crystals and nodules displace the laminae. The lenticular crystals are similar to those of the gypsum (Sect. 3.2.3.1) and are replaced by quartzine. The gastropods present in this chert are small (less than 5mm) turreted forms with well-defined ribbing (Pl. 14-3). The gastropod tests are replaced by flamboyant megaquartz and mosaic megaquartz cements the chambers.

Discussion: The crenulated, draped form of the lamination is reminiscent of stromatolitic structures. The gastropods have not

been identified but they resemble Purbeck Formation types in size and morphology (e.g. Hydrobia). The clast was found in the Gault Clay Formation in Dorset and is similar morphologically to the Portland Limestone Formation chert pebbles from this horizon. The probable source of the clast is the lagoonal deposits of the Purbeck Formation.

Stromatolitic and replaced-evaporite limestones are common in the basal Purbeck Formation in southern Dorset. Gastropods are more common in the limestones, particularly in the western outcrops of the Purbeck Formation (West, 1975). Gastropod- and gypsum-bearing cherts are found in the Soft Cap at Upway, north of Weymouth (West pers. comm., 1983) but other sources must also have existed.

3.2.3.3 Spherulitic lutecite chert

Description: Moderate yellowish brown (10.YR.4/2) to white (N9) weathered cherts, composed of spherulites with fine concentric lamination. The pebbles are subangular, bladed to compact-bladed and 4-75mm long. The clasts are weathered, commonly having yellowish brown cortices and white, porcellanous cores. In less weathered examples the core is of light grey vitreous silica. The margins of the clasts are uneven with slightly elongate nodes of silica projecting above the surrounding surface. The nodes are spherulites of silica with concentric laminae.

In thin-section, the clasts are composed of aggregates of pseudo-hexagonal lutecite (Pls. 8-2, 14-1) with distinctive lamination concentric to the spherulite nuclei. The concentric pattern in the lutecite is produced by microcrystalline inclusions, possibly of pyrite which outlines euhedral terminations in the silica. The spherulites are interlocked but equant microquartz and mosaic megaquartz are present between them. The megaquartz is clear and free from inclusions. No fabric is preserved by the microquartz, but it does contain Classopollis pollen, either as individual grains or as clusters. Classopollis grains have not been found in the lutecite.

Discussion: The coarsely crystalline aggregates of spherulitic lutecite contain few indications as to their source. Lutecite is

known as the replacement of evaporites (Folk & Pittman, 1971; Siedlecka, 1972), carbonate bioclasts (Wilson, 1966; Jacka, 1974) and fossil wood (Francis, 1983b). The abundance of Classopollis pollen in the clasts indicates a Jurassic origin. The association of spherulites with pollen grains makes it improbable that the lutecite replaced carbonate bioclasts. Silicified wood may contain Classopollis pollen (Francis, 1983b) but commonly preserves its original fabric.

The microquartz in the clasts probably represents replaced sediment displaced by the growth of either the silica or its precursor. Sediment may be found in silicified wood but is unlikely to be dispersed in the manner seen in these clasts. Similar textures are, however, recognised in enterolithic and nodular evaporites (West, 1965). Megaquartz present in the interstices between spherulites is probably a siliceous cement. In fossil wood from the basal Purbeck Formation, early cements are typically of spherulitic chalcedony. The characteristics of the clasts indicate that they are probably reworked replacements of Purbeck Formation evaporites and not replaced wood.

In Dorset, analogous chert has not been found in the Purbeck Formation, but small spherulites of lutecite after gypsum with similar concentric lamination are present in cherts from the Broken Beds at Durdle Door.

The lutecite spherulite cherts are locally derived, having undergone little abrasion during transportation. This distinctive group of chert pebbles has been found only in the pebble beds in the Lower Greensand Group (Sect. 4.2.2) of the Isle of Wight. This suggests erosion of the Purbeck Formation in the vicinity of the Isle of Wight during the Aptian Stage.

3.2.3.4 Microcrystalline cherts with lenticular pseudomorphs

Description: Pebbles of chert with lenticular pseudomorphs. Greyish black (N2) to brownish black (5.YR.2/1) in colour when unweathered, moderate brown (5.YR.3/4) to moderate yellowish brown (10.YR.5/4) when weathered. Lamination is preserved in some clasts. Pebble shape varies from compact to bladed or platy. The clasts are rounded

to subrounded and up to 25mm in length.

These cherts are composed of equant microquartz with lenticular or oblong inclusions, 50-250μm in length, scattered throughout the matrices. The pseudomorphs are composed of flamboyant megaquartz or chalcedonic silica. The chalcedony is length-fast and neither quartzine nor lutecite have been recognized. In rare examples, the chert is composed of clots or nodules of chalcedony.

Bioclasts are absent from the cherts. Rhombohedral pseudomorphs replaced by mosaic or flamboyant megaquartz are present in a number of samples. The rhombs are shorter but broader than the lenticular pseudomorphs (25-75μm). Lamination in the cherts is produced by small differences in crystallite size, varying pigmentation or varying abundance of pseudomorphs.

Discussion: Clast-shape and size indicate that these clasts belong to the same group of cherts as the dark, bioclastic cherts with Carboniferous fauna (Sect. 3.2.1.8). The presence of lenticular grains in matrices of microquartz resembles some evaporite facies but are quite distinct from clasts of Purbeck Formation origin. The lenticular pseudomorphs differ from the replaced dolomite/ankerite rhombs and do not appear to be organic in origin. The fine crystallite size of the matrices and the lack of matrix-orientation indicate that silicified volcanogenic, hydrothermal or vein rocks are also improbable sources. The clasts are tentatively interpreted as silicified evaporites. The laminated matrices and nodular textures are concordant with an evaporite origin but the absence of lutecite or quartzine replacements and the small size of the pseudomorphs leaves some doubt. The clasts bear little resemblance to Purbeck evaporites and are also dissimilar to silicified Permian and Triassic evaporites (Harrison, 1975; Tucker, 1975b).

The replacement fabrics in these clasts indicate that the pseudomorphs developed in mud-grade matrices, probably of carbonate. The silicified muds display evidence of primary sedimentary structures and partial dolomitization. The pebbles were probably derived from lagoonal or sabkha carbonates. British Devonian and

Dinantian evaporites and sabkha deposits are noted (Parnell, 1985, 1986; Llewellyn & Stabbins, 1970; Bhatt, 1976; Wright et al., 1981) and are possible sources of this material. The Devonian evaporites of the Orcadian Basin are unlikely to be source rocks for these pebbles and silicified Carboniferous evaporites are not known in Britain, but such rocks are reported in the Visean limestones of Belgium, Spitzbergen and Ireland (Swennen & Viaene, 1986; Hutchins, 1962; West et al., 1968). Carboniferous sabkha and evaporite deposits are present on the margins of massifs and cherts might be expected locally. Sources of silicified Carboniferous evaporites were possibly present on the margins of the Welsh and Anglo-Brabant Massifs. Evaporites are common in the Dinantian limestones of South Wales (Hird et al., 1987) and are also suggested to be present in limestones of similar age in southern England (Sonnenfeld, 1986).

3.2.4 Silicified wood phenoclasts

Rare phenoclasts of silicified plant matter are preserved in several of the horizons studied. The state of preservation is typically poor and the identification of source horizon is generally not possible (Sect. 3.2.4.4). However, three notable exceptions have been recognised. These clasts are similar to the silicified gymnospermous wood of P.Allen (1961; p.282).

3.2.4.1 White silicified wood

Description: A single light grey (N7) to very light grey (N8) silicified wood fragment. The clast collected was angular, bladed and 15mm in length. Limited rounding of the clast prior to deposition appears to have taken place.

The wood is composed of equant microquartz with organic filaments. The silicification preserves wood cells, 10-15μm in diameter, sub-spherical in shape and partially flattened (Pl. 14-6). Thickening of the cell walls is observed in an arcuate lineation perpendicular to the alignment of the tracheids. The wood contains well preserved ray cells. The quartz replacement of both cell types is sightly more coarsely crystalline than that replacing the wall material, but the silica fabric shows little other variation in the clast.

Discussion: The presence of growth rings, defined by the thickening of the cell walls and tightly packed bordered pits in this sample, resembles conifer wood (Dr. Jane Francis, pers. comm., 1985). Silicified wood is known from the Upper Carboniferous and Jurassic strata in Britain. Silicified Jurassic wood is relatively common in the basal Purbeck Formation in Dorset (Francis, 1983b) and is also found at intervals in the Wealden Beds and Lower Greensand Group but is rare (Francis, pers. comm., 1985).

The clast was collected from the Coarse Quartz Grit (Wessex Formation) in Dorset. The clast differs from the wood types commonly found in the Wealden Group (particularly Endogenites) and the lack of rounding suggests that derivation from Carboniferous sources is improbable. The clast was probably reworked from a Purbeck Formation source. Texturally, the pebble resembles Purbeck wood in the cell structure and the mode of silicification (Francis, pers. comm. 1985). Silicified wood is present in the Basal and Great Dirt Beds on the mainland of Dorset and the Isle of Portland, (Arkell, 1947a; Francis, 1983a). In an interpretation of the basal Purbeck environment, West (1975) considered trees to be restricted to swell areas. The Portland, Lulworth or some other local swell area, therefore, was the probable source of the detritus.

3.2.4.2 Partially silicified wood with possible shoot matter

Description: Black (N2) to dark grey (N3) pebbles of silicified wood. The clasts are angular to subangular and bladed to compact-bladed in shape. Striations elongate parallel to the clast-length are observed on the surface of the pebbles.

The wood fabrics are of two types; flattened tracheids (Pls. 14-7; 14-8) are not common but some clasts also contain small cells with thin cell walls (Pls. 14-5; 14-7). The wood fragments are composed of microflamboyant microquartz which infills the lumina and partially replaces the walls. Undulose megaquartz occurs dispersed throughout the silicified parts of some clasts. The megaquartz (70-110μm in length) cross-cuts the wood fabric and contains no inclusions. Cell walls are preserved by dark, reddish brown organic matter which also infills some of the cells. Calcite replacement of

the wood is in two forms:

1. poikilotopic calcite at the clast margins infills a number of cells. This is distinct from carbonate cement present in the host rocks of the clasts.
2. mosaic calcite spar with inclusions of organic matter replaces the filamentous cell structure in the clasts.

Discussion: The high carbonate and organic matter content in these clasts indicates that they are immature and unlikely to have been transported far from their source. A sample was examined by Dr. Francis who considered that the cell structures preserved in some parts of the clast resembled those of young shoots (Pls. 14-5, 14-7).

The clasts were collected from the middle Purbeck Formation, but were not found in association with silicified limestones. The source of the wood is therefore likely to be from local Upper Jurassic sources (basal Purbeck Formation) or from unidentified middle Purbeck Formation sources. Dr. Francis noted that the wood differed from that of the basal Purbeck Formation but resembled some Wealden Group or Lower Greensand Group material. This may favour a middle Purbeck Formation source.

3.2.4.3 Megaquartz-replaced wood

Description: A pebble of black (N1) chert with striated surface was collected. The clast is subrounded, compact-bladed and 14mm in length. Its surface is smooth and polished and has a faint lineation parallel to the clast length.

In thin-section, the clast was recognised as fossil wood with cells, 25μm in diameter and medullary rays up to eleven cells high. The wood is replaced by megaquartz (Pls. 14-9; 14-10), which is free from inclusions and replaces two or more cells. The crystallite sizes are related to the dimensions of the wood cells (Pl. 14-10). Cell walls are preserved as opaque inclusions or organic filaments.

Discussion: The pebble morphology indicates that the clast is probably not locally derived. The dark colouration of the wood results from minute opaque inclusions. Dr. Francis recognised uniseriate and biseriate rows of pits on the tracheid walls and noted

that the latter were characteristic of the conifer Araucarioxylon. The name Araucarioxylon is that commonly applied to Mesozoic wood of the Araucaria type. However, such wood is indistinguishable from the Palaeozoic wood Dadoxylon (Stewart, 1983).

The specimen was collected from the Carstone Member in the Isle of Wight. Rounded Carboniferous shelf chert pebbles and subangular, weathered Portland Limestone Formation chert pebbles are also found in this horizon. The difference in clast-morphology between this clast and those of Upper Jurassic origin and the possible Purbeck Formation wood clasts described above, suggests that the sample is from a different source. Lower and Middle Jurassic strata may contain wood of this type but other detrital clasts from such sources have not been recognised. The clast is probably of Carboniferous origin.

3.2.4.4 Miscellaneous silicified wood

Description: Pale grey (N7) to black (N1) coloured clasts of fossil wood. The pebbles are subrounded to rounded, bladed to compact-bladed and up to 15mm in length.

The pebbles are replaced by microflamboyant microquartz and contain faint traces of the original cell structure. Pits are rarely recognised but medullary rays eight to ten cells high are present in some clasts. The cells are 25-35μm in diameter. Replacement of the wood is by microflamboyant or equant microquartz which fills the cells.

Discussion: These clasts of poorly preserved wood are found in a number of the pebble beds. Preservation of the clasts is too poor to permit identification. Derivation of wood from the Middle Jurassic strata (Great Estuarine Group) of Yorkshire and the Anglo-Brabant Massif, is possible as is reworking of silicified material from Carboniferous sources flanking the Anglo-Brabant Massif. Pebbles of silicified wood are not easily identified and are not good indicators of detrital provenance.

3.2.5 Silicified bioclast phenoclasts

The selective replacement of bioclasts by silica has been considered previously by several workers (Jacka, 1974; Schmitt & Boyd, 1981; Holdaway & Clayton, 1982). Most noted the preferential silicification of brachiopods relative to other fossil fragments. Silica-replacement fabrics of British Jurassic and Carboniferous bioclasts were described by Wilson (1966) and Orme (1974) respectively.

Silicified bioclasts are common in chert pebbles but are rare as separate grains. Fragments of silicified crinoid ossicles from the Woburn Sands in Bedfordshire and silicified shell material from the basal Gault Clay Formation in Dorset have been collected. The crinoid fragments have similar fabrics to those described in Section 3.2.1.8. In contrast, the silicified shell debris has a distict fabric and is described below.

3.2.5.1 Silicified bivalve

Description: The clast is a translucent to dark grey (N3) laminated chert, subrounded, bladed and 48mm in length. In shape, the pebble is convexo-concave with lamination parallel to the pebble surface. The clast is unweathered but friable, fracturing parallel to the lamination. Small beekite rings, 1-2mm in diameter and light grey to white in colour, are observed on the pebble surface.

In thin-section, the clast has a finely laminated texture with bundles of arcuate laminae separated by crescent-shaped pores (Pl. 15-1). Laminae are replaced by spherulites of lutecite and quartzine and pores are partially filled by mosaic megaquartz (Pl. 15-2). Spherulite size and orientation are proportional to lamina thickness and alignment. The state of preservation of the original carbonate shell structure varies in the clast. Spherulites of lutecite contain inclusions of carbonate, elongated parallel to the clast length, and therefore preserve the original shell-wall fabric. Quartzine spherulites contain fewer inclusions and their shape does not closely match the original shell structure. Aggregates of length-slow microflamboyant microquartz, elongate parallel to the length of the clast, are common. In size and shape, the fibrous bundles are

PLATE 15

LIMESTONE AND SILICIFIED BIOCLAST FABRICS

PLATE 15

LIMESTONE AND SILICIFIED BIOCLAST FABRICS

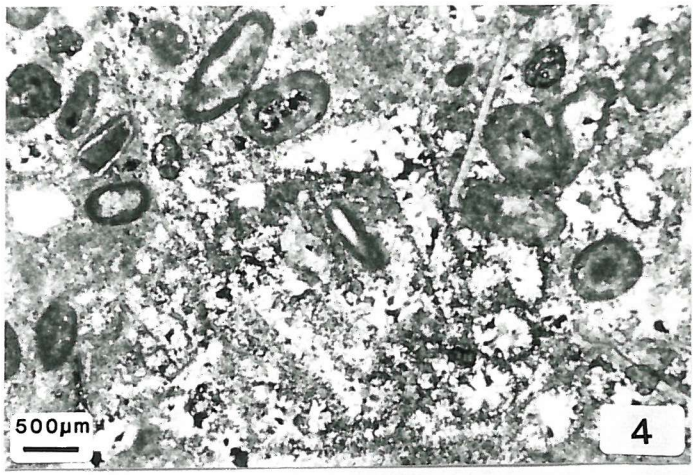
15-1. Silicified bivalve replaced by megaquartz and lutecite. Dissolution cavities in the shell are cemented by chalcedonite and megaquartz (bottom-centre).
Thin-section photomicrograph, cross-polarized light.
Pebble: Gault Clay Formation, Holworth House, Dorset.
Source: Portland Limestone Formation, the Portland Sand Formation or the Corallian Group, probably from the South Dorset High.

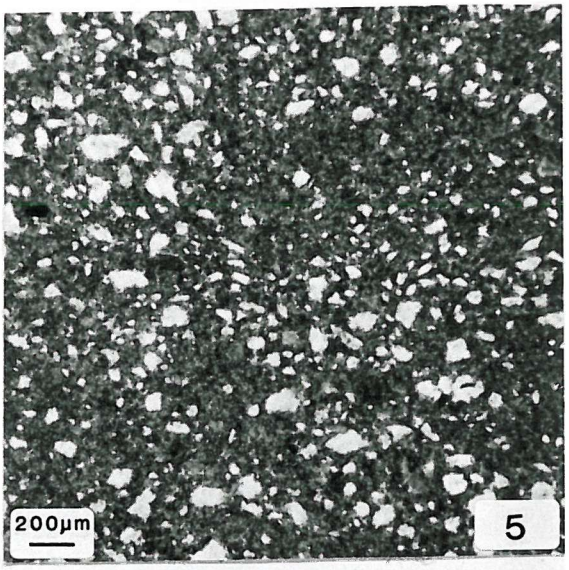
15-2. Quartzine or lutecite replacement of a bivalve shell.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Gault Clay Formation, Holworth House, Dorset.
Source: Portland Limestone Formation, the Portland Sand Formation or the Corallian Group, probably from the South Dorset High.

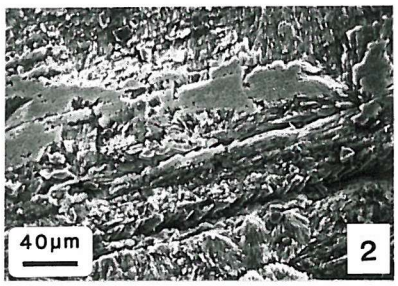
15-3. Cross-lamellae fabric, probably of aragonite replaced by chalcedonic silica.
Etched polished samples, S.E.M. photomicrograph.
Pebble: Gault Clay Formation, Holworth House, Dorset.
Source: Middle Purbeck Formation, probably from the South Dorset High.

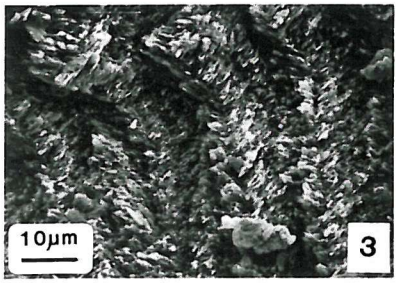
15-4. Partially silicified bioclastic and oolitic packstone. Pachastrella antiqua sponge spicule moulds (Centre) are cemented by mosaic megaquartz. The ooids are only partially silicified and contain micrite relics.
Thin-section photomicrograph, cross-polarized light.
Pebble: Faringdon Sponge Gravel, Wicklesham Pit, Faringdon, Oxfordshire.
Source: Corallian Group (possibly from the Upper or Lower Trigonia Beds).











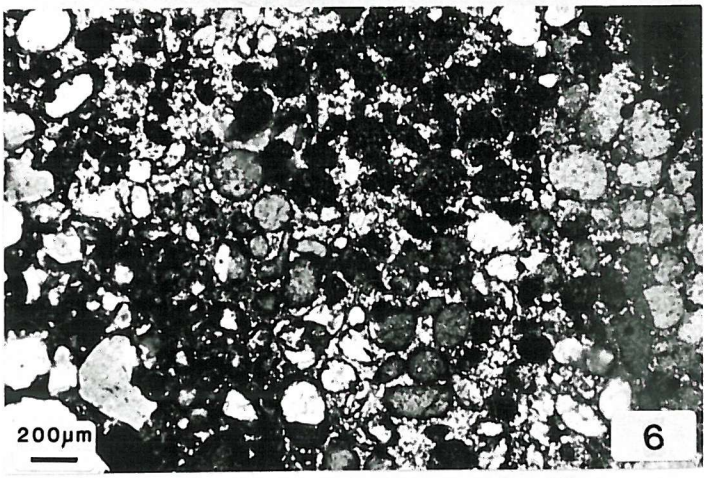


PLATE 15

15-5. Glauconitic sandstone with a ferroan-calcite microspar matrix. Thin-section photomicrograph, plane-polarized light.

Pebble: Faringdon Sponge Gravel, Wicklesham Pit, Faringdon, Oxfordshire.

Source: Corallian Group (possibly from the Calcareous Grit).

15-6. Oolitic grainstone with a finely crystalline megaquartz cement. The ooids have been totally dissolved which suggests that they were originally aragonitic. The resulting pores have been cemented by poikilotopic calcite.

Thin-section photomicrograph, cross-polarized light.

Pebble: "Unio" Member, Friar Waddon, Dorset.

Source: Portland Limestone Formation, possibly from the Winspit Member, probably from the South Dorset High.

similar to those of the original carbonate crystallites and the silica appears to have replaced the original crystallites individually.

Arcuate pores between the quartzine and lutecite sheaths are partially filled with megaquartz and low birefringence chalcedonite. The megaquartz is nucleated on the replacive lutecite and quartzine spherulites and projects into the pores with a mosaic or petaloid quartz fabric. Calcite inclusions are present in the megaquartz at the contact with the spherulitic silica.

Discussion: The ordering of the laminae and replacement fabrics in this clast are indicative of a silicified bioclast. The thickness of shell preserved (15-20mm) and the curvature of the laminae imply that the clast formed part of the umbo of a bivalve or a brachiopod. The preservation of the umbo may have resulted from its preferential silicification because of the higher proportion of organic matter in this part of the shell. The decay of organic sheaths, probably within the sulphate reducing zone, resulted in a local decrease in pH, causing dissolution of carbonate and precipitation of silica.

The good preservation of the shell fabric suggests that the replacement of the carbonate crystallite occurred individually. Replacement probably took place by a dissolution-precipitation mechanism similar to that proposed for aragonite-to-calcite neomorphism (Bathurst, 1975; p.481-483). In studies of petrified wood in which the fabric is similarly preserved by quartzine and lutecite, nucleation and growth of silica was controlled by organic matter (e.g. Schmitt & Boyd, 1981). The preservation of the original shell texture by silica suggests that organic sheaths coating carbonate crystals were influential in the initiation of silicification.

Selective silicification of bioclasts is noted in a number of limestones, including those of Carboniferous age (Green & Welch, 1965, p.17; Brunton, 1984), the Corallian Group (Wilson, 1966) and the Portland Limestone Formation (Wilson, 1966; Raisin, 1903). In the bioclast collected, the laminae are thicker than those common to the secondary layer of brachiopods and there is no evidence for preservation of a primary layer. The clast is therefore assumed to

be part of a silicified bivalve. The replacement fabrics are reminiscent of foliated calcite, a texture present in some bivalves (Bathurst, 1975, p.9). The pebble was collected from the basal Gault Clay Formation in Dorset, a horizon which contains appreciable amounts of Portland Limestone Formation chert detritus.

The shell thickness indicates that the bioclast was probably a Trigonid or an oyster. Foliated calcite is a fabric more typically found in the latter (Bathurst,1975, p.17-18).

3.2.6 Partially silicified limestone phenoclasts

Partially silicified limestones have textural similarities with some of the completely silicified limestones described above (Sect. 3.2.1), and may be found in association with such clasts. The presence of calcite relics in the clasts, however, indicates that in general they are significantly less mature. Three principal types of partially silicified limestone phenoclasts have been recognised.

3.2.6.1 Partially silicified oolitic grainstones and packstones

Description: Greyish yellow (5.Y.8/4) to dark yellowish orange (10.YR.6/6) pebbles and cobbles of partially silicified oolitic grainstone and packstone. The clasts are 50-200mm in length, subrounded to rounded and bladed in shape. Staining by goethite which browns the clast margins, leaves their cores grey. Clasts have bulb-shaped borings and are encrusted by bryozoa and serpulids. Borings are commonly present on all the surfaces of the pebbles.

The clasts are composed of ooids and bioclasts in microcrystalline quartz matrices or siliceous cement (Pl. 15-4). The matrices are composed of equant microquartz and include little or no argillaceous matter. Early calcite cementation occurred as finely crystalline granular fringes around the allochems and was enveloped by mosaic megaquartz cement. Cementing quartz has a mosaic habit and forms bladed fringes around the allochems and becoming more equant towards the pore centres. Pores not cemented by quartz are commonly filled with coarsely crystalline calcite spar.

The ooids are 250-500μm in diameter and are unsilicified or

partially silicified (Pl. 15-4). They are composed of non-ferroan micrite or equant microquartz. The micrite of the ooids forms tangential sheaths around sand or bioclast grains. Coarse to medium-grained quartz sand is plentiful in these clasts and glauconite is common. Quartz grains have syntaxial quartz overgrowths.

The oolitic limestones contain bioclasts in varying abundances. The main constituents are bivalves, echinoderms, brachiopods and foraminifera. Replacement of bivalves is by microflamboyant microquartz but in some examples the shell cores are composed of megaquartz cement. Generally, the brachiopod and echinoderm fragments are only partially silicified. Fracturing of brittle grains, grain-contact elongation and inter-grain penetration indicates that some compaction occurred prior to silicification.

Discussion: The preservation of primary fabrics in bivalves indicates that silicification of the limestones occurred prior to or contemporaneously with dissolution or inversion of aragonite to calcite. The absence of chalcedonic cements and partial silicification of the limestones suggests that the fluids associated with the replacement were not highly saturated with respect to silica. Quartz nucleation was therefore slow, enabling better ordering in the silica and the formation of megaquartz cements. Such conditions occurred in late-stage silicification in some limestones (Dapples, 1979). The replacement of the aragonite fabrics and the presence of only minor pre-silicification calcite fabrics, however, implies relatively early silicification. Grain-fringing calcite cements are typically of early marine origin.

In consideration of the size and roundness of the clasts, it is probable that the clast-source was close to the site of deposition. The fauna of the partially silicified oolites is similar to that found in many Jurassic limestones but is not distinctive. Silicification of limestones is known in the Corallian Group and Portland Limestone Formation in England and in the Bathonian and Bajocian limestones of northern France. Bajocian chert was noted in the Henfield borehole, Sussex (Taitt & Kent, 1958). All of these limestones contain oolites and might be considered as potential sources.

These clasts were found only in the Faringdon Sponge Gravel of Oxfordshire. This unit rests unconformably on the Corallian Group and Kimmeridge Clay Formation (Arkell, 1947b) and is not known to have overstepped onto the Middle Jurassic limestones in the local area. An Upper Jurassic source for the clasts is therefore probable. The Portland Group which contains oolitic cherts in Dorset, is less oolitic and contains only sparse cherts in Oxfordshire (Arkell, 1933a; Wimbledon, 1976). In contrast, the Corallian Group of Oxfordshire includes the oolites of the "Trigonia" Beds, Urchin Marls and Coral Rag and these beds are known to have undergone silicification locally (Wilson, 1966; Milodowski & Wilmot, 1984). Features such as the presence of coarse-grained quartz and glauconitic sand and a fauna including moderately abundant echinoids and foraminifera, are more indicative of a Corallian Group limestone rather than a Portland Group limestone source in Oxfordshire.

3.2.6.2 Partially silicified bioclastic packstones

Description: Light grey (N7) to pinkish grey (5.YR.8/1) clasts of bioclastic and peloidal packstone. The clasts are subangular to subrounded, bladed and 10-40mm in length.

The bioclastic packstones are composed of rounded skeletal fragments, some of which have oolitic coatings and irregular-shaped peloids supported in matrices of equant microquartz. The bioclasts include bivalves, bryozoa, echinoderm plates and sponge spicules. Siliceous replacement of the bioclasts is less common than replacement by mosaic calcite spar. The calcite contains no inclusions and in some examples extends beyond the shell boundary into the matrix. The spicules are small reniform bodies of Rhaxella or tetrads of Pachastrella antiqua. Spicules have fringes of microquartz on their margins and the centres are cemented by poikilotopic calcite. There is no evidence of collapse or compaction of the spicule moulds prior to cementation by calcite.

Discussion: The identification of Rhaxella and Pachastrella spicules in the partially silicified limestones indicates that the clasts are of Jurassic origin and probably derived from the Corallian Group or Portland Limestone Formation. The clasts are found in the

"Unio" Member of the Purbeck Formation, at Friar Waddon, Dorset and are associated with bioclastic chert pebbles of Portland Limestone Formation origin. Silicification in the Corallian Group of Dorset is limited and commonly postdates earlier carbonate cements (Wilson, 1966). In the bioclastic packstones however, it is the calcite cementation which postdates silicification. This, and the local abundance of Portlandian chert in Dorset, indicates that the partially silicified clasts were derived from the Portland Limestone Formation. These clasts resemble the limestones of the Portland Limestone Formation in the area to the north of Weymouth where they are dominated by lime mudstones and Rhaxella limestones, with few coarse-grained bioclastic or oolitic deposits (Fig. 3.2; Townson, 1975).

3.2.6.3 Bioclastic grainstones with siliceous cement

Description: Dark grey (N3) to greyish black (N2) bioclastic grainstones. Only one clast of this type has been found and it is bladed, subrounded and 9mm in length.

The chert contains comminuted bivalve fragments (100-300μm in length), echinoderm plates and sparse foraminifera. The bivalves are replaced by non-ferroan calcite spar which does not preserve the original shell fabric. Quartz sand is moderately abundant in the chert which also contains grains of glauconite. Mosaic megaquartz cements the shelly debris and partially replaces some of the bioclasts. The replacement silica destroyed the shell structure. Where quartz failed to cement the pores completely they remain unfilled.

Discussion: The clast was derived from a marine limestone. The faunal assemblage suggests that the source was probably of Jurassic age. The morphology of the clast indicates that the source was close to the site of deposition.

Silicification of Jurassic limestones in England is restricted principally to the Corallian Group and Portland Limestone Formation. This clast was collected from the Intermarine Member of the Purbeck Formation in Dorset and both the Corallian Group and the Portland Limestone Formation are possible sources.

The proportion of quartz and glauconite sand in the chert is greater than that commonly present in Portland Limestone Formation cherts but this is not indicative of a Corallian Group source. The form of the silicification in the clast is also not one commonly found in Portland Limestone Formation chert. Somewhat similar fabrics are found in oolitic chert detritus from the Portland Limestone Formation in the Gault Clay Formation (Sect. 3.2.1). On purely petrographic grounds it is not possible to distinguish between a Corallian Group and Portland Limestone Formation source. In Dorset, the greater abundance of chert in the Portland Limestone Formation implies that this was the more probable source.

3.2.7 Limestone phenoclasts

Extrabasinal pebbles of limestone are very rare in the Upper Jurassic and Lower Cretaceous rocks studied and such clasts have only been found at a few localities. This is principally a function of their relative weakness (e.g. Sneed & Folk, 1958), but may also imply that weathering conditions were unsuitable for the preservation of limestone clasts. Four types of limestone pebble have been identified.

3.2.7.1 Fossiliferous mudstones and wackestones

Description: White (N9) to very pale orange (10.YR.8/2) clasts of chalky, micritic limestone. The micrite pebbles and cobbles are platy to bladed, well-rounded to rounded and range in length from 20-90mm.

The clasts are composed of non-ferroan calcite microspar (5-8μm in diameter). The limestones are predominantly fossiliferous lime mudstones but include sparse bioclastic wackestones. The faunal remains include disarticulated bivalves, echinoderm plates and spines, brachiopods and foraminifera. Echinoderm plates are partially recrystallized at their margins and their stereome structures are infilled by microcrystalline opaque inclusions. Replacement of the bivalves is by neomorphic calcite.

Borings are common in the limestone clasts but the cavity-forming organisms are not found in situ. Two types of boring are recognised:

1. large bulb-shaped cavities, 10-30mm in diameter at the widest point and tapering to between 5mm and 8mm at the neck are the most common. Abrasion of the clasts, subsequent to boring, increased the diameters of the cavity necks;
2. sinuous tubular cavities, 0.5-2.0mm in diameter and up to 50mm in length.

The bored pebble surfaces were encrusted by bryozoa and serpulids following post-boring abrasion.

Discussion: The shape and size of the micritic limestone clasts indicates that they were initially rounded, bored, abraded further and subsequently encrusted. The pebbles were found in stratified bioclastic sands and were clearly transported following encrustation. The larger borings are of Gastrochaenolites-type and were produced by bivalves (Wilson, 1986). The smaller tubular cavities resemble polychaete borings (Warme, 1970).

The fauna of these pebbles indicates that they were derived from Jurassic marine limestones. Fossiliferous mudstone and wackestone pebbles have only been collected from the the Faringdon Sponge Gravel which overlies unconformably the Kimmeridge Clay Formation and the Corallian Group and is not known to overstep onto older Jurassic limestones. It is improbable that the limestone phenoclasts could have withstood prolonged transportation and therefore derivation from Upper Jurassic limestones is probable. The Portland Group does not subcrop below the Cretaceous deposits in this area and is therefore a less probable source than the Kimmeridge Clay Formation and Corallian Group limestones. The restricted fauna in the Portland Group (Townson, 1975; Ager, 1976) is also inconsistent with that observed in the pebbles and indicates that Portlandian limestones were probably not the pebble sources. The bioclastic mudstones and wackestones were probably derived from limestones of the Corallian Group or possibly from the Kimmeridge Clay Formation. These pebbles are similar to those from the same horizon described briefly by Wilson (1986).

3.2.7.2 Sandstones with carbonate matrices

Description: Pale yellowish orange (10.YR.8/6) to greyish yellow (5.Y.8/4) clasts of sandstone with calcareous matrices. The clasts are subrounded to rounded, bladed to platy and range in size from 20-100mm. Gastrochaenolites borings similar to those in the micritic limestones (Sect. 3.2.7.1) are present in these clasts but are not common.

In thin-section, two types of sandstone are recognised:
1. packstones and wackestones with non-ferroan microspar matrices,
2. ferroan calcite-cemented grainstones (Pl. 15-5).

Both sandstone types are medium-grained, glauconitic quartz arenites, with minor quantities of feldspar (1-3%), heavy minerals (less than 1%) and phosphorite (less than 1%). Bioclasts are rare and are replaced by neomorphic ferroan calcite. The fauna is dominated by bivalves and echinoderms.

The microspar matrices of the packstones and wackestones are composed of crystallites 4-8μm in diameter and appear to be aggraded neomorphic replacements of lime mud. The calcite cement of the grainstones has a mosaic habit and bladed calcite fringes on sand grains pass into equant spar at the pore centres.

Discussion: The sandstones are soft with calcareous matrices and it is improbable that they were transported far from their source. The predominance of bivalves, echinoderm plates and foraminifera in the sandstones indicates that they were derived from Jurassic marine deposits. The phenoclasts are found only in the Faringdon Sponge Gravel and therefore derivation from Upper Jurassic sources is probable (cf. Sect. 3.2.7.1). Calcareous sandstones are present in the Portland and Corallian Groups. The Portland Group sandstones and limestones were considered to have a less diverse fauna than the older Jurassic deposits (Townson, 1975) and it is improbable that the clasts were derived from such a source. The pebbles are similar to the calcite-cemented sandstones of the Calcareous Grit (Corallian Group) described by Milodowski & Wilmot (1984).

3.2.7.3 Bioclastic packstones and wackestones

Description: Yellowish grey (5.Y.7/2) to greyish yellow (5.Y.8/4) bioclastic limestones. The pebbles are cemented in a sandy limestone and their shape is not readily discernible. Cut sections indicate that the clasts are probably bladed to platy. Borings are not recognised.

The limestones are bioclastic packstones and wackestones with non-ferroan micrite matrices. The fauna of the clasts includes sponge spicules (Rhaxella and Pachastrella), bivalves and rare echinoderms, bryozoa, serpulids and foraminifera. Rhaxella spicules are common in the wackestones and Pachastrella spicules are more abundant in the packstones. Moulds of both spicule types are cemented by calcite spar. Bivalves are replaced by granular or finely crystalline bladed calcite. Oolitic coatings are observed on some bivalve fragments and the larger bioclasts are rounded.

Discussion: The faunal diversity of the limestones indicates that they were deposited in the marine environment, probably in relatively quiet conditions. However, the superficial coatings present on some bioclasts indicates that reworking of the grains occurred.

The presence of Rhaxella and Pachastrella spicules in the limestone clasts indicates that they were derived from a Jurassic source. Rhaxella spicules are found in the Bajocian and Bathonian limestones in England and Normandy but they are more common in limestones of the Upper Jurassic Corallian Group and Portland Limestone Formation. The Upper Jurassic limestones are not readily distinguished, but the limited faunal diversity in the limestone pebbles is more characteristic of the Portlandian limestones (Townson, 1975). The pebbles are from the "Unio" Member (Purbeck Formation) at Friar Waddon, Dorset and derivation from the western basin limestones of the Portland Limestone Formation (Winspit and Dancing Ledge Members, Fig 3.2; Townson, 1975) is probable.

3.2.7.4 Oolitic grainstones and packstones

Description: Dark grey (N3) to black (N1) oolitic grainstones and oolitic and bioclastic packstones. The pebbles are subrounded and

compact-bladed to compact and are up to 15mm in length.

The micritic ooids are 250-400μm in diameter and are concentrically laminated. Bioclasts and sand grains have thin oolitic coatings. The bioclasts are replaced by blocky neomorphic calcite. The oolites have micrite matrices or finely crystalline mosaic calcite cements.

Discussion: The oolitic grainstones and packstones contain few distinctive characteristics. The preservation of tangential fabrics and the absence of radial structures in the ooids is more typical of Jurassic limestones than Palaeozoic limestones (Wilkinson et al., 1985), but is not diagnostic. Similar fabrics were considered to be diagnostic of aragonitic ooids formed in high-energy environments (Strasser, 1986).

Limestone clasts rarely survive long distance transportation from their source and the pebble roundness suggests only limited reworking of the clasts. The pebbles were collected from the "Unio" Member (Purbeck Formation) at Stair Hole, Dorset and derivation from local Upper Jurassic limestones is probable. The sparsity of quartz sand grains and the tangential ooid fabrics are characteristic of oolites from the Portland Limestone Formation. The clasts were probably derived from the Winspit Member of swell facies (Fig. 3.2).

3.2.8 Sandstone and siltstone phenoclasts

Sandstone pebbles are ubiquitous in the pebble beds examined but are rarely common. Sandstones with calcareous, geothitic and phosphatic matrices are described in Sections 3.2.7.2, 3.2.9.5, 3.2.10.2 respectively. The four principal types of sandstone clasts without such matrices are described below. These pebbles resemble the clases defined as sedimentary quartzites grading to clastic quartzites by P.Allen (1967a; p.244-246, 252) and the quartzites of Wells & Gossling (1947; p.217-219).

3.2.8.1 Quartz arenites

Description: Yellowish grey (5.Y.8/1) to moderate red (5.R.4/6) pebbles of quartz arenite. The clasts are rounded to subangular,

compact-bladed to compact and up to 45mm long. The pebbles are well lithified with smooth, polished surfaces.

The quartz arenites have been separated into two groups:

1. undeformed quartzites. Medium- to fine-grained, subangular to subrounded, quartz arenites (Pl. 16-1). The quartz grains are predominantly unstrained and monocrystalline. If strained, grains have no common orientation. Feldspar grains are rare (less than 2%) and are frequently altered to sericite and microquartz. Muscovite is present in varying abundances (0-5%) and the quartzites grade into micaceous arenites. Lithic grains of cherty microquartz are present in trace amounts. The sandstones contain heavy minerals in trace amounts. These are principally tourmaline and zircon.

   Compaction in these arenites is indicated by elongated grain contacts but appears to have been of minor importance in the destruction of primary porosity. Pores are infilled by syntaxial quartz overgrowths. Argillaceous and carbonate cements were not found and there is no evidence for the replacement of earlier cements.

2. deformed quartzites. Moderately-sorted, medium-grained quartz arenites. Quartz grains exhibit undulose extinction and fluid-inclusion trails pass from one grain to the next. More deformed clasts resemble cataclasites with poorly developed fabrics. Grain contacts appear to be pressure-solution surfaces and quartz overgrowths are rare. Cherty grains of microquartz are present in minor quantities (less than 5%). The microquartz aggregates are of a similar size to the quartz grains and some contain minute flakes of sericite. The grains are probably silicified volcanics. Heavy minerals are sparse (less than 1%).

Discussion: Quartzite pebbles are rarely found in abundance in the pebble beds studied and are generally small and well rounded. This suggests that quartzite sources were scarce during Jurassic and Cretaceous times. The rounding probably indicates reworking from older pebble beds.

Few characteristic features exist in the quartzites apart from

PLATE 16

SANDSTONE AND SILTSTONE FABRICS

PLATE 16

SANDSTONE AND SILTSTONE FABRICS

16-1. Quartz arenite. Medium-grained quartzite with much of the primary porosity occluded by quartz overgrowths.
Thin-section photomicrograph, cross-polarized light.
Pebble: Gault Clay Formation, Hardene Wood, Wiltshire.
Source: Lower Palaeozoic or Precambrian quartzite, probably from the Welsh or Anglo-Brabant Massifs.

16-2. Quartz siltite. The siltstone is composed of interlocked quartz with scattered larger grains of medium-sand grade quartz.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight.
Source: Probably a Lower Palaeozoic siltstone from the Welsh or Anglo-Brabant Massifs.

16-3. Poorly sorted lithic arenite. Note the larger grains are predominantly of strained and polycrystalline quartz.
Thin-section photomicrograph, cross-polarized light.
Pebble: Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight.
Source: Lower Palaeozoic sandstone, probably from the Welsh or Anglo-Brabant Massifs.

16-4. Medium-grained, lithic arenite. The lithic grains are altered to microcrystalline quartz and sericite.
Thin-section photomicrograph, plane-polarized light.
Pebble: Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight.
Source: Lower Palaeozoic or Precambrian sandstone, probably from the Welsh or Cornubian Massifs.

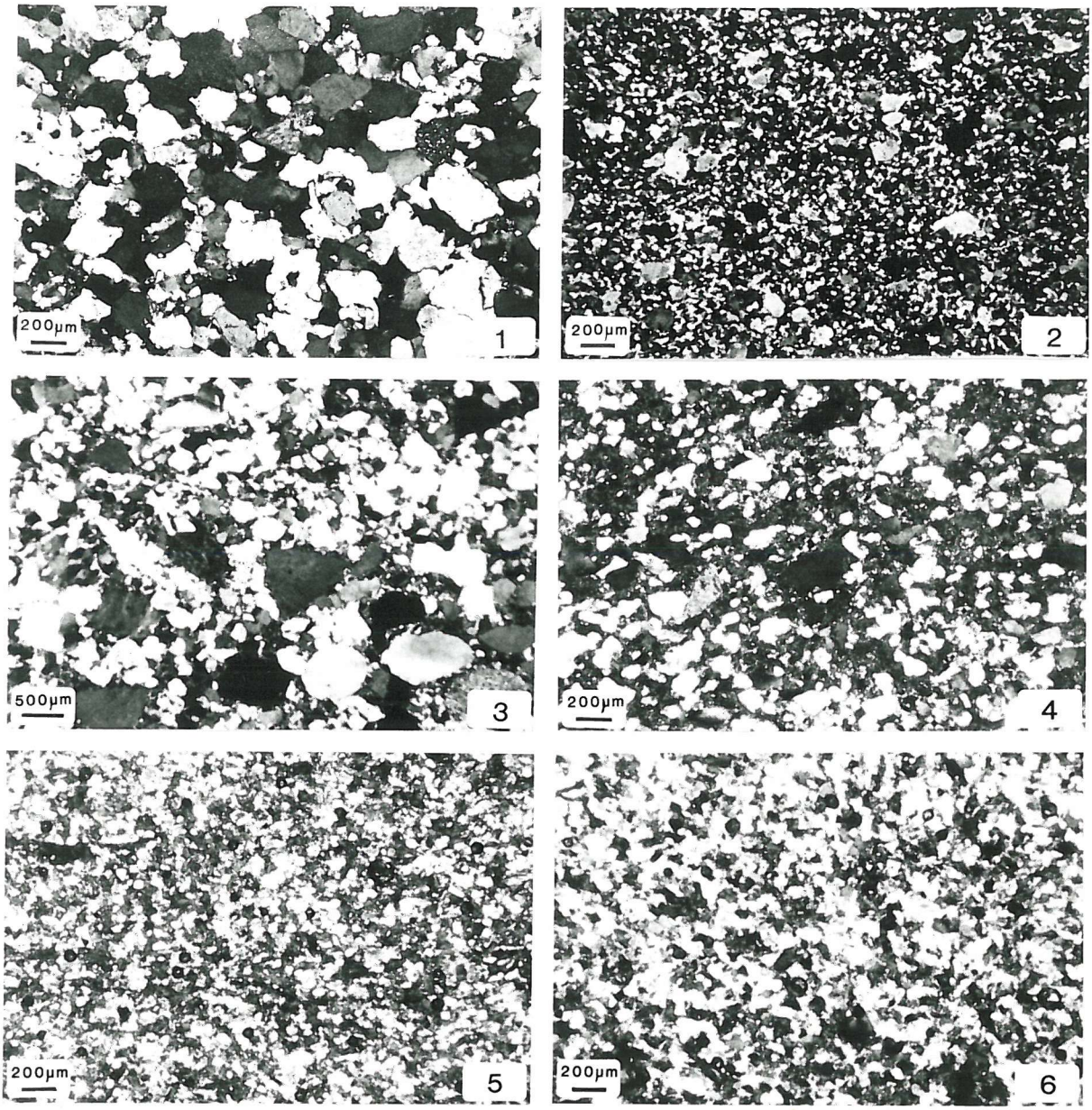


PLATE 16

16-5. Very fine-grained micaceous arenite. Glauconitization of the pebble has caused the replacement of micas.
Thin-section photomicrograph, plane-polarized light.
Pebble: Folkestone Beds Formation, Folkestone, Kent.
Source: Silurian or Devonian sandstone, probably from the Anglo-Brabant Massif.

16-6. Tightly cemented fine-grained micaceous arenite. The clast is composed of quartz, muscovite and altered lithic grains. Porosity has been destroyed by compaction and quartz cementation.
Thin-section photomicrograph, cross-polarized light.
Pebble: Folkestone Beds Formation, Folkestone, Kent.
Source: Silurian or Devonian sandstone, probably from the Anglo-Brabant Massif.

the distinction between deformed and undeformed types. The maturity of the sands indicates that they were reworked or underwent intense weathering prior to burial and cementation. The preservation of evidence for limited compaction in the undeformed quartzites indicates that they are unlikely to have formed by diagenetic maturation of the sandstone (Shanmugam, 1985). Exposed quartzites of Jurassic age are not common in Britain and those in the Permo-Trias are typically distinctive (grain-rimming haematitised clay; millet-seed sandstones). A number of Lower Palaeozoic and Precambrian quartzite outcrops exist in southern Britain and the surrounding area and these are the probable sources.

Sources for the undeformed quartzites are present in the Cambro-Ordovician of the English Midlands (Lickey, Wrekin and Nuneaton Quartzites) and the northwest of Scotland. Quartzites are also known in the Ordovician and Silurian of the Welsh Borders (Cowie et al., 1972). The Upper Devonian strata of Devon contains quartzites and Devonian quartzite probably also existed on the margins of the Anglo-Brabant and Welsh Massifs. Pebbles of quartzite are noted in the Devonian pebble beds of South Wales and the Welsh Borders (J.R.L.Allen, 1974, 1975).

Only the deformed quartzites display evidence of being derived from a metamorphic area and even these lithotypes are not highly deformed. Deformed quartzite clasts are commonest in Dorset where they are associated with detritus derived from Cornubia and Armorica (Kirkaldy, 1947a; P.Allen, 1972; and Sects. 3.2.11, 3.2.12, 3.2.15).

In the exposed rocks of southwest England, quartzites are reported in the Upper Devonian of north Devon (Edmonds et al., 1979). The Devonian quartzites have quartz overgrowths, but the grains are unstrained or were strained prior to incorporation in the sandstone (Edmonds et al., 1979). This suggests that they were improbable sources for the deformed quartzite pebbles in Dorset.

The Lower Palaeozoic quartzites of northwest France (e.g. Grēs Armorican and Grēs de May) were deformed in the Variscan Orogeny and are possible sources for detritus in southwest England. The clasts were either derived direct from source or were reworked from older pebble beds. The quartzite pebbles in the Triassic Budleigh

Salterton and Kidderminster Conglomerates were considered by Wills (1956) to have been derived from Armorica and could therefore have been the source of the younger pebble beds. The low abundance of quartzite pebbles in the Cretaceous pebble beds and the scarcity of reddened clasts, however, suggests that the Triassic pebble beds were not significant detrital contributors.

In the absence of any indicators as to the precise source of the quartzite, few of these possible sources can be discounted. Nor can the possibility of reworking from older pebble beds (Devonian or Triassic) be ignored.

3.2.8.2 Lithic arenites (including lithic, litho-feldspathic and sublithic arenites)

Description: Dark grey (N3) to yellowish grey (5.Y.8/1) and occasionally greyish orange (10.YR.7/4) sandstone pebbles. The clasts are rounded to subangular, bladed to compact and 4-40mm in length. In some cases, weathering of the clasts has resulted in reddening and the development of a friable texture. These pebbles resemble the lithic ?pelletal sandstones/quartzites which grade to 'subgreywackes' described by P.Allen (1967a; p.246-249).

The sandstones are composed of 60-70% quartz (principally of monocrystalline quartz) with lithic grains of microquartz, illite and chlorite (Pl. 16-3, 16-4). The quartz grains are subangular to subrounded and medium to fine-grained. A number of clasts have a bimodal grain-size distribution and contain coarse to medium-grained sand in association with fine sand to silt-grade detritus (Pl. 16-3). The coarser grained fractions are commonly concentrated in laminae.

Quartz grains have diagenetic overgrowths which partially or completely cement pores. Pressure-solution contacts are developed in some clasts, but straining of the quartz is not pronounced and is possibly inherited. Grains of biotite are rare in most of the arenites, but muscovite is abundant in some clasts. The mica grains are 150-250μm in length and are partially altered.

Goethite-replacement of mica grains is common. Heavy minerals tend to be rounded to subrounded and are predominantly of tourmaline and zircon. The lithic grains are of microquartz with fine illite flakes and minute inclusions of quartz or feldspar (20-50μm in diameter). The quartz and feldspar are more coarse-grained than the surrounding microcrystalline groundmass. The lithic grains are possibly silicified volcanics or diagenetically altered mudstones. Pellets of vermiform chlorite which are possibly altered basic volcanic fragments or mafic minerals are present in some clasts.

Discussion: Lithic arenites have a high quartz content and also contain appreciable quantities of rock fragments, probably of volcanic origin. The abundance of cherty lithic grains indicates that although the sandstones are classified as lithic and sublithic arenites, they are compositionally mature.

The absence of deformed grains suggests that the pebbles were not derived from a metamorphic source. The highly lithified state of these clasts is inconsistent with derivation from Mesozoic sandstones and the probable source was the Palaeozoic sedimentary rocks of England and Wales. The absence of an included fauna precludes identification of the precise source. Lithic and sublithic arenites are present in low abundance in many of the pebble beds studied but are common in the Lower Greensand Group of the eastern Weald Basin. Palaeozoic sedimentary rocks subcropping beneath the Mesozoic strata to the north are likely sources. Reworking from older pebble beds, in particular those of Devonian age is probable (P.Allen, 1967a).

3.2.8.3 Micaceous arenites

Description: Pinkish grey (5.YR.8/1) to moderate red (5.R.4/6) and occasionally greenish grey (5.GY.6/1) clasts of laminated micaceous sandstone. The pebbles are subangular to rounded, platy to compact and 4-35mm in length (average less than 12mm). Fracturing along micaceous laminae is common. The grains are of fine-grained sand to coarse-grained silt. These pebbles are similar to the micaceous quartz-sandstones and siltstones which grade into 'subgreywackes' of P.Allen (1967a, p.246-249, 252) and the siltstones of Wells & Gossling (1948, p.219-222).

The arenites are composed of quartz (85-95%) with variable amounts of muscovite (5-10%). Feldspar and lithic grains are present in low abundance (1-2%) and heavy minerals are sparse (Pls. 16-5; 16-6). The quartz sand grains are elongate to compact in shape. Quartz overgrowths are recognised on some grains but are not readily identifiable. Mica grains occur in two forms, thin plates, 150-200μm long and thicker prismatic grains, 100μm long and 70-80μm in thickness. The latter are commonly splayed and partially kaolinitised along cleavage planes. The laminae in the sandstones are the result of quartz and mica alignment.

The red colouration of the clasts is seen only in some of the pebble beds. In the Lower Greensand Group suite of Kent, the colouration is commonly less intense towards the clast centres.

Discussion: Micaceous arenites are found in small quantities in most areas but are common in the pebbly Lower Greensand Group deposits of the eastern Weald. It is in the Lower Greensand Group sandstones of Kent that the reddened clasts are found. The decrease in iron staining towards the grain centres indicates that the colouration results from weathering in the pebble beds and does not necessarily indicate derivation from a "red bed" sequence.

The laminated sandstones are compositionally mature. They lack evidence of being deformed, but have some pressure-solution features and are quartz cemented. The well-lithified state of these clasts indicates that they are probably of Palaeozoic origin. The micaceous arenites in the Lower Greensand Group of Kent were probably derived from the Palaeozoic basement on the Anglo-Brabant Massif. Chaloner & Richardson (1977) reported Devonian micaceous sands in some of the borings around London and these are probable sources. Ordovician and Silurian rocks on the Massif also contain sandstones (Ziegler et al., 1974) but there is little information concerning their petrography.

3.2.8.4 Siltstones

Description: Light grey (N7) to medium grey (N5) pebbles of quartz siltstone. The pebbles are subangular to rounded, bladed to compact and up to 35mm in length. Clast surfaces are typically polished with small percussion marks. Staining of clasts is occasionally observed.

The clasts resemble the micaceous quartz-sandstones and quartz siltstones which grade to 'subgreywackes' of P.Allen (1967a, p.246-249, 252), and the siltstones of Wells & Gossling (1947, p.219).

The pebbles are composed of quartz (greater than 90%), with accessory muscovite, feldspar and heavy minerals. Feldspar in the clasts is commonly altered. Mica may represent up to 5% of the detrital grains and is generally aligned and concentrated in laminae. The quartz grains are equant in shape and have an interlocking fabric. Quartz overgrowths were not recognised and the quartz grains were not strained. Occasionally siltstone clasts have bimodal grain-size distribution, with medium to fine-grained quartz sand supported in a matrix of quartz silt (Pl. 16-2).

Discussion: The siltstones are mature siliciclastics and compositionally resemble the undeformed quartzites. The absence of quartz overgrowths results from the difficulty in recognising such features in fine-grained lithotypes. Pressure-solution, however, may be more effective in destroying the primary interparticle porosity in the siltstones (Nagtegaal, 1978).

The absence of deformation features such as quartz veining and undulose extinction indicates that the clasts are probably from undeformed source areas. The well-lithified fabric suggests Palaeozoic rather than Jurassic sources. The clasts were found in small quantities in a number of pebble beds and were probably derived from more than one source area.

3.2.9 Ironstone phenoclasts

Clasts composed of microcrystalline goethite are present in many of the Lower Cretaceous pebbly sandstones of marine origin and are particularly abundant in sands with goethite ooids. The ironstone clasts have been separated into five principal types. Similar clasts were described as ironstone pebbles by Wells & Gossling (1947, p.213).

3.2.9.1 Microcrystalline homogeneous ironstones

Description: Dark reddish brown (2.9.R.3/4) to dusky red (5.R.3/4) pebbles and cobbles of microcrystalline goethite. The clasts are subrounded to angular, bladed to compact-bladed and up to 70mm in length.

X.R.D. analysis indicates that the clasts are composed of goethite. In thin-section, the goethite is seen to be micro or cryptocrystalline with a mottled texture. Minor amounts of quartz and phyllosilicate silt are present in the clasts and are occasionally aligned. S.E.M. investigations reveal that the goethite is composed of tabular to equant prisms, 2-5μm in length.

Discussion: The size and roundness of these clasts indicates that they were not transported great distances and were probably locally derived. The absence of bioclasts in the pebbles hinders identification of the source, but the association with other clasts may provide an indication of origin. The ironstone pebbles are commonly found in sandstones with abundant goethitic oolites. Ooids are occasionally present in the pebbles and this suggests a similar source for both. The ironstone clasts and ooids are restricted stratigraphically and it is improbable that they are reworked from significantly older formations. However, in horizons with locally derived material from mud-rich sources (e.g. Ferruginous Sands Formation), reworking of ironstone concretions from underlying rocks cannot be discounted.

The origin of sedimentary ironstones is still unresolved. Three modes of formation are favoured at present:

1. pedogenic origin was suggested by Siehl & Thein (1978),
2. early diagenetic formation in estuarine or restricted marine-shelf sediments was favoured by Van Houten & Bhattacharyya (1982),and
3. formation by the replacement of carbonate precursors was proposed by Kimberley (1979).

The detrital clasts examined contain no evidence for the replacement of carbonate lithotypes but the distinction between pedogenic and marine sources is not possible. The association with oolitic ironstones and goethite-cemented sandstones with detrital

sedimentary fabrics suggests that reworking in a subaqueous environment following formation is probable.

3.2.9.2 Ferruginous oolitic packstones

Description: Dusky red (5.R.3/4) to blackish red (5.R.2/2) pebbles of goethitic ooids in microcrystalline ferruginous matrices. The clasts are very angular to subrounded, bladed to compact-bladed and up to 25mm in length. The ooids are dissected on clast-surfaces or more commonly are plucked from the clast, leaving small semi-ovoid pits.

The pebbles are composed of goethite ooids, 350-475μm in diameter, set in matrices of microcrystalline goethite (Pls. 17-1, 17-2, 17-3, 17-4). Ooids are ovoid to spherical in shape and are composed of tangential sheaths of microcrystalline goethite (Pls. 17-1, 17-4, 17-5, 17-6). The nuclei of the ooids include berthierine/chamosite or goethite pellets, replaced bioclasts and fine-grained quartz sand. Broken ooids are sparse in the pebbles but some such grains have post-breakage concentric coatings. The oolites are predominantly packstones or occasionally wackestones.

Discussion: The goethite ooids have tangential fabrics similar to recent marine aragonitic ooids of Bahamian type. In carbonates, such fabrics are considered to result from an accretionary process or from modification of early diagenetic growth by attrition (Bathurst, 1975). Similar mechanisms were probably of importance in the formation of the goethitic ooids. Carbonate inclusions were not present and the ironstones are unlikely to be replaced limestones as suggested by Sorby (1856) and Kimberley (1974, 1979). The absence of radial fabrics, such as those seen in bauxite peloids, was considered by Bhattacharyya & Kakimoto (1982) to distinguish the subaqueous ferruginous ooids from pedogenic pisolites.

The microcrystalline goethite matrices are either ferruginous replacements of detrital mud or microcrystalline cements. In the detrital clasts, there is little evidence to distinguish between the two. The presence of detrital quartz grains and the absence of coarsely bladed goethitic cements supports a sedimentary origin for the matrices.

PLATE 17

OOLITIC IRONSTONES

PLATE 17

OOLITIC IRONSTONES

17-1. Goethite ooids in a microcrystalline goethite matrix. Note the tangential fabrics of the ooids and their compact-bladed shape. Polished sample photomicrograph, reflected light.

17-2. Goethite ooids in a microcrystalline goethite matrix. Note the peeling of tangential sheaths from the ooid.
S.E.M. photomicrograph.

17-3. Broken goethite ooids with tangential fabrics. The ooids are set within a structureless microcrystalline goethite matrix.
S.E.M. photomicrograph.

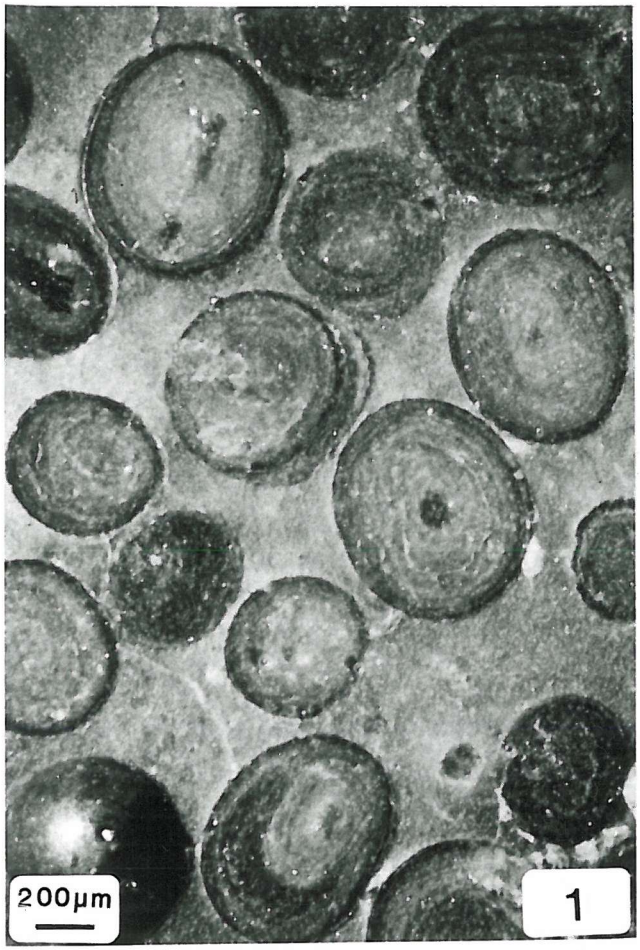
17-4. A broken goethite ooid with a tangential fabric. Note the weak alignment of the microcrystalline goethite in the ooid parallel to the ooid margin.
S.E.M. photomicrograph.

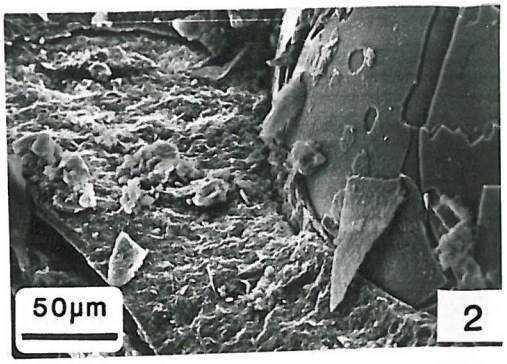
17-5. Tangential lamination in a goethite ooid. Note the absence of orientated goethite in this sample and the well developed lamination caused by variations in the extent of lithification.
S.E.M. photomicrograph.

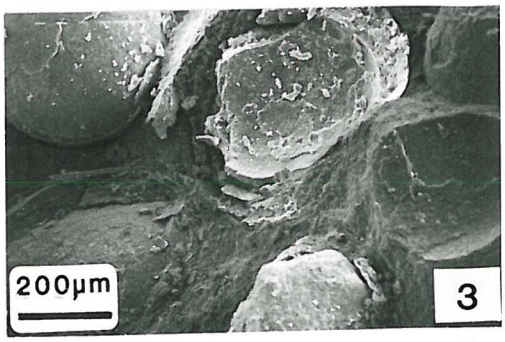
17-6. Equant and structureless microcrystalline goethite replacement of an ooid lamina. Note the absence of orientated goethite in the lamina.
S.E.M. photomicrograph.

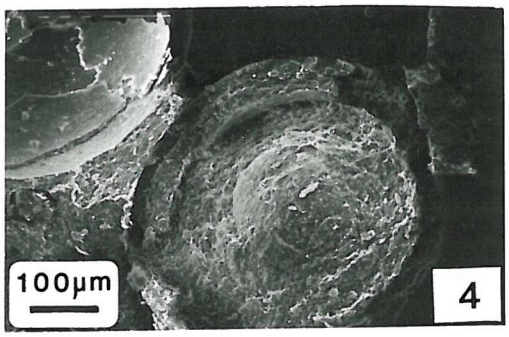
All the samples depicted in Plates 17-1 to 17-6 are pebbles from the Carstone Member, Nettleton Bottom, Lincolnshire.

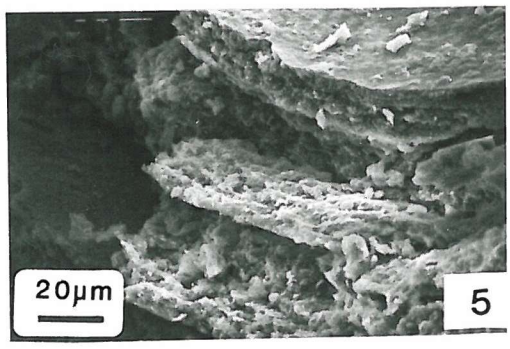
Source: Contemporaneous or other Lower Cretaceous deposits, East Midlands Shelf.











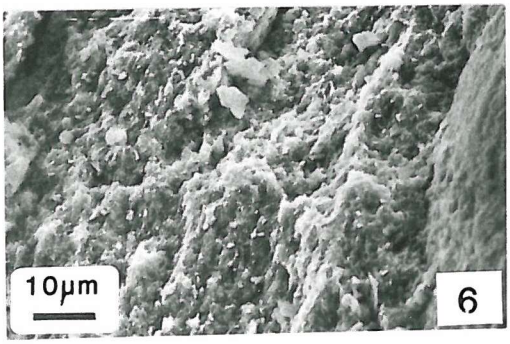


PLATE 17

The ferruginous oolite clasts are found in the Carstone Member of the East Midlands, but are rare in the other pebble beds. Goethitic ooid grains are common in the Sandgate Beds Formation, Folkestone Beds Formation, Ferruginous Sands Formation and the Carstone Member in the south of England and the Claxby Ironstone Formation and Roach Formation in the East Midlands.

The roundness of ferruginous oolite clasts in the Carstone Member of the East Midlands indicates that the pebbles did not undergo appreciable abrasion and are unlikely to have been transported far from their source. The ooid fabrics of these clasts differ from those seen in the Jurassic ironstones (Taylor, 1949) and derivation from such source rocks in eastern England is improbable. The Claxby Ironstone Formation, Roach Formation and the Sandringham Sands Formation contain goethitic ooids and concretionary ironstones and are possible sources for the Carstone Member clasts. However, rounded phosphorite clasts of probable Lower Cretaceous origin are also present in the Carstone Member (Sect. 4.7.4). The difference in roundness cannot be fully explained by differences in clast hardness and reworking of contemporaneous ironstone deposits is likely.

Hallam & Bradshaw (1979) suggested that oolitic ironstone formed in the marine environment where the influx of terrigenous detritus was minimal; ironstone formation taking place in sheltered areas between sand banks or ridges. The sedimentological characteristics of the Carstone Member are consistent with those of sand-ridge complex deposits (Sect. 2.2.6.3; Gallois & Morter, 1982). Ridge-migration, therefore, possibly resulted in erosion of inter-ridge deposits and the formation of ironstone pebbles.

3.2.9.3 Goethitic bioclast casts

Description: Dark reddish brown (2.9.R.3/4) to blackish red (5.R.2/2) bioclasts. The bioclasts are generally well-preserved with little evidence of abrasion or rounding. The clasts range up to 20mm in length.

The bioclasts are composed of microcrystalline goethite without sand or silt grains. Ammonites are the most common type of fossil cast preserved but belemnite phragmacones and gastropods were also

found. The ammonites are commonly broken with only part of the whorls preserved. Identification is possible and examples of Creniceras cf. renggeri, Cardioceras and Quenstedtoceras cf. williamsoni have been recognised (Pl. 20-8). The fragment of belemnite phragmacone (Pl. 18-1) has few characteristic features and was not identified.

The goethite bioclast casts are composed of microcrystalline goethite which displays several fabrics. The ammonite whorls were found to contain two fabrics:

1. the shell was replaced by homogeneous microcrystalline goethite (Pls. 18-3, 18-4),
2. the camerae are filled with "spongy" goethite (Pls. 18-3, 18-4), with cubic or rhombohedral-shaped pores (5-10μm in diameter) surrounded by bladed goethite (Pl. 18-5). The goethite blades (1-2μm in length) project into the pores but do not totally cement them.

The goethite belemnite phragmacone is composed of microcrystalline goethite which partially fills the chambers but does not replace the septa (Pl. 18-2). Where the chambers are only partially infilled, goethite pseudomorphs project into the pore-space (Pls. 18-2, 19-1, 19-2). The pseudomorphs are euhedral (20-50μm in diameter) and have a cubic habit. The euhedra are composed of microcrystalline goethite (Pls. 19-3, 19-4) and in some cases are hollow (Pl. 19-4) and partially cemented by bladed goethite (Pl. 19-4). The main chamber-fill is by granular goethite (20-25μm in diameter) surrounded by bladed goethite (Pls. 19-1, 19-5).

A further feature recognised in the belemnite phragmacone was the presence of filamentous goethite. The filaments are present only in partially filled chambers where they drape euhedral pseudomorphs (Pls. 19-3, 19-6, 19-7). These structures are composed of microcrystalliine goethite (Pl. 19-8), similar to that replacing the euhedra (Pl. 19-3).

Discussion: The ammonite casts are found in the Bargate Beds Formation of the northwest Weald. This derived fauna was described previously by Arkell (1939b) who noted that most of the clasts were reworked from the mariae Zone of the Oxford Clay Formation, with

PLATE 18

GOETHITE-REPLACED BIOCLAST FABRICS

PLATE 18

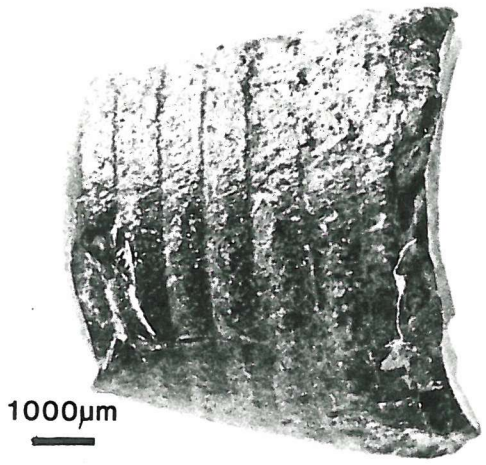
GOETHITE-REPLACED BIOCLAST FABRICS

18-1. Goethite cast of a belemnite phragmacone. Note the traces of the septa and the goethite-cement infilling the chambers between the septa.
Hand-specimen photograph, reflected light.
Pebble: Folkestone Beds Formation, Chilworth, Surrey.
Source: Upper Jurassic pyrite nodule, probably from the Oxford Clay Formation, probably from the Hog's Back High.

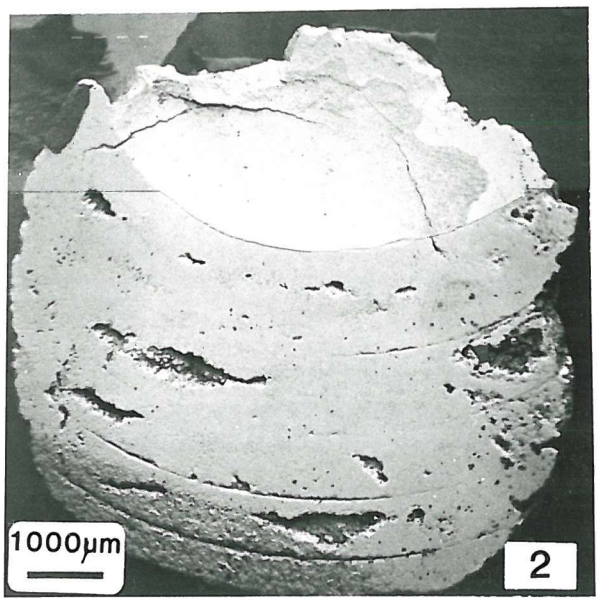
18-2. Section through the belemnite phragmacone in Plate 18-1. Note the partially filled chambers and the unfilled moulds after septa (bottom).
Polished sample, S.E.M. photomicrograph (backscatter image).
Pebble: Folkestone Beds Formation, Chilworth, Surrey.
Source: Upper Jurassic pyrite nodule, probably from the Oxford Clay Formation on the Hog's Back High.

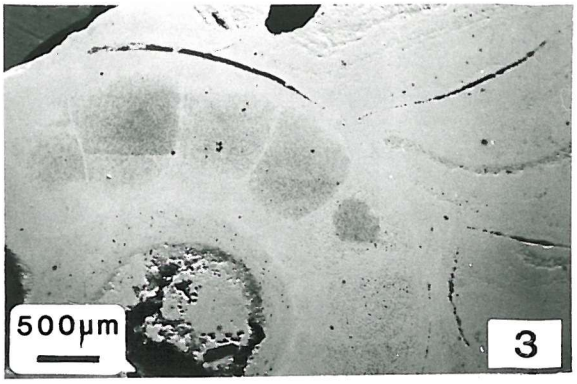
18-3. Ammonite protoconch replaced by goethite. The septa are replaced by homogeneous microcrystalline goethite and the chambers are filled with porous goethite.
Polished sample, S.E.M. photomicrograph (backscatter image).
Pebble: Bargate Beds Formation, Compton, Surrey.
Source: Oxford Clay Formation, probably from the Hog's Back High.

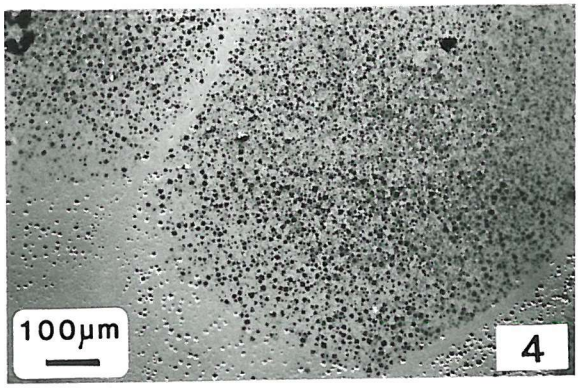
18-4. Goethite cement in an ammonite chamber. Note the variation in the porous texture across the chamber cement. In the centre, the cement contains unfilled pores, but at the bottom the pores are largely filled with goethite.
Polished sample, S.E.M. photomicrograph (backscatter image).
Pebble: Bargate Beds Formation, Compton, Surrey.
Source: Oxford Clay Formation, probably from the Hog's Back High.



1







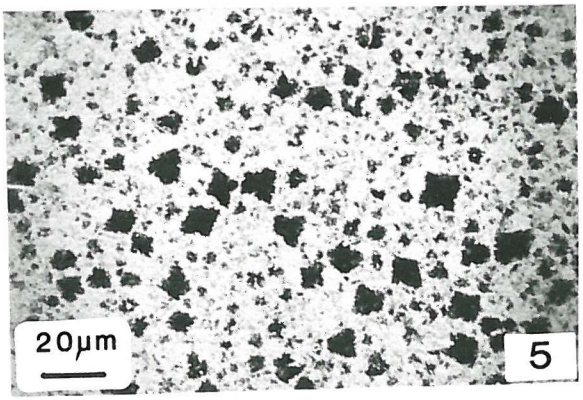


PLATE 18

18-5. Euhedral cubic moulds, probably after pyrite, in the ammonite chamber cement (Pls. 18-3, 18-4). Note the bladed goethite fringing the moulds.

Polished sample, S.E.M. photomicrograph (backscatter image).

Pebble: Bargate Beds Formation, Compton, Surrey.

Source: Oxford Clay Formation, probably from the Hog's Back High.

PLATE 19

GOETHITE-REPLACED BIOCLAST FABRICS

PLATE 19

GOETHITE-REPLACED BIOCLAST FABRICS

19-1. Octahedral pseudomorphs of goethite after pyrite, partially cementing a belemnite phragmacone chamber (Pls. 18-1, 18-2). Note the spherical-shaped masses with surrounding blades (Pl. 19-5) which form the chamber fill on either side of the pore (top).

19-2. Partially filled phragmacone chamber. The septum (top left) is not preserved and the chamber is largely filled with spherical masses (centre) which pass into euhedral pseudomorphs where the chamber has remained unfilled (centre and bottom right).

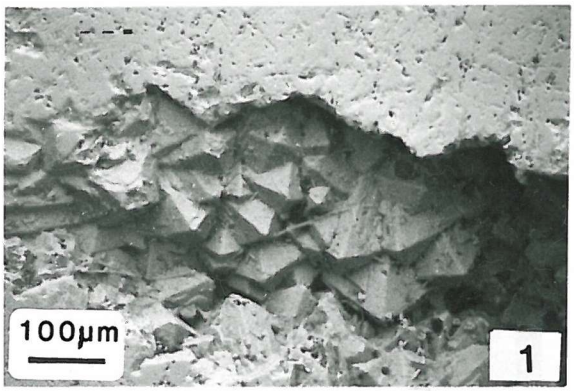
19-3. Goethite pseudomorphs after octahedral pyrite. The replacement goethite is finely crystalline and has a microgranular texture. Note the filamentous structures (Pl. 19-7, 19-8) draping the octahedra (centre).

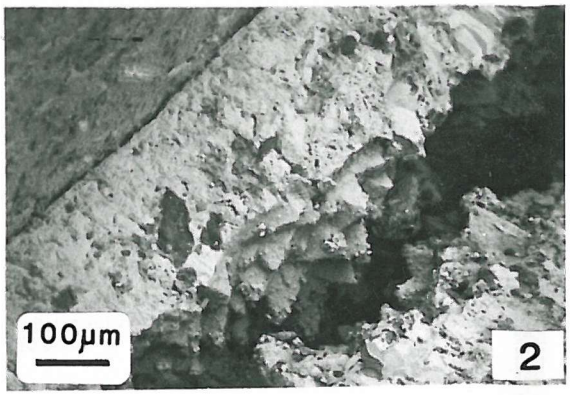
19-4. Dissected hollow octahedral pseudomorph. The margins of the octahedra are replaced by microcrystalline goethite; the centre of the euhedra is partially cemented by bladed goethite.

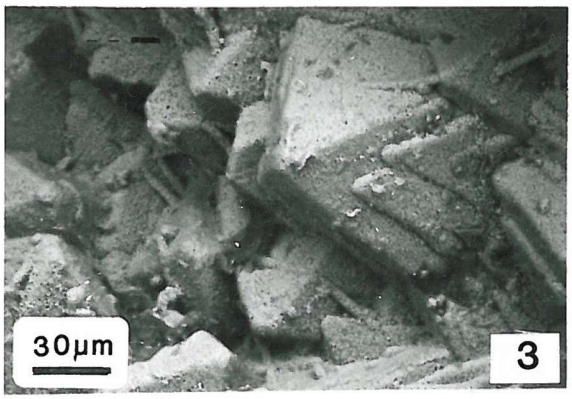
19-5. Goethite pseudomorphs probably after framboidal and lenticular pyrite. These form the principal cement phase in the belemnite phragmacone chambers (Pl. 19-1).

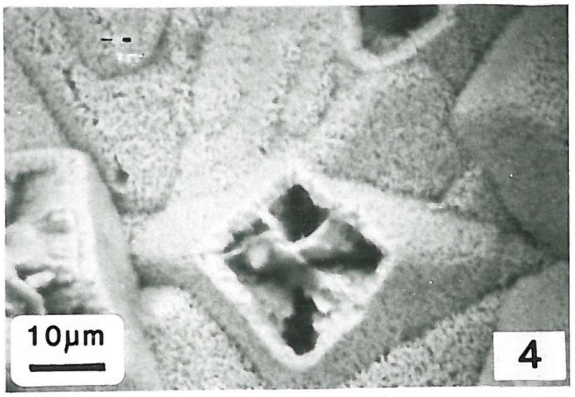
19-6. Octahedra replaced by goethite after pyrite, partially filling a phragmacone chamber. The goethite also replaces filamentous material which drape the pseudomorphed euhedra (centre-right).

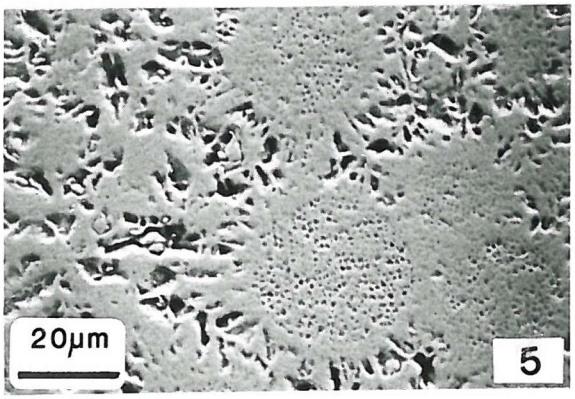
19-7. Filamentous structures replaced by goethite draping pseudomorphed octahedra. Note the uniform size of the filaments and their random orientation.

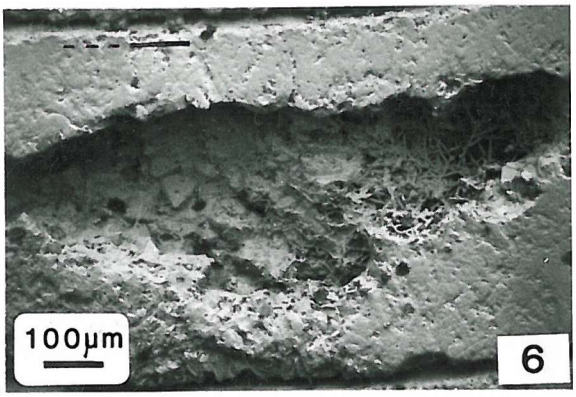


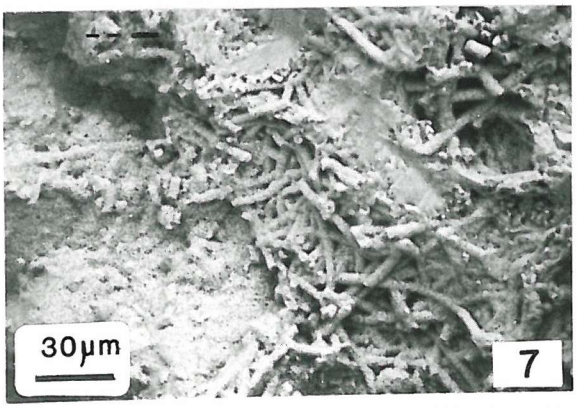












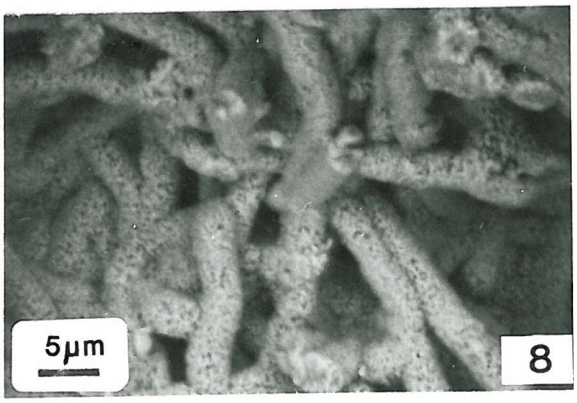


PLATE 19

19-8. Goethite replacement of filamentous structures. Note that the microgranular texture of the goethite is similar to that of the goethite-replaced octahedra (Pls. 19-3, 19-4).

All the plates (19-1 to 19-8) are S.E.M. photomicrographs (backscatter images) from one polished sample.

Pebble: Folkestone Beds Formation, Chilworth, Surrey.

Source: Upper Jurassic pyrite nodule, probably from the Oxford Clay Formation, Hog's Back High.

lesser amounts of material from the cordatum and athleta Zones.

The cubic shape of the pores in the ammonite chamber suggests that they are moulds of a former filling material, probably pyrite. The goethite fabric is similar to that described by Hudson (1982; fig. 5d) as equant pyrite. Similarly, the cubic habit of the euhedral pseudomorphs in the belemnite phragmacone is also indicative of pyrite. The pseudomorphs resemble octahedral pyrite from the host sediment adjacent to pyritized ammonites (Hudson, 1982; fig. 18b). Welton (1984) also described and illustrated pyrite octahedra. Thomsen & Vorren (1984; fig. 4k) noted that pyrite octahedra were generally formed in open cavities such as in borings. This observation is consistent with the formation of euhedra in the belemnite phragmacone camerae. The euhedra described by Thomsen & Vorren (1984) were significantly smaller than the goethite pseudomorphs.

The 'granular' goethite forming the main chamber-filling phase is similar to the aggregates of pyrite, forming well-ordered framboids in ammonite whorls (Hudson, 1982; fig. 5a). The acicular pseudomorphs resemble bladed pyrite surrounding framboids, a fabric also described by Hudson (1982; fig. 5c).

The textural similarity of the goethite filaments and the goethite replacing the euhedra suggests that the filaments were also originally composed of pyrite. The filaments display no clear orientation and are smaller than the stalactitic pyrite described by Hudson (1982). The uniform size of the filaments suggests that they are of organic origin. They resemble algal, bacterial and fungal filaments described from modern sediments by Beier (1985), Hook et al. (1984) and in ancient rocks by Southgate (1986).

3.2.9.4 Laminated ironstones

Description: Dusky brown (5.YR.2/2) to dusky red (5.R.3/4) and occasionally moderate yellowish brown (2.9.YR.5/4) clasts of laminated microcrystalline goethite. Pebbles are very platy to platy, angular to subrounded and 4-15mm long. Clast shape was controlled by the fine-scale lamination which is commonly parallel to the maximum projection surface of the pebble. The laminae weather

differentially, producing colour banding (Pl. 20-7). Parallel planar lamination is the norm, but in some clasts the laminae are sub-parallel to the pebble surfaces. In extreme examples of the latter, laminae parallel all sides of the pebbles. The laminae differ from those of goethite ooids, in that their orientation changes sharply and for much of their length they are planar.

The laminae are 300-500μm thick and composed of bladed or tabular microcrystalline goethite, 5-10μm in length. Colour or occasionally grain-size variation define the lamination. Ooids and silt are present in some clasts, but quartz sand is scarce.

Discussion: The laminated ironstones appear to be of two types:
1. those with sedimentary lamination, and
2. those with concretionary lamination.
The former contain rare detrital grains and have graded laminae, the latter are those in which lamination is curved or box-like.

The source of the laminated ironstones is difficult to ascertain. The clasts are found in greatest abundance in the ferruginous arenites of Early Cretaceous age. Their virtual absence from non-ferruginous sand deposits indicates that the majority are probably of contemporaneous origin. It is probable that they are reworked from ferruginous mudstones with diagenetic concretions.

3.2.9.5 Quartz arenites with goethitic matrices

Description: Dusky red (5.R.3/4) to very dark red (5.R.2/6) clasts of quartz arenite with microcrystalline ferruginous matrices. The clasts are angular to rounded, platy to compact-bladed and up to 20mm in length. Clast surfaces are rough because of projecting quartz grains.

The arenites are composed of well-sorted quartz of fine to very coarse sand-grade. The sands are mineralogically mature, composed of greater than 90% quartz. Feldspar is present in low abundance (less than 5%) and heavy minerals form less than 1% of the detrital suite. Zircon is moderately common but tourmaline is rare. Glauconite is absent, but goethite pellets are present in some clasts. The pellets are ovoid in shape and composed of microcrystalline goethite (Pl.

PLATE 20

PHOSPHORITE AND IRONSTONE FABRICS

PLATE 20

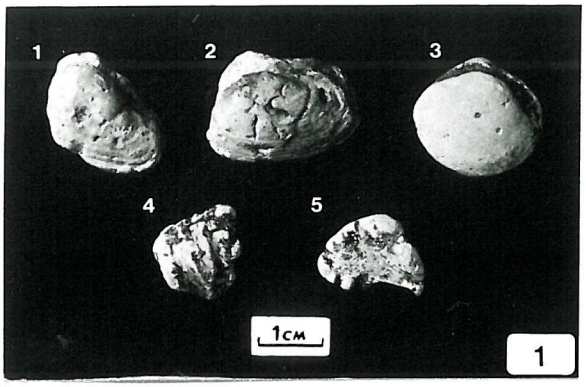
PHOSPHORITE AND IRONSTONE FABRICS

20-1. Phosphatic bioclast casts: 1, 2) bivalves (*Pleuromya*), 3) bivalve (*Protocardia*), 4) part of an ammonite whorl (possibly *Pavlovia*), 5) ammonite camerae (perisphinctid).
Hand-specimen photograph, reflected light.
Pebbles: Pebble bed RC1, Ferruginous Sands Formation, Redcliff, Isle of Wight.
Source: *pallasioides* or *rotunda* nodule beds, Kimmeridge Clay Formation, probably from the Isle of Wight High.

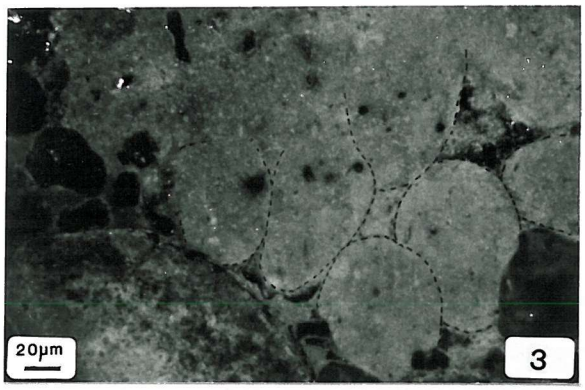
20-2. Phosphatic cast of a belemnite phragmacone. The cast is composed of glauconitic sand in a microcrystalline phosphate matrix. Note the mottling probably caused by burrowing (possibly *Chondrites*).
Hand-specimen photograph, reflected light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Cretaceous phosphate nodule bed, probably from the East Midlands Shelf.

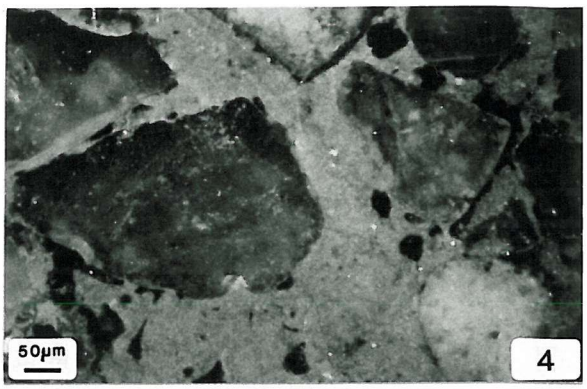
20-3. Pelletal phosphorite. Pellets of microcrystalline phosphate and sand grains set in a phosphatic matrix.
Polished sample photomicrograph, reflected light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Cretaceous phosphate nodule bed, probably from the East Midlands Shelf.

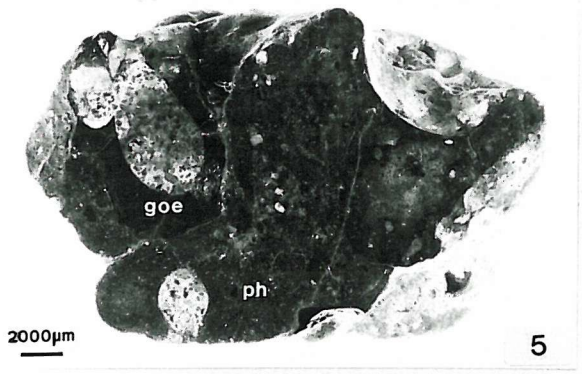
20-4. Phosphorite-cemented sandstone with scattered phosphorite pellets.
Polished sample photomicrograph, reflected light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Cretaceous phosphate nodule bed, probably from the East Midlands Shelf.

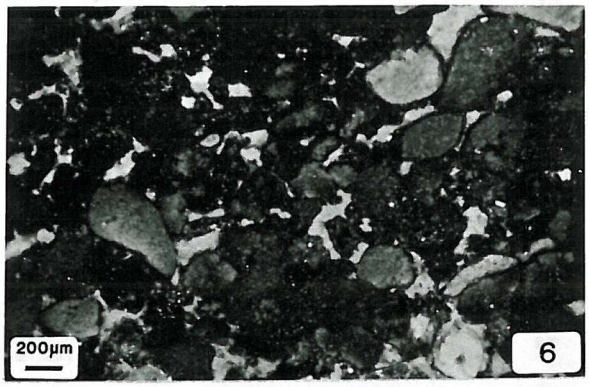

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2


20µm
3


50µm
4


goe
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6


1000µm
7

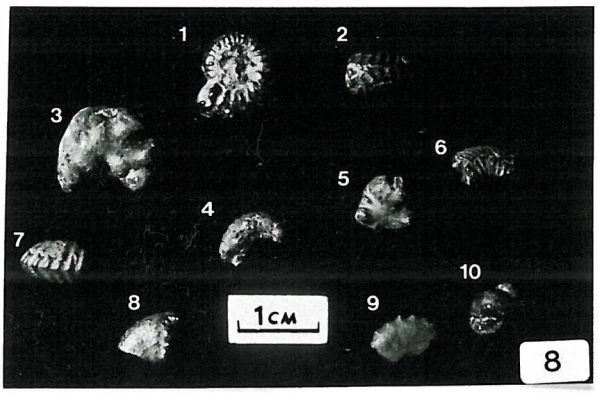

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1cm
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PLATE 20

20-5. Poorly rounded phosphorite pebble with Gastrochaenolites borings. The phosphorite contains glauconite and quartz sand. The borings are filled by calcite-cemented sand. Note that adjacent to the boring, the phosphorite has been altered to goethite (goe). At the centre of the clast the phosphorite (ph) is unweathered.
Polished section photograph, reflected light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Cretaceous phosphate nodule bed, probably from the East Midlands Shelf.

20-6. Pelletal ironstone. Goethite pellets are cemented by bladed goethite and the centre of the pores are filled by microcrystalline goethite.
Polished sample photomicrograph, reflected light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Cretaceous ironstone or contemporaneous deposits, probably from the East Midlands Shelf.

20-7. Finely laminated ironstone composed of microcrystalline goethite. The lamination results from variations in hardness of the ironstone following weathering. Note the sharp change in orientation of the laminae (left), a feature probably indicating that the clast was derived from a concretion.
Hand-specimen photomicrograph.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Cretaceous ironstone concretion, probably from the East Midlands Shelf.

20-8. Derived goethitic and phosphatic fossil casts. 1) ammonite protoconch, 2) Quenstedtoceras cf. mariae, part of a whorl, 3) phosphatic ammonite camerae (possibly a perisphinctid), 4) ammonite whorl, 5) ammonite whorl, 6) Quenstedtoceras cf. mariae, 7) Quenstedtoceras cf. mariae, part of a whorl, 8) ammonite whorl, Creniceras cf. renggeri, 10) gastropod cast.
Hand-specimen photomicrograph.
Pebbles: Bargate Beds Formation, Compton, Surrey.
Source: Oxford Clay Formation (1,2,4,5,6,7,8,9 & 10) and Kimmeridge Clay Formation (3), probably from the Hog's Back High.

20-6). Sparse ironstone pebbles display the contacts between quartz sand and ferruginous oolite or ferruginous mudstone. The matrices of the sandstones are of microcrystalline or fibrous goethite (Pl. 20-6).

Discussion: Compositionally the clasts are mature quartz sands. The microcrystalline goethite matrix contains no distinctive fabric. It is probably a ferruginous mud sediment in many examples, but in some pebbles the microcrystalline goethite infills pores lined by bladed goethite. It is therefore interpreted as a cement.

The maturity of the detrital suite indicates that it was either reworked from older sediments or had undergone leaching following deposition. The scarcity of tourmaline, a relatively stable mineral phase, suggests that the maturity is possibly a function of ironstone diagenesis.

The pebbles are found in association with other types of ironstone in the Weald, the East Midlands and the Isle of Wight and were probably derived largely from contemporaneous marine or estuarine deposits.

3.2.10 Phosphorite phenoclasts

Phosphorite clasts are composed principally of phosphate (apatite). Such lithotypes are present in several of the units studied. They are particularly common in marine gravel lag deposits where they may represent the main coarse-grained detrital component. These clasts were described as 'phosphorites' by P.Allen (1960, p.161, 163) and 'phosphatic pebbles' by Wells & Gossling (1947, p.212-213). Four principal phosphorite phenoclast-types have been recognised in this study.

3.2.10.1 Microcrystalline homogeneous phosphorite

Description: Dusky yellowish brown (10.YR.2/2) to moderate yellowish brown (10.YR.5/4) clasts of microcrystalline phosphorite. The pebbles are subrounded to well rounded, bladed to compact-bladed

and up to 50mm in length. Pebble surfaces are polished but may have mottled colouring. The mottling is generally produced by phosphate-infill burrows or borings with slightly different colour (Pl. 20-2).

The phosphorites are composed of microcrystalline apatite, 2-5μm in diameter. The matrices are typically structureless, but examples of foliated phosphate have been identified. Quartz and mica silt are present in many of the clasts. The quartz is commonly bladed but rarely aligned.

Discussion: The clasts are reworked phosphorite nodules. The well defined edges of the clasts and the compositional difference from the pebble bed matrices indicates that they were not formed in situ. However, the phosphorites are generally poorly rounded. They were probably derived from local sources.

More than one source probably existed for the phosphorite clasts since they are found in a number of pebble beds in southern Britain and northern France. In southern England, phosphorite nodules are found in the Lower Greensand Group in the Isle of Wight and the Weald (Casey, 1961), and in the rotunda and pallasioides Zones of the Kimmeridge Clay Formation (Oakley, 1942; Arkell, 1947a). Pyrite nodules are present in the Oxford Clay Formation, but phosphorites are not common. In southern England, Lower Jurassic rocks are also generally devoid of phosphorite nodules (Oakley, 1942). Phosphates are found on the East Midlands Shelf at several Lower Cretaceous and Lower Jurassic horizons, but are scarce in the Ancholme Group (Oakley, 1942).

The absence of preserved fossils in the pebbles precludes precise identification of the sources of this group. The association with other types of phosphorite, however, provides an indication of the source horizons.

3.2.10.2 Glauconitic arenites with phosphatic matrices

Description: Dusky yellowish brown (10.YR.2/2) to darkish yellowish brown (10.YR.4/2) pebbles of microcrystalline phosphorite with fine to medium-grained sand. The clasts are subrounded to well rounded,

bladed to compact-bladed and 4-50mm in length. Some of the pebbles have phosphate- or occasionally goethite-filled borings (Pl. 20-5). In pebble beds with a high ironstone content, goethite veins cross-cut clasts.

The phosphorites are composed of detrital grains in matrices of microcrystalline phosphate (Pls. 20-4, 20-5). Both grain-supported and matrix-supported fabrics are identified in the same clast. The sands are glauconitic with 70-90% quartz (principally monocrystalline) and 5-10% glauconite. Goethite grains are rare in the clasts but feldspar may be present in low abundance (up to 10%). Phosphate pellets are found, but are difficult to identify, being composed of microcrystalline phosphate of similar crystallite-size to the matrices. Glauconite grains are rounded to subrounded. Bioclasts are not abundant in the pebbles and are unphosphatized or only partially phosphatized. Comminuted bivalves have been recognized.

Discussion: Pebbles of this type are found in several of the Lower Cretaceous pebble beds in southern Britain. As with the homogeneous phosphates, the source of these clasts is difficult to ascertain. The fauna is rarely well preserved, indicating little more than a Jurassic or Cretaceous origin. Again the best method for identification of source is by comparison with phosphatized bioclast casts (Sect. 3.2.10.4) present in the same horizons.

3.2.10.3 Phosphatic oolitic packstones

Description: Dark yellowish brown (10.YR.4/2) to light olive grey (5.Y.5/2) pebbles. Rounded to subrounded, bladed and up to 25mm in length. The clasts contain ooids in microcrystalline matrices of phosphate. The ooids are dissected at the grain-surfaces, revealing a concentric fabric.

The clasts are composed of ooids of microcrystalline phosphate or more commonly goethite set in matrices of microcrystalline apatite. Ooid grains are ovoid in shape and 350-500μm in length. Quartz sand or silt nuclei are present in some grains. The goethite ooids are similar to those of the oolitic ironstones (Sect. 3.2.9.2). Phosphatic ooids are composed of microcrystalline apatite in

concentric sheaths. Inclusions are common in the phosphate and iron-staining is also observed.

Discussion: The phosphatic oolites are restricted in distribution to the East Midlands and Normandy where they are present in the Carstone Member and Poudingue Ferrugineux respectively. The source of the clasts is uncertain since they contain no identifiable fossils. In the East Midlands, the probable sources are the Lower Cretaceous or Jurassic nodule beds of the area. Phosphatic ooids are not common, but examples have been described by Horton et al. (1980) and Young et al. (1982) in the Upper Lias from Lincolnshire to Oxfordshire. These oolites, however, are set in matrices of micrite, are commonly associated with bioclasts and are petrographically dissimilar to the pebbles. Upper Jurassic phosphorites are not common in this area beneath the basal beds of the Spilsby Sandstone Formation (Oakley, 1942). Kelly (1980) noted that Kimmeridgian phosphorites had been reworked into the basal Spilsby Nodule Bed and Swinnerton (1935) found phosphorites in the Tealby Formation. The source of the phosphorite pebbles in the Carstone Member was probably from the Spilsby Sandstone and Tealby Formations, but minor quantities of Lower Jurassic phosphorite are possibly present in the pebble beds at the basin margin. The oolitic phosphorite clasts in the pebble beds of Albian age in northern France are more common where the Cretaceous pebble beds overlie the Kimmeridge Clay Formation and reworking from the Upper Jurassic rocks is likely. Reworking of contemporaneous phosphorite nodules may also have occurred.

3.2.10.4 Phosphatic bioclast casts

Description: Brownish grey (5.YR.4/1) to brownish black (5.YR.2/1) pebbles of phosphorite which are angular to rounded, bladed and up to 50mm in length. The clasts have undergone both attrition and weathering. Abrasion of the pebbles resulted in the loss of fine detail on the nodule surfaces and probably destroyed any remaining carbonate material. Weathered phosphorites are paler in colour than unweathered types and have a porous texture. Intense weathering resulted in the clasts becoming dusky yellowish orange (10.YR.6/6) in colour (Pl. 3-4).

The bioclast casts are composed of phosphatic-cemented glauconitic sands or homogeneous phosphate. Ammonites and bivalves are the most common types of bioclast preserved (Pl. 20-1), but serpulids and belemnites (Pl. 20-2) are also found. The ammonites are normally fragmented with one or two camerae, suture lines and ribbing preserved (Pl. 20-1). Rare ammonite casts with five to ten camerae are present in some pebble beds. Phosphatized bivalve casts are normally of articulated specimens with some shell texture preserved.

The phosphatized bioclast assemblages differ between areas. In the Isle of Wight, well preserved perisphinctid ammonites (Pavlovia) and bivalves (Protocardia and Pleuromya) are common in the Lower Greensand Group pebble beds (Pl. 20-1). The Lydite Beds at Swindon and the Tour de Croi Nodule Bed (Kimmeridgian Stage), near Boulogne, contain a similar fauna to the Lower Greensand Group pebble beds, but ammonite casts are less abundant. The Faringdon Sponge Gravel also contains phosphatic bivalve and ammonite casts, but the casts are abraded and poorly preserved. In the East Midlands, phosphatic bioclast casts are rare, but include examples of belemnite phragmacones resembling those of Lower Cretaceous belemnitinids, ammonite camerae and bivalves in the Carstone Member.

Discussion: The phosphatized bioclasts are of Jurassic or Cretaceous origin. The phosphorite-bioclast assemblage in pebble beds of the Isle of Wight, Dorset, Faringdon, Swindon and Boulogne are all similar to those described from the rotunda and pallasioides nodule beds in Dorset (Arkell, 1947a). Reworking of detritus from the Kimmeridge Clay Formation is probable for all of these pebble beds. The Swindon and Boulogne pebble beds are of Late Kimmeridgian and Early Portlandian age and reworking has clearly been minimal. The East Midlands phosphorite assemblage differs from those to the south. This probably reflects the limited development of the Kimmeridgian phosphorites in the area and the greater importance of reworked Lower Cretaceous phosphates.

3.2.11 Tourmalinite phenoclasts

Tourmalinites are defined as clasts composed principally of

tourmaline and quartz, with accessory amounts of cassiterite and rutile. They include both reworked pneumatolytic and metamorphic lithotypes. Clasts of this type are similar to the 'pebbles of igneous and pneumatolytic origin' described by Wells & Gossling (1947, p.214-217). Four principal tourmalinite phenoclast-types have been identified.

3.2.11.1 Quartz with acicular tourmaline

Description: Very light grey (N8) to translucent clasts of granular quartz with dark blue acicular crystals. The pebbles are subangular, compact to compact-bladed and 4-20mm in diameter. The clasts are poorly rounded with pitted surfaces.

The pebbles are composed of granoblastic quartz up to 500μm in diameter. The quartz crystals are slightly opaque but normally unstrained. Tourmaline is present in the pebbles in two forms:

1. blue-purple acicular crystals (400-4000μm in length) occurring in radiating fans and set in matrices of clear quartz (Pl. 21-1),
2. blue-green or occasionally green-brown prismatic crystals, 200-300μm long and 70-150μm wide. These may be zoned.

The prismatic tourmaline crystals in the clasts appear to have formed prior to the acicular tourmaline.

Feldspar and mafic grains are absent from these clasts, but some pebbles contain clusters of sericite, probably after feldspar. Quartz veins, free from tourmaline, cross-cut the pebbles.

Discussion: Tourmaline is a mineral phase commonly associated with granite intrusions and related pneumatolytic rocks. The clasts resemble siliceous varieties of luxullianite from Cornwall, described by Wells (1946) and Lister (1978). It is probable, therefore, that the clasts are of pneumatolytic origin.

The paucity of feldspar and mica in the clasts suggests that they are not replaced granites and are possibly from veins adjacent to igneous intrusions. Such veins are common in the metamorphic aureoles around the granites of Devon and Cornwall and are also present in association with the granites of northwest France. The absence of deformation features in the clasts indicates that they

PLATE 21

TOURMALINITE FABRICS

PLATE 21
TOURMALINITE FABRICS

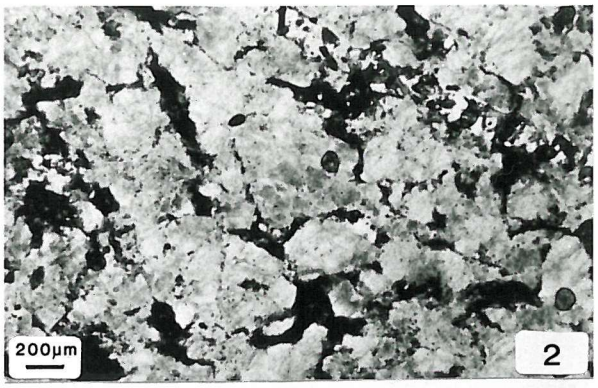
21-1. Radiating, bladed tourmaline with interstitial quartz (luxullianite-type tourmalinite).
Thin-section photomicrograph, cross-polarised light.
Pebble: Gault Clay Formation, Golden Cap, Dorset.
Source: Quartz-vein, probably from adjacent to a granite, Cornubian Massif.

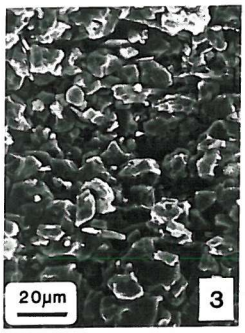
21-2. Tourmalinized quartzite. The bladed microcrystalline tourmaline occurs between 'grains' of quartz. Note the quartz-vein (top right) contains coarsely crystalline, bladed tourmaline.
Thin-section photomicrograph, plane-polarised light.
Pebble: Faringdon Sponge Gravel, Wicklesham Pit, Faringdon, Oxfordshire.
Source: Triassic pebble bed, probably from the margins of the Welsh Massif.

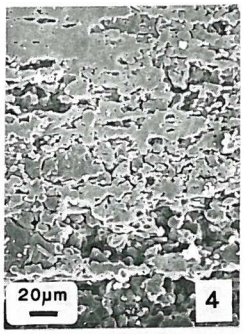
21-3. Intergrown equant, microquartz and bladed tourmaline. Note the contrast between the crystallinity of the microquartz in this tourmalinite and the matrix microquartz of the Jurassic chert (Pl. 7-5), see Appendix IV.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Tourmalinized sediment, probably from the Cornubian or Armorican Massifs.

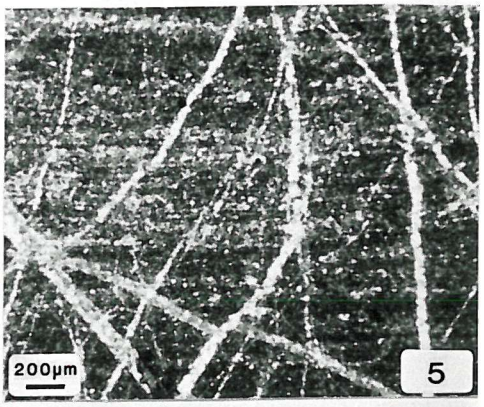
21-4. Laminated tourmalinite composed of equant quartz and bladed tourmaline.
Etched polished sample, S.E.M. photomicrograph.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Tourmalinized sediment, probably from the Cornubian or Armorican Massifs.

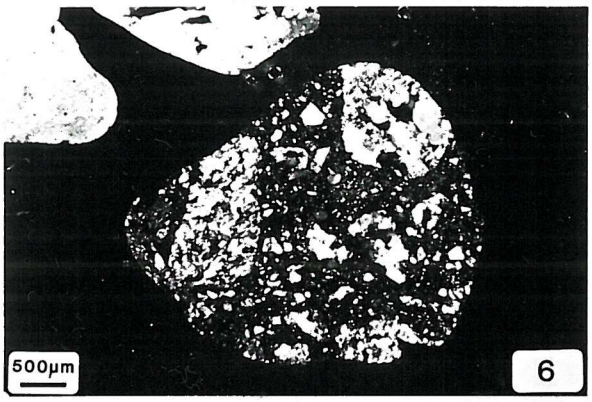

50µm
1


200µm
2

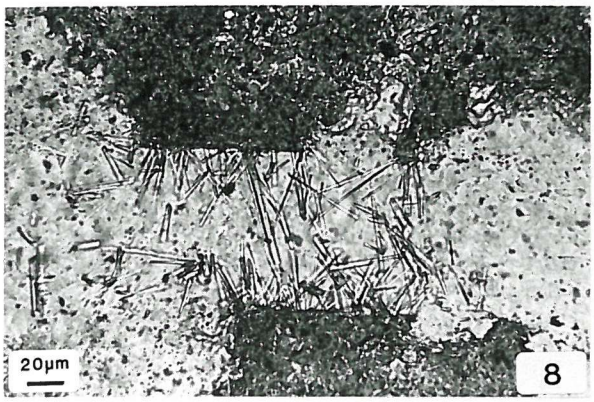

20µm
3


20µm
4


200µm
5


500µm
6


500µm
7


20µm
8

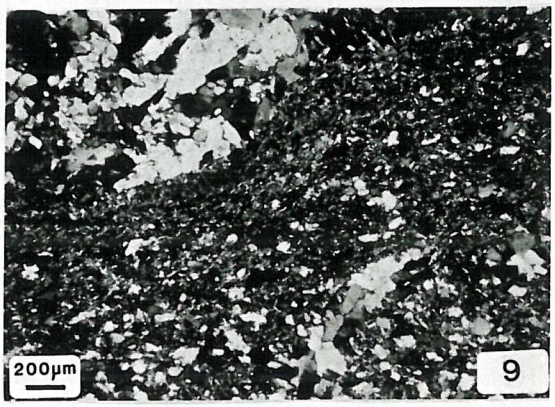

200µm
9

PLATE 21

21-5. Foliated tourmalinite, cut by tourmaline-free quartz-veins. The clast is possibly from a tourmalinized mudstone.
Thin-section photomicrograph, cross-polarised light.
Pebble: Gault Clay Formation, St. Oswald's Bay, Dorset.
Source: Tourmalinized sediment, probably from the Cornubian or Armorican Massifs.

21-6. Pneumatolytic breccia. Fragments of partially tourmalinized quartzite in a matrix of microcrystalline tourmaline.
Thin-section photomicrograph, cross-polarised light.
Pebble: Gault Clay Formation, Golden Cap, Dorset.
Source: Pneumatolytic breccia pipe adjacent to a granite, probably from the Cornubian or Armorican Massifs.

21-7. Pneumatolytic breccia. Quartz-tourmaline clasts in a matrix of microcrystalline tourmaline and quartz fragments. The cross-cutting quartz-vein (top) is free of tourmaline.
Thin-section photomicrograph, plane-polarised light.
Pebble: Wealden Group, Corfe Castle (Westlake Collection), Dorset.
Source: Pneumatolytic breccia adjacent to a granite, probably from the Cornubian or Armorican Massifs.

21-8. Quartz vein with acicular needles (possibly of pumpellyite) in a laminated tourmalinite.
Thin-section photomicrograph, plane-polarised light.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Probably tourmalinized sediments on the Cornubian or Armorican Massifs.

21-9. Foliated tourmalinite. The foliated tourmaline is concentrated adjacent to a quartz pod (top centre) which is relatively free from tourmaline. The equant quartz (bottom) is intergrown with aligned bladed tourmaline.
Thin-section photomicrograph, cross-polarised light.
Pebble: Gault Clay Formation, Durdle Door promontory, Dorset.
Source: Tourmalinitic schist, probably from the Armorican Massif.

have not subsequently undergone metamorphism, which discounts the Cadomian granites of Armorica as probable sources. Tourmaline is present in association with other granites in Britain, but is rarely abundant. Tourmalinite pebbles are present in a number of other pebble beds (Hutchins, 1963; Campbell-Smith, 1963; P.Allen, 1967a; Williams, 1969; P.Allen et al., 1974; Fieremans & De Paepe, 1982, Kennan, 1983). The poor rounding of the pebbles studied, however, indicates that reworking from older pebble beds is unlikely. The pebbles of quartz with acicular tourmaline are most common in the Lower Cretaceous pebble beds of Dorset. A Cornubian source is thus most probable. An Armorican source is also possible, but the clast-angularity suggests that the pebbles were not transported for long distances.

3.2.11.2 Quartz-tourmaline rock

Description: Pebbles, bluish black (5.B.2/1) to very light grey (N8) in colour, the latter with black laminae. The clasts are rounded to subangular, bladed to compact in shape and up to 80mm in length. Smaller pebbles are typically less rounded than the larger clasts. Rounded pebbles may have chatter-marked surfaces. These pebbles are similar to the 'tourmaline-quartz ?veinstone' of P.Allen (1967a, p.255).

The clasts are composed of granoblastic quartz of variable grain size, with foliated very finely crystalline tourmaline (Pl. 21-9). The tourmaline is 10-20μm in length and bladed in shape. Its colour varies between clasts; olive green weakly-pleochroic tourmalines are most common, but brown and dark blue tourmalines are also present.

The tourmaline occurs in a foliated mass with the C-axes of the crystals elongated parallel to the foliation. The groundmass is composed of microcrystalline quartz and prismatic tourmaline. Larger quartz crystals are commonly strained and contain inclusions. Cross-cutting quartz veins are common and some are packed with bladed tourmaline. Cassiterite and rutile are present both in veins and in the host rock but are never abundant.

Discussion: This variety of quartz-tourmaline rock appears to have tectonic fabrics and is both boudinaged and sheared. The abundance

of tourmaline suggests that the clasts are of pneumatolytic origin, but metamorphic tourmalinites are also found (Slack et al., 1984) and derivation from such sources cannot be discounted.

As noted above (Sect. 3.2.11.1), quartz tourmaline pebbles have been found in pebble beds from different parts of Britain and the surrounding area. Clasts of this type are present only in the Lower Cretaceous pebble beds of Dorset. The closest sources, therefore, are the Cornubian and Armorican Massifs. However, the Permian and Triassic pebble beds of Devon are also potential sources (Hutchins, 1963; Campbell-Smith, 1963).

The microfabrics of the clasts indicate that the host rocks were metamorphosed or were from areas subject to repeated deformation. This indicates that the Precambrian metamorphic basement of Armorica was the most probable source. P.Allen (1972) also suggested that foliated tourmalinites were derived from Armorica and dated tourmaline grains in the Wessex Formation of Dorset as being of Proterozoic age.

3.2.11.3 Tourmalinised sediments (quartzites and siliceous mudstones).

Description: Black (N1) to bluish black (5.B.2/1) fine-grained granular clasts. The pebbles are rounded to subrounded, bladed to compact-bladed and up to 50mm in length. Clasts of the finer grained lithotypes are polished with chatter-marked surfaces; the coarser grained lithotypes tend to have pitted surfaces. Similar clasts were described as 'tourmalinised quartzites and deformed quartzites' by P.Allen (1967a, p.255-256).

The clasts are composed of quartz and foliated or prismatic tourmaline and range from siliceous mudstones to quartzites. The siliceous mudstones are composed of microquartz and bladed or prismatic tourmaline (100-150μm in length) with well developed fabrics (Pls. 21-3, 21-4, 21-5). Aggregates of finely crystalline tourmaline are present in some clasts and are similar in appearance to knots in hornfelses.

The quartzites are composed of equigranular quartz (greater

than 90%), with rare feldspar and lithic grains (less than 5%). Elongate grain contacts probably result from pressure-solution. Quartz overgrowths are not recognised on the quartz grains. The tourmaline occurs in the interstices between quartz or overprints the quartzite fabric (Pl. 21-2).

The clasts are of two types:

1. those with prismatic tourmaline crystals without a well-defined fabric, and
2. those with foliated tourmaline which overprints the former texture.

Veins of quartz are common in the clasts (Pls. 21-2, 21-5). Tourmaline in the veins is bladed and aligned sub-perpendicular to the fracture walls (Pl. 21-2). Fine acicular grains are also present in some veins (Pl. 21-8). These are 60-70μm in length, 5-10μm in width and colourless to bluish black. The crystals resemble pumpellyite, but their identity has not been confirmed. Sparse cassiterite and rutile crystals are present in the host lithotype and veins.

Discussion: These pebbles have fabrics characteristic of lithotypes of sedimentary or volcanic origin. Some tourmaline-bearing quartzites contain lithic grains which indicate that they are of sedimentary origin. However, for many clasts a sedimentary origin cannot be proved and quartz-tourmaline vein rocks could have similar fabrics. The cherty clasts are probably siliceous mudstones or felsic volcanics and resemble the untourmalinized pebbles of these types.

The clasts with prismatic tourmaline are probably tourmalinized sediments. The phenoclasts with foliated tourmaline are probably of metamorphic origin. Whether the tourmalinization in the clasts with foliated tourmaline was associated with the formation of the fabric or was controlled by a pre-tourmalinization fabric cannot be discerned.

Tourmalinized sediments are found adjacent to the granites of southwest England and this is a probable source for many of the

pebbles in the Dorset area. Some Armorican detritus is possibly included in this group. Pebbles of tourmalinized quartzites have been collected from the Faringdon Sponge Gravel, Oxfordshire. The distance from Cornubian or Armorican Massifs suggests that derivation from such sources is improbable. The pebbles were probably reworked from Triassic pebble beds in the English Midlands.

3.2.11.4 Pneumatolytic breccias

Description: Black (N1) to greenish black (5.G.2/1) siliceous clasts. The pebbles are subrounded to rounded, compact to bladed and up to 45mm in length. Clast-surfaces are polished and have small arcuate percussion marks. The pebbles are composed of brecciated quartz-tourmaline in matrices of microcrystalline tourmaline (Pls. 21-6, 21-7). Quartz veins cross-cut earlier fabrics and are commonly devoid of tourmaline.

The brecciated fragments are angular to subrounded and are compositionally and morphologically distinct from the adjacent fragments. The breccias are either clast- or matrix-supported. Breccia fragments are of two principal types:
1. granoblastic quartz with prismatic tourmaline (Pl. 21-6), and
2. microquartz with foliated prismatic tourmaline (Pl. 21-7).
The former is the more common type. In some clasts, the breccia fragments are tourmalinized only at their margins, but in others the tourmalinization is pervasive.

The matrices of the breccias are typically of green, prismatic tourmaline (30-70μm in length; Pl. 21-7), but in rare examples they are of mosaic quartz with little tourmaline. Both types of groundmass are present in some clasts and the microcrystalline tourmaline matrix fabric cross-cuts the quartz with tourmaline groundmass.

Discussion: The pebbles consist of breccias and are probably of pneumatolytic origin. Commonly the brecciated lithotypes underwent a series of tourmalinization phases, both prior to and contemporaneously with brecciation. The breccia fragments appear to be tourmalinized sediments or quartz-tourmaline rocks, displaced and slightly rounded prior to incorporation in the breccias.

Breccia pipes and associated tourmalinization in Cornwall were described by Goode & Taylor (1980) and reworking of such material is probable. The fabrics found in the Cornish breccias are similar to those observed in the detrital clasts. Goode & Taylor (1980) observed that tourmalinized breccia pipes are found closer to granite bodies than the more common lithic breccia pipes of the area.

Evidence of metamorphic overprinting of the breccias was not detected and the sources were probably associated with unmetamorphosed granites. Tourmalinization is common in rocks adjacent to granite intrusions, but in Britain, extensive tourmalinization is particularly common in southwest England. Tourmalinization is also commonly associated with Variscan granites in Armorica and Galicia. Clasts of this type have been collected from the pebble beds of Dorset and western sources for the detritus are probable. However, pebbles of tourmaline breccia were recognised in Permian conglomerates in Devon (Hutchins, 1963) and in the Triassic pebble beds of the Midlands and Devon (Campbell-Smith, 1963). Reworking of detritus from the older conglomerates in southwest England into the Lower Cretaceous pebble beds is possible.

3.2.12 Silicified hydrothermal or vein rocks

Description: Pinkish grey (5.YR.8/1) to light grey (N3) siliceous clasts. The pebbles are rounded to subangular, compact to bladed and up to 20mm in length.

This group of pebbles is composed of imbricate, flamboyant, mosaic or rarely petaloid megaquartz. The quartz crystals are 250-750μm in diameter with inclusions of haematite (less than 1μm in diameter). The haematite inclusions occur at the centres of petaloid megaquartz in some grains, whereas in others they ghost euhedral pseudomorphs. Pseudomorphs of three types have been recognised:

1. acicular or lenticular pseudomorphs, 150-200μm in length and orientated perpendicular to finely crystalline megaquartz with haematite inclusions. The pseudomorphs are enveloped and replaced by inclusion-free mosaic megaquartz;
2. bladed pseudomorphs with similar fabrics to the first;
3. cubic or oblong pseudomorphs which occasionally contain haematite

along cleavage planes. Pseudomorph-centres are void or cemented by mosaic megaquartz. The pseudomorphs are found in a groundmass of mosaic megaquartz free from inclusions.

Discussion: The clasts are siliceous replacements of lithotypes with euhedral crystal forms. The acicular and lenticular pseudomorphs of the first type resemble gypsum crystals, but they are not replaced by quartzine or lutecite and are typically thinner and more elongate than the pseudomorphs after gypsum described in Section 3.2.3.1. The lenticular pseudomorphs are also dissimilar to the carbonate rhombs (Sect. 3.2.1.10). The bladed pseudomorphs are similar in shape to anhydrite, but again there is no evidence to confirm the original composition.

The cubic and oblong pseudomorphs are distinctly different from the other pseudomorph types. The cubic grains are possibly after pyrite or galena, the former is more likely in consideration of the ferruginous inclusions. Oblong pseudomorphs are more reminiscent of barite.

It is probable that the clasts are silicified vein rocks, with replacement of sulphide, carbonate or sulphate minerals. The pebbles were found only in the Wessex Formation pebble beds of Dorset which also contain detritus of Cornubian and Armorican origin. Derivation from similar source areas is therefore suggested.

3.2.13 Silicified igneous phenoclasts

Foliated cherty clasts of possible volcanic origin are present in low abundance in most of the sampled horizons, but other igneous pebbles are very scarce. These clasts resemble 'acid lavas/porphyries' and 'green acid volcanics' of P.Allen, (1967a, p.251, 252, 258) and the 'pebbles of igneous and pneumatolytic origin' of Wells & Gossling (1947, p.241-247).

3.2.13.1 Laminated argillaceous cherts (silicified mudstones, felsic tuffs or aphanitic rhyolites)

Description: Black (N1) to dark grey (N3) clasts of microcrystalline

quartz with streaky lamination. Several examples also contain minute angular to rounded inclusions, coarser than the matrix. Quartz veins cross-cut some of the phenoclasts which are rarely weathered. The clasts are resistant to etching with hydrofluoric acid. Pebble shapes range from compact to compact-bladed; the clasts are rounded to subrounded and up to 35mm in length. Chatter marks on the surfaces of the clasts are arcuate and 0.5-1.0mm long.

The clasts are composed of dark microquartz with elongate chlorite and illite grains. The microquartz and phyllosilicate flakes are crystallographically aligned. Bioclasts are not recognised in the pebbles, but some contain spherical bodies, 50-150μm in diameter, resembling radiolaria (Pl. 22-5). The structures are slightly ovoid in shape, contain no internal fabric and have no spines. They are composed of chalcedony or megaquartz and their long axes are typically parallel to the foliation in the clasts.

Discussion: The high phyllosilicate content and the alignment of the clast fabric indicate that the clasts are not silicified limestones. The absence of bioclasts distinguishes these clasts from the radiolarian pebbles, but the matrices are similar. The inclusions in the microquartz matrices do not appear to be organic in origin and resemble phenocrysts in siliceous tuffs or felsic lavas. A volcanic origin cannot be confirmed since characteristic features such as glass shards, feldspar or mafic phenocrysts were not recognised.

The sources of the clasts are probably either silicified argillaceous sediments or silicified felsic volcanics. Suitable sources for the former exist in the Lower Carboniferous rocks of southwest England and also in sediments associated with the volcanic complexes of North Wales and the Lake District. Silicified volcanics are present in the Devonian rocks of Cornubia (Selwood et al., 1984), the Ordovician volcanics of the Lake District (Moseley, 1983) and Wales. Cherts are also found in association with the Precambrian volcanics on Anglesey (Greenly, 1919). On the Anglo-Brabant Massif, Precambrian volcanics were recorded in the North Creake borehole in Norfolk (Kent, 1947). Uriconian volcanics are found in small inliers in the Welsh Borders and the Midlands (Earp & Hains, 1971). Rocks in these areas provide further potential sources for pebbles. The

PLATE 22

QUARTZ, MYLONITE, TUFF AND JASPER FABRICS

PLATE 22

QUARTZ, MYLONITE, TUFF AND JASPER FABRICS

22-1. Granoblastic vein-quartz, with subhedral to euhedral crystals. Note the zoning in the quartz.
Thin-section photomicrograph, cross-polarised light.
Pebble: Coarse Quartz Grit, Wessex Formation, Dorset.
Source: Quartz-vein or pod, probably from the Cornubian or Armorican Massifs.

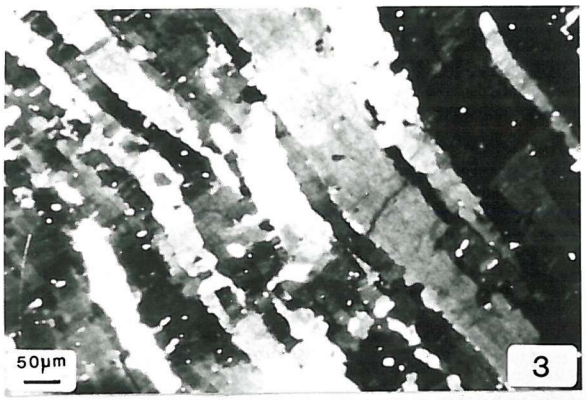
22-2. Elongate partially deformed quartz crystals. Note granulation along the crystal boundaries.
Thin-section photomicrograph, cross-polarised light.
Pebble: Coarse Quartz Grit, Wessex Formation, Dorset.
Source: Quartz-vein or pod, probably from the Cornubian or Armorican Massifs.

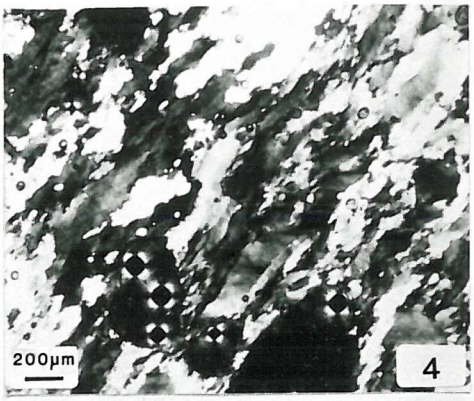
22-3. Fibrous vein-quartz. Note the granulation along grain boundaries and strain lamellae perpendicular to the quartz crystal length (elongation of the quartz is parallel to the c-axes).
Thin-section photomicrograph, cross-polarised light.
Pebble: Coarse Quartz Grit, Wessex Formation, Dorset.
Source: Quartz-vein, probably from the Cornubian or Armorican Massifs.

22-4. Mylonitic (para-)quartzite. Quartz c-axes are orientated parallel to the direction of crystal elongation.
Thin-section photomicrograph, cross-polarised light.
Pebble: Carstone Member, Nettleton Bottom, Lincolnshire.
Source: Lower Palaeozoic or Precambrian metamorphic basement, probably reworked from older pebble beds.











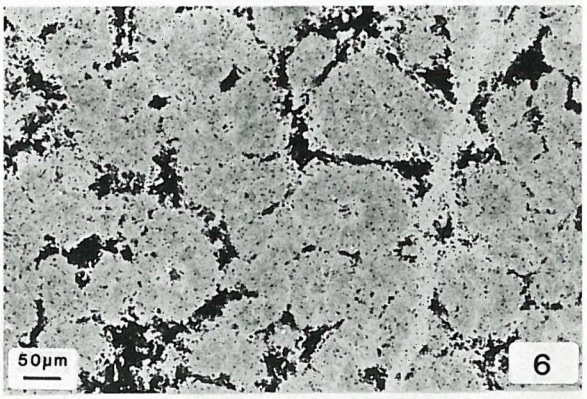


PLATE 22

22-5. Argillaceous chert, probably a silicified tuff or lava. The matrix is composed of aligned microquartz and minute phyllosilicate grains. Note the phenoclasts of quartz.
Thin-section photomicrograph, plane-polarised light.
Pebble: Top Lower Tunbridge Wells Sandstone pebble bed, Hastings Beds Formation.
Source: Silicified Lower Palaeozoic or Precambrian volcanics, probably from the Anglo-Brabant Massif but reworked from older pebble beds.

22-6. Spherulitic jasper. Note the microcrystalline haematite surrounding the spherulites and the haematite-free 'colourless' quartz-vein (*right centre*).
Thin-section photomicrograph, plane-polarised light.
Pebble: Coarse Quartz Grit, Wessex Formation, Dorset.
Source: Silicified volcanics, probably from the Armorican or Cornubian Massifs.

Devonian pebble beds in South Wales and the Welsh borders contain chert pebbles (J.R.L.Allen, 1974, 1975) as do the Carboniferous pebble beds of northern England (Gilligan, 1919). Reworking of pebbles from such sedimentary rocks is possible.

The clasts of laminated argillaceous chert are found in most of the pebble beds studied, both in southern England and the East Midlands. It is probable that the clasts were derived from a number of sources.

3.2.13.2 Silicified porphyritic lava

Description: Light brown (5.YR.5/6) to moderate red (5.R.4/6) clast of granoblastic quartz with bladed inclusions. A single clast of this lithotype has been identified and is 11mm in length, subrounded and bladed. The colouration is pervasive throughout the clast and does not result from weathering.

The pebble is composed of mosaic megaquartz, with minute haematite inclusions. Subhedral phenocrysts set in the quartz matrix are of two types:

1. bladed pseudomorphs of sericite and quartz. These phenocrysts are replaced by quartz at their margins with sericite at their centres;
2. equant or bladed, brown euhedral biotites, partially replaced by quartz at their edges and along cleavage planes. The replacement quartz is clear and free from inclusions.

The groundmass of the clast has a turbid texture and contains few inclusions other than the haematite.

Discussion: The presence of euhedral phenocrysts in a siliceous matrix indicates that this clast is a silicified igneous rock. The absence of inclusions in the groundmass probably indicates that it was originally homogeneous and finely crystalline or glassy. The phenocrysts of sericite and quartz are probably after feldspar. The partial silicification of the biotite suggests that the mica is original and not a replacement. The absence of quartz phenocrysts indicates that the source rock was probably of intermediate composition, but a felsic volcanic source cannot be discounted.

The clast was collected from the type area of the Folkestone Beds Formation. These beds contains a high proportion of sandstone pebbles derived from the Palaeozoic rocks of the Anglo-Brabant Massif (Sect. 4.2.3.2). The silicified felsic or andesitic volcanic clast was probably derived from a similar source area. Volcanics are known to be present in the Lower Palaeozoic rocks of Wales and the Lake District (Sect. 3.2.13.1) and Precambrian volcanics existed on the Anglo-Brabant Massif (Kent, 1947). The absence of known local sources suggests that the pebble was reworked from older pebble beds. Its primary origin therefore remains somewhat uncertain, but derivation from Lower Palaeozoic or Precambrian source rocks is probable.

3.2.14 Quartz and vein-quartz phenoclasts

Pebbles of quartz are ubiquitous in the horizons studied and have relatively few features indicative of their sources. Variations in the abundance of quartz relative to other phenoclast-types are of importance for the determination of the provenance of detritus. Three principal quartz phenoclast-types are identified by their petrographical textures, with further sub-divisions possible if colour differences are considered. Similar clasts were described as 'vein quartzes' by P.Allen (1967a, p.250) and Wells & Gossling (1947, p.222).

3.2.14.1 Equant granoblastic quartz

Description: White (N9) to translucent pebbles of polygranular quartz. Greyish orange pink (10.R.8/2) and light red (5.R.6/6) pebbles are also found, but are less common. The pebbles are subangular to rounded, bladed to compact and up to 80mm in length. Clasts are typically less than 40mm long. The surfaces of the pebbles are frosted with small arcuate chatter marks.

The crystals of quartz are 300-1500μm in diameter and have an interlocking granoblastic fabric (Pls. 22-1, 22-2). Deformation of the quartz is observed in some clasts. The quartz has undulose extinction and trails of fluid inclusions. Strain lamellae are present in more elongate crystals.

Inclusions in the equant quartz are scarce but occasional grains of muscovite or feldspar are found. Vermiform chlorite has also been identified, but is not common.

Discussion: Pebbles of equant granoblastic quartz are common to all the pebble beds studied. A number of sources are therefore likely. Equant quartz was probably derived from granitoid or metamorphic terrains. In the former, where quartz is associated with pegmatites and hydrothermal veining, the clasts may be expected to contain minor quantities of mica and feldspar. Metamorphic quartz may occur as mineral segregation pods or quartz veins and may contain inclusions of other vein minerals. Vein quartz is commonly elongate and slightly deformed. Recrystallized sedimentary quartzite may develop similar textures.

The pebbles of quartz in the pebble beds studied were probably derived from the massifs surrounding the Mesozoic and more specifically the Cretaceous basins. Angular and subangular pebbles of quartz are not common in the pebble beds, other than those of the Wessex Formation in Dorset and the Lower Greensand Group in the eastern Weald. It is probable that many of the clasts are reworked from older pebble beds. Reworking would also have resulted in removal of the less stable clasts, such as those with non-quartz grains. Pebbles of quartz with inclusions are not common, but are moderately abundant in the pebble beds of Dorset and Normandy where derivation from the Cornubian Massif and the Cotentin High respectively is probable.

3.2.14.2 Fibrous quartz

Description: White (N9) pebbles of polycrystalline elongate quartz. The pebbles are platy to bladed, subrounded to angular and up to 30mm in length. Some clasts include the contacts between fibrous quartz and siliceous sedimentary rocks. The latter is typically sandstone or chert.

Fibrous quartz is composed of bladed crystals elongated parallel to their C-axes (Pl. 22-3). The crystals are 2-7mm in length and 100-1000μm in width. Their margins are typically straight but granulation at grain contacts is observed. Fluid-inclusion trails

are common and are aligned perpendicular to the length of the quartz. Strain bands and lamellae are orientated parallel to the inclusion trails.

The sites of quartz-nucleation are either at the contact with the host rock or more commonly along planes perpendicular to the quartz-elongation. Inclusions in the quartz are rare but chlorite has been recognised.

Discussion: The elongation, size and shape of the crystals and deformation features are all typical of vein quartz. The presence of host rocks in contact with the quartz is evidence that some of these clasts are of vein origin. The deformation of the quartz and the large crystal size indicate that the clasts are not of mylonitic origin. Vein quartz is found in all the Palaeozoic and Precambrian massifs of northwest Europe and therefore precise sources cannot be identified. Pebbles of fibrous quartz are most common in the Lower Cretaceous pebble beds of Dorset, where material appears to have been derived directly from western sources.

Fibrous quartz appears to be an indicator of the maturity of the pebble suite; the greater the proportion of fibrous quartz relative to equant quartz, the less mature the suite.

3.2.14.3 Deformed quartzite (cataclasites and mylonites)

Description: Very light grey (N8) or white (N9) to greyish black (N2) pebbles of granular quartz. The pebbles are rounded to subangular, bladed to elongate and up to 50mm in length. These clasts resemble the 'mylonitic quartz schists' of P.Allen 1967a, p.256, 259-260).

This pebble group includes a complete range of lithotypes from partially deformed polygranular quartz to strongly foliated quartzites. The clasts are composed almost entirely of quartz, but foliated quartzites with feldspar and muscovite are occasionally found.

Partially deformed quartzites are composed of equigranular to slightly elongate quartz, with granulation at the mineral contacts, strain-bands and lamellae (Pl. 22-2). The strain-bands and lamellae

are orientated perpendicular to the axis of crystal-elongation. The quartz in these clasts is of varying size and evidence of former sedimentary fabrics is rare. In strongly foliated lithotypes, the quartz is aligned and elongate (Pl. 22-4), with separation of coarsely crystalline quartz in finely crystalline matrices. The quartz is aligned with the C-axes of the crystals parallel to the elongation. The crystals have curved margins, but granulation at the grain contacts is minimal. Porphyroblasts are present in some of the pebbles. These are typically of quartz, but may occasionally be of feldspar. Opaque inclusions, probably of pyrite, are present in the dark clasts of this group. Undeformed cross-cutting quartz veins are recognised in some pebbles.

Discussion: The pebbles of deformed quartzite probably have a number of origins. Some of the clasts with elongated quartz crystals and granulation at the crystal margins are probably deformed vein rocks. Deformation resulted from repeated movements along the plane of the vein. The deformed equant quartzites appear to be cataclasites in which brittle deformation of the quartz caused a reduction in its crystal-size. The absence of sedimentary fabrics indicates that many of these textures are likely to result from the straining and deformation of equant granoblastic quartz. The mylonitic clasts were produced by more intense deformation which resulted in the recrystallization of the quartzose rock and the formation of a foliated fabric. The quartzose composition of these clasts suggests that the deformed rocks were primarily of this composition prior to shearing. Ortho- or paraquartzites were therefore the probable sources.

Pebbles of this group are found in a number of the pebble beds, but are particularly common in those of Dorset. Sources of the less deformed lithotypes probably exist on the Welsh or Anglo-Brabant Massifs, but the more highly deformed clasts are likely to have been derived from higher-grade metamorphic areas, such as the Scottish and Norwegian Highlands, Anglesey or the Variscan and Cadomian massifs of Armorica. There is little evidence for detritus being derived directly from these areas, except in Dorset and Normandy. It is probable therefore that such clasts are reworked from older pebble beds.

3.2.15 Jasper phenoclasts

Description: Moderate red (5.R.3/6) to very dark red (5.R.2/6) microcrystalline siliceous pebbles. The clasts are rounded to subrounded, bladed to compact-bladed and up to 45mm in length. Pebbles are polished with small chatter marks on the surfaces. Polyphase quartz veins are common in the clasts. These pebbles are similar to the 'jaspers' of P.Allen (1967a, p.250, 252).

The jaspers are a diverse group of red cherts containing a variety of textures. The most common are of equant microquartz. In these clasts, the colouration results from minute haematite grains (less than 1μm) evenly distributed throughout the matrix.

Spherulitic jaspers are common and are composed of microquartz or finely crystalline megaquartz with quartz spherulites (Pl. 22-6). The spherulites are 50-200μm in diameter and composed of petaloid megaquartz (Pl. 8-4) or quartzine. Commonly, spherulite centres are composed of quartzine which passes outwards into petaloid megaquartz. Colouration of the spherulitic jaspers is uneven. Frequently the spherulites are a darker red colour than the surrounding matrix.

Tabulate pseudomorphs are observed in some jasper clasts. The pseudomorphs are composed of microquartz and are set in microcrystalline quartz matrices. The pseudomorphs are possibly after feldspar, barite or zeolites.

Discussion: The clasts of red chert differ from the other cherts found in that they contain neither organic allochems nor detrital grains. Jaspers are commonly reported in association with volcanic suites, in both modern (Hein et al., 1983) and ancient sequences (Greenly, 1919; Selwood et al., 1984). The cherts reported by Hein et al. (1983) are organic in origin, the silica having been derived from siliceous radiolaria or diatoms. The jaspers present in the pebble beds, however, contain no evidence of such an origin. It is possible that they were formed from siliceous gels precipitated from silica-supersaturated solutions of volcanic origin (e.g. hot springs). Dapples (1979) suggested that direct precipitation of silica on the sea floor is improbable and proposed that early replacement might be the mode of formation for the jaspers. Jaspers

are also noted associated with thrusting in some areas and are interpreted as having formed by remobilization of silica during deformation (W.Oswin, pers.comm., 1984). Such cherts are typically foliated.

A number of sources of jasper pebbles exist in Britain and the surrounding areas. The clasts are most common in Dorset where they were probably derived from Armorica. Red cherts and jaspers are present in the Devonian rocks of Devon (Selwood et al., 1984), but they are not common. Reworking of jaspers from the Triassic pebble beds is unlikely considering the scarcity of arenite pebbles in the Cretaceous beds. Jasper pebbles are also present in the pebble beds of the Weald, Isle of Wight and sparse examples are present in the East Midlands Shelf. In these areas, derivation was probably from the Welsh or Anglo-Brabant Massifs where the source rocks were probably of Precambrian or Lower Palaeozoic volcanics. Reworking from Devonian pebble beds is also probable.

3.3 PHENOCLAST LITHOTYPE ASSOCIATIONS

In a provenance study of locally derived, coarse-grained detritus, detailed lithological descriptions are essential for comparison of detritus and potential source rocks. For the study of regional variations in pebble assemblages, however, the precise source of the clasts is frequently undetectable. Phenoclasts have, therefore, to be separated into groups either from the same source-horizon or from the same area. Comparisons may then be made between suites from different areas. Excluding intraformational clasts, fourteen phenoclast lithotype associations are recognised in the Upper Jurassic and Lower Cretaceous pebble beds in southern Britain.

3.3.1 Quartz

Quartz was found in all the pebble beds examined and is frequently the dominant phenoclast-type. The lateral distribution of the quartz clasts (Chap. IV) indicates that the pebbles were derived from a number of sources and they are less useful as provenance indicators than some of the other phenoclast-types. The quartz

pebbles differ in size, colour and clast-morphology and are important indicators of pebble-assemblage maturity (Sect. 3.14). The more immature pebble-assemblages contain poorly rounded quartz pebbles with a high proportion of fibrous quartz and quartz with inclusions. In contrast, mature or reworked pebble-assemblages are composed principally of rounded granoblastic quartz.

3.3.2 Jurassic cherts and cherty limestones (including Portland Limestone Formation and Corallian Group cherts)

This association incorporates the silicified limestones (Sects. 3.2.1.1, 3.2.1.2, 3.2.1.3, 3.2.1.4), the partially silicified limestones (Sects. 3.2.6.1, 3.2.6.2, 3.2.6.3) and the silicified bivalve (Sect. 3.2.5.1). The phenoclast lithotypes are related by clast-morphology, silicification fabric and their preserved fauna. The faunal assemblage is dominated by bivalves, sponge spicules (Rhaxella and Pachastrella), and also includes gastropods, foraminifera and echinoderms. The assemblage indicates derivation of clasts from Jurassic marine limestones. Cherts are restricted in the Jurassic rocks of Britain to the Corallian Group of Yorkshire (Wilson, 1939) and the Portland Limestone Formation of southern England (Raisin, 1903). Cherts were reported in the Great Oolite Group in the Weald (Taitt & Kent, 1958) and the Lias is known to be silicified locally in the Mendips (Harptree Beds; Green & Welch, 1965). Upper Jurassic sources are locally of importance, but derivation from Lower and Middle Jurassic source rocks has not been confirmed.

Bathonian, Bajocian and Upper Oxfordian cherty limestones are present in the Calvados area of northern France. Chert pebbles in the Lower Cretaceous pebble beds of Normandy, derived from these horizons, are included in this association.

3.3.3 Purbeck cherts

The pebbles derived from the Purbeck Formation are distinguished from the Jurassic cherts (Sect. 3.3.2) by indicators of hypersaline or freshwater conditions of deposition. The majority of the silicified evaporite pebbles identified were derived from the Purbeck Formation (Sects. 3.2.3.1, 3.2.3.2, 3.2.3.3). The detrital

silicified evaporites are dated by the presence of pollen grains or are petrographically matched with cherts in the probable source rocks. The Purbeck Formation evaporites are distinguished from probable silicified Carboniferous evaporites (Sect. 3.2.3.4) by the silica fabrics and clast-morphologies.

The silicified wood specimens (Sects. 3.2.4.1, 3.2.4.2) were noted to resemble Upper Jurassic or Lower Cretaceous woods and were found in areas where the Purbeck Formation was the most probable source. These woods are distinguished petrographically from probable Carboniferous woods (Sect. 3.2.4.3).

Chert pebbles with silicified charophytes, ostracods, bivalves and sponge spicules (Sect. 3.2.1.5) are interpreted as having been derived from silicified freshwater limestones. The faunal and floral assemblage of these cherts is identical to those in the middle Purbeck Formation. Other cherts include ostracods (Sect. 3.2.1.8), but they also contain marine bioclasts such as echinoderms and brachiopods. Foraminifera in such cherts indicate that they were derived from Carboniferous limestones.

3.3.4 Carboniferous shelf cherts (including silicified Carboniferous woods and evaporites)

Clasts of this type form one of the most common pebble associations. The group contains a diverse variety of chert lithotypes, but the pebbles are related by their size, shape and silicification fabrics. The phenoclast-types included in this group are the silicified limestones (Sects. 3.2.1.8, 3.2.1.9, 3.2.1.10, 3.2.1.11, 3.2.1.12, 3.2.1.13, 3.2.1.14, 3.2.1.15), silicified wood (Sects. 3.2.4.3, 3.2.4.4) and the possible silicified evaporites (Sect. 3.2.3.4).

The pebbles are typically rounded to subrounded, equant-bladed to bladed and up to 35mm in length. The pebble colour is a function of weathering, but the clasts are normally brownish or bluish black. The faunal assemblage of the silicified limestones is dominated by echinoderm plates, brachiopods, bryozoa, foraminifera, ostracods and sponge spicules. Sparse (rugose?) corals and dasycladacean algae are also found. This assemblage indicates derivation from silicified

shallow marine limestones of Carboniferous age and is therefore referred to as the Carboniferous shelf chert association.

The unfossiliferous pebbles in this group are included because of the similarity in clast-shape and the silicification fabrics. The oolitic cherts (Sect. 3.2.1.9) differ from those in the Jurassic chert association (Sect. 3.3.2), since the ooids have radial and tangential fabrics and megaquartz ooid replacements are scarce. The laminated, mottled, pelletoid and peloidal cherts (Sects. 3.2.1.11, 3.2.1.13, 3.2.1.15) commonly contain rhombic pseudomorphs, a feature not recognised in the Jurassic marine cherts nor in the Purbeck cherts. Dolomitizaion of Jurassic limestones did occur (Wilson, 1966; Townson, 1975; Ian West, pers.comm., 1984) in southern England, but dolomite rhombs or rhombic pseudomorphs have not been detected in the cherts.

The silicified wood pebbles (Sects. 3.2.4.3, 3.2.4.4) are included in this group, since they differ petrographically from the Purbeck Formation type woods. The pebbles also bear greater resemblance to the silicified Carboniferous limestone pebbles than the Jurassic pebbles. The clasts were probably derived from Upper Carboniferous sources, but precise dating of the specimens has not proved possible.

The dark coloured pebbles of silicified evaporites (Sect. 3.2.3.4) are distinct from the Purbeck Formation evaporites. The clast-morphology is similar to that of the Carboniferous shelf cherts and derivation from silicified Carboniferous evaporites is proposed.

3.3.5 Carboniferous basinal (Culm) cherts

These chert pebbles (Sect. 3.2.2) are similar to the Carboniferous shelf chert pebbles in appearance, but are distinguished by petrographic features. The basinal cherts are foliated and contain a high proportion of phyllosilicate grains. Their faunal assemblage is limited, and although radiolaria and sponge spicules are abundant, they do not contain a benthic fauna. Radiolarian cherts are not common in Britain and the best examples are in the Lower Carboniferous Culm sediments of Devon and Cornwall (e.g. Meldon Chert Formation, Barracados Cherts).

3.3.6 Quartzites (arenites and siltites)

Quartzite pebbles (Sects. 3.2.8.1, 3.2.8.4) are found in low abundance in many of the pebble beds examined and are probably derived from a variety of sources. The petrographic characteristics of the pebbles suggest that they were probably reworked from Palaeozoic or Precambrian basement sources.

3.3.7 Micaceous and lithic arenites

Micaceous and lithic arenite phenoclasts (Sects. 3.2.8.2, 3.2.8.3) are rare in most of the pebble beds studied. The Folkestone Beds Formation pebble suite in the central and eastern Weald is distinct, however, since such pebbles in this area are abundant. These clasts are considered to have been derived from Devonian and Silurian sources on the Anglo-Brabant Massif. Pebbles in other areas were probably derived from Palaeozoic or Precambrian arenites on the basement massifs.

3.3.8 Ironstone bioclast casts

Ironstone bioclast casts (Sect. 3.2.9.3) are rare, but provide good indicators of detrital provenance. The pebbles found are composed of microcrystalline goethite after pyrite. The casts include ammonites, gastropods and belemnites and were derived principally from the upper Oxford Clay Formation. Liassic and Kimmeridgian ironstone casts were not recognised.

3.3.9 Ironstones

Ironstone pebbles (Sects. 3.2.9.1, 3.2.9.2, 3.2.9.4, 3.2.9.5) are more common than ironstone bioclast casts and are found in a number of pebble beds in southern Britain. The pebbles are typically poorly rounded and associated with goethite ooids. It is probable that many of the clasts and ooids were derived from contemporaneous deposits, but some local reworking of Jurassic and Cretaceous ironstones may have occurred.

3.3.10 Phosphorites

Phosphorite pebbles (Sect. 3.2.10) are found in several of the Upper Jurassic and Lower Cretaceous pebble beds and the clasts were probably derived from more than one source. In southern England, the inclusion of pavlovid ammonites and the bivalves Pleuromya and Protocardia in many of the phosphorite pebble-assemblages suggests that the phosphate nodule beds in the upper Kimmeridge Clay Formation were the most important detrital sources. In the East Midlands, similar clasts are scarce, but belemnites (probably from Lower Cretaceous sources) and oolitic phosphorites are present. It is likely that the Ancholme Group (including the Kimmeridge Clay Formation) was not an important source of phosphorite, but the Lower Cretaceous nodule beds probably were.

3.3.11 Jurassic limestones

Limestone pebbles (Sect. 3.2.7) in the Upper Jurassic and Lower Cretaceous pebble beds of southern Britain are rare. The fauna preserved in the limestone pebbles indicates that they were derived from Jurassic marine deposits. The limestone pebbles may be separated into two types:

1. the limestone phenoclasts in the upper Purbeck Formation in Dorset include sponge spicules, bivalves and ooids and they resemble limestones from the local Portland Limestone Formation.
2. the Faringdon Sponge Gravel limestone phenoclasts contain a more diverse fauna, including bivalves, sponge spicules, echinoderms and foraminifera. Derived scleractinid corals and perisphinctid ammonites are also present in this pebble suite. Oolitic limestone clasts and sandy limestone clasts are also moderately abundant. The limestone pebbles are probably derived from the local Corallian Group limestones, but Kimmeridge Clay Formation and Portland Group clasts may also be present in this suite.

3.3.12 Tourmalinites

Tourmalinite pebbles (Sect. 3.2.11) are composed principally of quartz and tourmaline and are of two types:

1. quartz with intergrowths of tourmaline or tourmalinised sediments are the most common. These were probably derived from granitoid

basement massifs.

2. foliated tourmalinites. These clasts are interpreted as having been derived from metamorphic basement massifs (possibly including deformed granites).

The concentration of tourmalinite clasts in the pebble beds of Dorset suggests that the sources for the majority of the clasts were on the Cornubian and Armorican Massifs. Rare tourmalinite pebbles in other areas are probably reworked from Triassic pebble beds.

3.3.13 Jaspers

Red cherts (Sect. 3.2.15) are found in several pebble beds, but in many cases they are altered Carboniferous shelf cherts. True jaspers, haematite-impregnated cherts, are found in very low abundance in a number of pebble beds. The siliceous fabrics indicate that such clasts are unlikely to be replaced limestones and are probably cherts associated with volcanic rocks. The jasper pebbles were probably derived from Palaeozoic or Precambrian sources on the basement massifs surrounding the Mesozoic basins.

3.3.14 Silicified volcanics

The siliceous pebbles composed of foliated microcrystalline quartz and phyllosilicates (Sect. 3.2.13.1) resemble the Carboniferous basinal chert pebbles (Sect. 3.2.2), but do not contain planktonic bioclasts. The pebbles are similar to felsic volcanics and they are tentatively interpreted as silicified tuffs or lavas. The pebbles are present in low abundance in many of the pebble beds studied and it is probable that they were derived from Lower Palaeozoic or Precambrian igneous centres on the basement massifs. Rounding of the pebbles suggests that reworking from older pebble beds is probable.

CHAPTER IV
PHENOCLAST-SUITE COMPOSITIONS

4.1 GENERAL

The composition of the phenoclast assemblage, the abundance of clasts in a bed and the clast-size and shape distinguish the pebbly horizons in the Upper Jurassic and Lower Cretaceous rocks of southern Britain. Abundance, shape and size are factors relating to the environment of deposition, but the phenoclast-assemblage composition reflects variations in the origin of sediment entering a basin. Phenoclast-assemblage compositions are commonly presented as frequencies or percentage frequencies (see App. I for details of phenoclast-assemblage compositions). It has been recognised, however, that although percentage-frequency variations depict major changes in the detrital suites, they are less useful for demonstrating transitional regional variation.

This problem has been overcome by the comparison of selected phenoclast pairs. The relationship between a pair of phenoclasts is unaffected by variations in the abundance of other components of the detrital suite and variations may therefore be interpreted as resulting from provenance differences. In the study of the Upper Jurassic and Lower Cretaceous pebble beds of southern Britain and Normandy, the three lithotypes that may be most readily used for this technique are:

1. quartz (Sect. 3.3.1),
2. Carboniferous shelf chert (Sect. 3.3.4), and
3. sandstone (Sects. 3.3.6, 3.3.7).

Quartz is a constituent of all the pebble beds in the area, but is derived from a number of basement sources. Carboniferous shelf chert is absent only in pebble suites from Dorset and Normandy, but is present elsewhere in southern Britain. The chert was probably derived from the Anglo-Brabant and Welsh Massifs and possibly from the Pennine High (Chap. III). Sandstone clasts are present in low abundance in most of the pebble suites studied, but form an important constituent of pebble suites locally. In certain pebble beds, ironstone (Sect. 3.3.9) and phosphorite (Sect. 3.3.10) clasts are present in sufficient abundance to facilitate the lateral comparison of their abundances.

The Carboniferous shelf chert phenoclasts contain various

lithotypes, but an assessment of regional variations can not be readily made. However, comparison of the proportions of bioclastic (Sect. 3.2.1.8) or rhombic-pseudomorph (Sect. 3.2.1.10) cherts in the suite has been made and has indicated variations between the pebble suites.

For purposes of presentation and interpretation, ratios of two components were considered less manipulable and instead percentages of two components were calculated, using the simple formula:

$$\frac{X}{X + Y} \times 100 = \text{Pebble index},$$

where X and Y are the proportions of each pebble type by weight or frequency. Six indices have been used during the present investigation:

$$\text{Q:C index} = \frac{\text{Quartz}}{\text{Quartz + T.C.S.C.}} \times 100,$$

$$\text{Q:S index} = \frac{\text{Quartz}}{\text{Quartz + Sandstone}} \times 100,$$

$$\text{S:C index} = \frac{\text{Sandstone}}{\text{Sandstone + T.C.S.C.}} \times 100,$$

$$\text{I:P index} = \frac{\text{Ironstone}}{\text{Ironstone + Phosphorite}} \times 100,$$

$$\text{Dolo-chert index} = \frac{\text{R.B.C.}}{\text{T.C.S.C.}} \times 100,$$

$$\text{Bio-chert index} = \frac{\text{B.C.C.}}{\text{T.C.S.C.}} \times 100,$$

where, T.C.S.C. = Total Carboniferous shelf chert (Sect. 3.3.4),

R.B.C. = Rhomb-bearing Carboniferous shelf chert (Sect. 3.2.1.10),

B.C.C. = Bioclastic Carboniferous shelf chert (Sect. 3.2.1.8).

It has been recognised in this (Sect. 4.2.3) and earlier studies (Wells & Gossling, 1947; Sneed & Folk, 1958; P. Allen, 1967a), that significant differences in composition occur with variation in clast size. These variations are of less importance if samples of similar grain-size are selected and compared. Sample grain-size selections were made for most horizons, but it was not possible for all horizons, due either to the scarcity of phenoclasts, or the pebble-size range of the suites.

Care was taken in collection of samples to prevent preferential sampling of certain phenoclast types. Both the matrix and phenoclasts were collected and sieved if unconsolidated, acid-leached if in a calcareous matrix or examined on cut surfaces if cemented by goethite. Sieving was carried out using a Rotap shaker, with the collection of clasts greater than -2.00 ø in diameter (Udden-Wentworth scale) in half ø sieves. The mean pebble length for the majority of the pebble beds studied was 10-15mm and clasts of this size were trapped in the -2.75 ø and -3.00 ø sieves. Hence, between -2.50 ø and -3.00 ø, quarter ø sieve divisions were used (Fig. 4.1).

Samples of 100 or more pebbles trapped in the -2.75 ø sieve were used where possible. Where sample size prevented this, coarser and finer grained fractions were incorporated in the material for comparison.

Pebble-breakage was a problem encountered with some lithotypes and resulted in a greater proportion of friable lithotypes in the finer-grained fractions. Where possible, fragments from broken clasts were counted once.

4.1.1 Statistically significant variations in abundance (operator, sampling and natural errors)

Compositional variations in the pebble suites studied are of four principal types:

1. geographical variations,
2. stratigraphical variations,

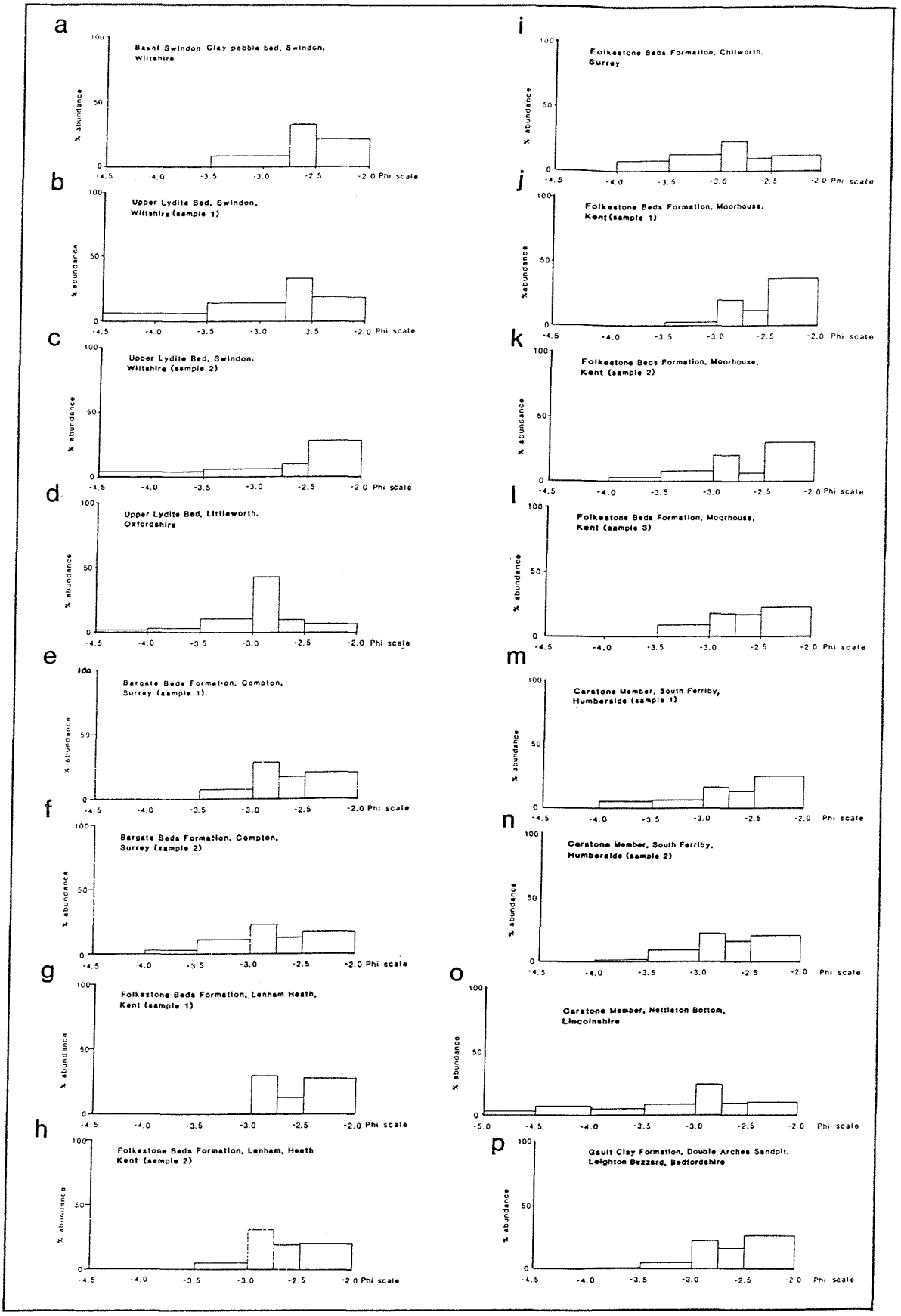


Figure 4.1 Grain-size histograms for selected Upper Jurassic and Lower Cretaceous pebble beds (pebble grade only).

3. grain-size variations, and
4. inter-sample variations.

1. geographical variations: these are observed in the composition of phenoclast assemblages from the same stratigraphic horizon (e.g. pebble beds of earliest nutfieldiensis Zone age in the Isle of Wight, Surrey and Oxfordshire; Fig. 4.2).

2. stratigraphical variations: differences in the composition of pebble suites from distinct closely spaced stratigraphical levels from the same locality are noted in some of the areas studied (e.g. Lower Greensand Group of Redcliff, Isle of Wight; Fig. 4.3; Table 4.1).

3. grain-size variations: differences in the composition of the detrital assemblages are also seen in the examination of assemblages from different grain-sizes (e.g. Sandrock Formation of Compton Bay, Isle of Wight; Table 4.2).

4. inter-sample variations: these occur between samples from the same horizon, locality and of the same size-fraction (e.g. Sandrock Formation, Compton Bay, Isle of Wight, Fig. 4.4; Table 4.3).

Stratigraphical and geographical variations are geologically the most interesting, but before they may be interpreted, grain-size and inter-sample variables have to be considered. Grain-size variation is readily counteracted by the selection and comparison of sieved samples of the same size grade. Inter-sample variations cannot be removed by selection of the study sample and three main sources for this error exist.

1. Errors may result from preferential selection during sampling. The probability of such errors was reduced by sample-collection from random points at the exposure and collection of large samples including both phenoclasts and matrix.

2. Errors may occur during the processing of the samples in the laboratory. Samples were examined and identified using a binocular microscope. For the majority of phenoclast lithotypes this is relatively simple, but identification of certain phenoclast types (e.g. microcrystalline or fine-grained siliceous lithotypes) were, in some samples, tentative. One operator carried out the study (Ross Garden) and errors resulting from

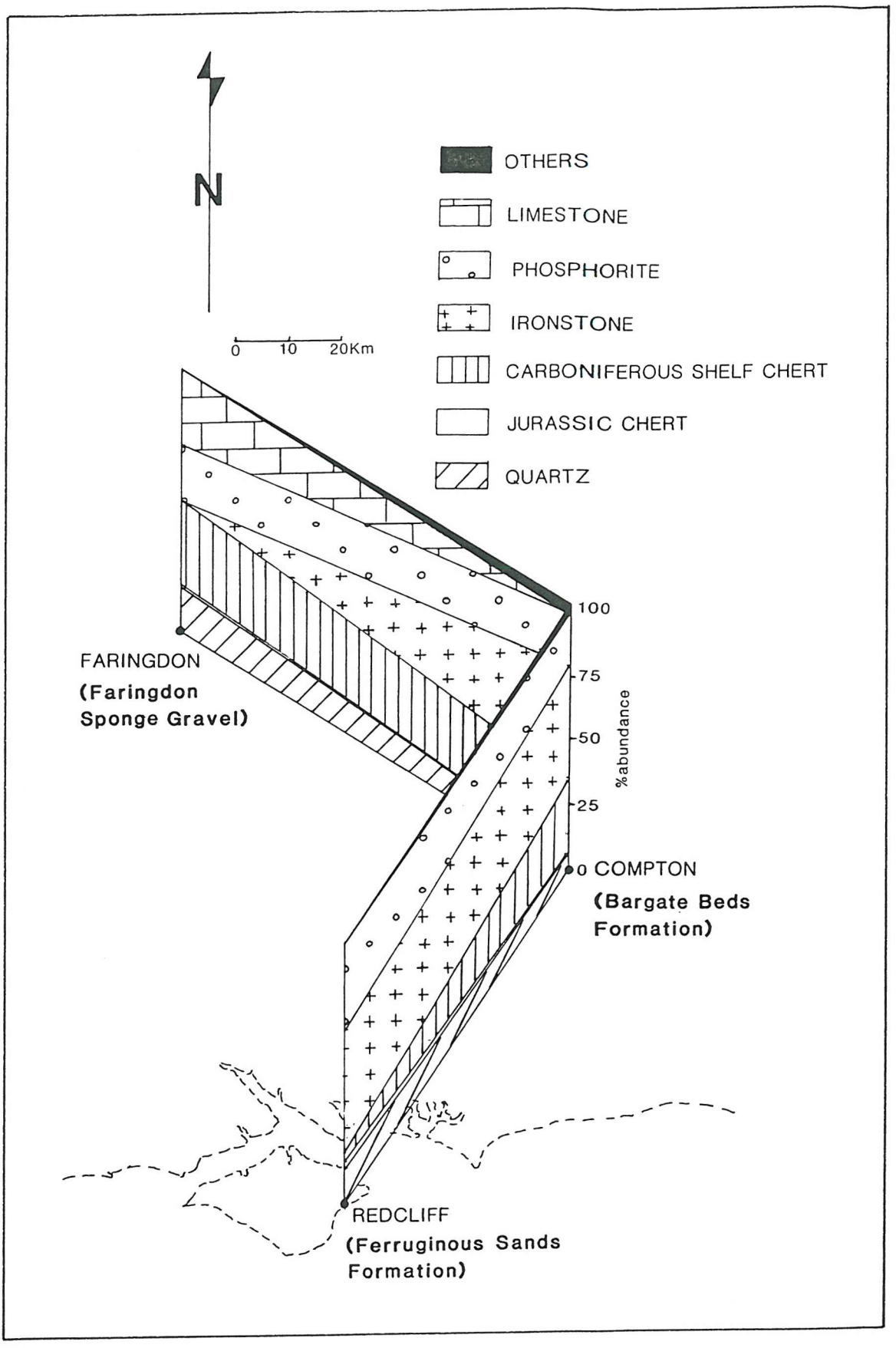


Figure 4.2 A geographical-variation diagram for the composition of pebble beds of nutfieldiensis Zone age in southern England (-2.75 ø fraction).

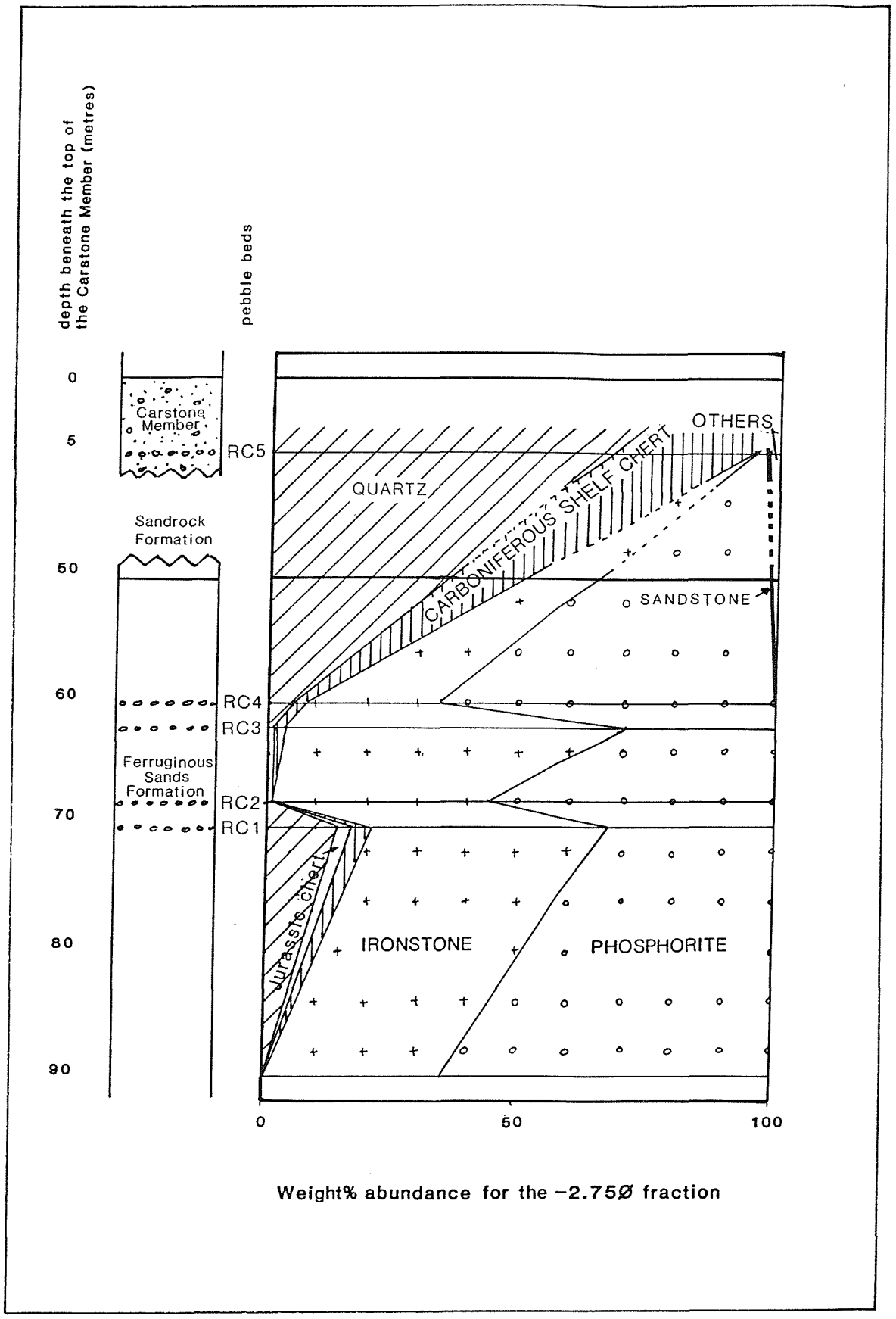


Figure 4.3 A stratigraphical-variation diagram for the composition of the Lower Greensand Group pebble beds at Redcliff, Isle of Wight (-2.75 ø fraction).

Location: Redcliff, Isle of Wight.
Horizon: Ferruginous Sands Formation.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% Weight

Composition	RC1 12fs4	RC2 12fs5	RC3 12fs6	RC4 12fs7	Mean
Quartz	12.5	1.0	0.5	1.5	4
Jurassic chert	2.0	-	-	-	1
Carboniferous shelf chert	3.0	<0.5	0.5	1.0	1
Ironstone	50.5	47.5	88.0	63.0	62
Phosphorite	32.0	51.5	11.0	34.5	32
Number of clasts	c.221	c.257	c.1745	c.1042	
Q:C index	81	82	29	64	64
I:P index	61	48	89	64	66

where
pebble bed RC1 is 16m beneath the base of the Sandrock Formation,
pebble bed RC2 is 15m beneath the base of the Sandrock Formation,
pebble bed RC3 is 11m beneath the base of the Sandrock Formation, and
pebble bed RC4 is 10m beneath the base of the Sandrock Formation.

Table 4.1 Compositions of the Ferruginous Sands Formation pebble suites at Redcliff, Isle of Wight.

a QUARTZ ABUNDANCE

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight, 10c1.	43%	NM	56%	NM	76%
Pebble bed CB4, Sandrock Formation Compton Bay, Isle of Wight, 10sr13.	50%	83%	90%	96%	94%
Faringdon Sponge Gravel, Faringdon, Oxfordshire, 130fsg3.	0	0	15%	25%	35%
Carstone Member, Nettleton Bottom, Lincolnshire, 205c1.	0	NM	13%	17%	37%
Carstone Member, South Ferriby, Humberside, 203c2.	0	0	17%	30%	63%

b CARBONIFEROUS SHELF CHERT ABUNDANCE

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight, 10c1.	49%	NM	38%	NM	22%
Pebble bed CB4, Sandrock Formation Compton Bay, Isle of Wight, 10sr13.	0	3%	1%	3%	trace
Faringdon Sponge Gravel, Faringdon, Oxfordshire, 130fsg3.	0	NM	28%	38%	36%
Carstone Member, Nettleton Bottom, Lincolnshire, 205c1.	27%	NM	32%	15%	9%
Carstone Member, South Ferriby, Humberside, 203c2.	0	5%	5%	4%	4%

c Q:C INDEX

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Pebble bed CB6, Carstone Member, Compton Bay, Isle of Wight, 10c1.	47	NM	61	NM	78
Pebble bed CB4, Sandrock Formation Compton Bay, Isle of Wight, 10sr13.	100	97	99	97	100
Faringdon Sponge Gravel, Faringdon, Oxfordshire, 130fsg3.	NM	NM	35	40	49
Carstone Member, Nettleton Bottom, Lincolnshire, 205c1.	<1	NM	29	53	80
Carstone Member, South Ferriby, Humberside, 203c2.	NM	<1	77	88	94

d SANDSTONE ABUNDANCE

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Folkestone Beds Formation, Moorhouse, Kent, 186fb6.	0	9%	32%	13%	5%
Folkestone Beds Formation, Lenham Heath, Kent, 189fb1.	NM	NM	71%	38%	52%
Pebble bed CB4, Sandrock Formation Compton Bay, Isle of Wight, 10sr13.	17%	8%	7%	0	3%

e IRONSTONE ABUNDANCE

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Bargate Beds Formation, Compton, Surrey, 176bb1.	25%	22%	27%	33%	46%
Woburn Sands, Haddenham, Cambridgeshire, 198ws2.	0	0	7%	11%	5%
Carstone Member, Hunstanton, Norfolk, 199c1.	5%	12%	20%	NM	NM
Carstone Member, Nettleton Bottom, Lincolnshire, 205c1.	33%	NM	32%	51%	51%

f PHOSPHORITE ABUNDANCE

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Upper Lydite Bed, Swindon, Wiltshire, 71ulb2.	94%	NM	71%	63%	72%
Faringdon Sponge Gravel, Faringdon, Oxfordshire, 130fsg3.	16%	NM	18%	6%	8%
Carstone Member, Nettleton Bottom, Lincolnshire, 205c1.	41%	NM	24%	15%	1%

g I:P INDEX

GRAIN-SIZE PHI-SCALE	-3.5	-3.0	-2.75	-2.5	-2.0
Bargate Beds Formation, Compton, Surrey, 176bb1.	33	34	36	52	68
Carstone Member, Nettleton Bottom, Lincolnshire, 205c1.	45	NM	57	77	98
Carstone Member, South Ferriby, Humberside, 203c2.	< 1	31	84	100	88

Table 4.2 Variations in the abundances of quartz (a), Carboniferous shelf chert (b), sandstone (d), ironstone (e), phosphorite (f) and the Q.C. index (c) and I.P. index (g) with grain size for selected Upper Jurassic and Lower Cretaceous pebble suites.

Location: Compton Bay, Isle of Wight.
Horizon: Pebble bed CB5, Sandrock Formation, Lower Greensand Group.
Grain-size: -2.75Ø.

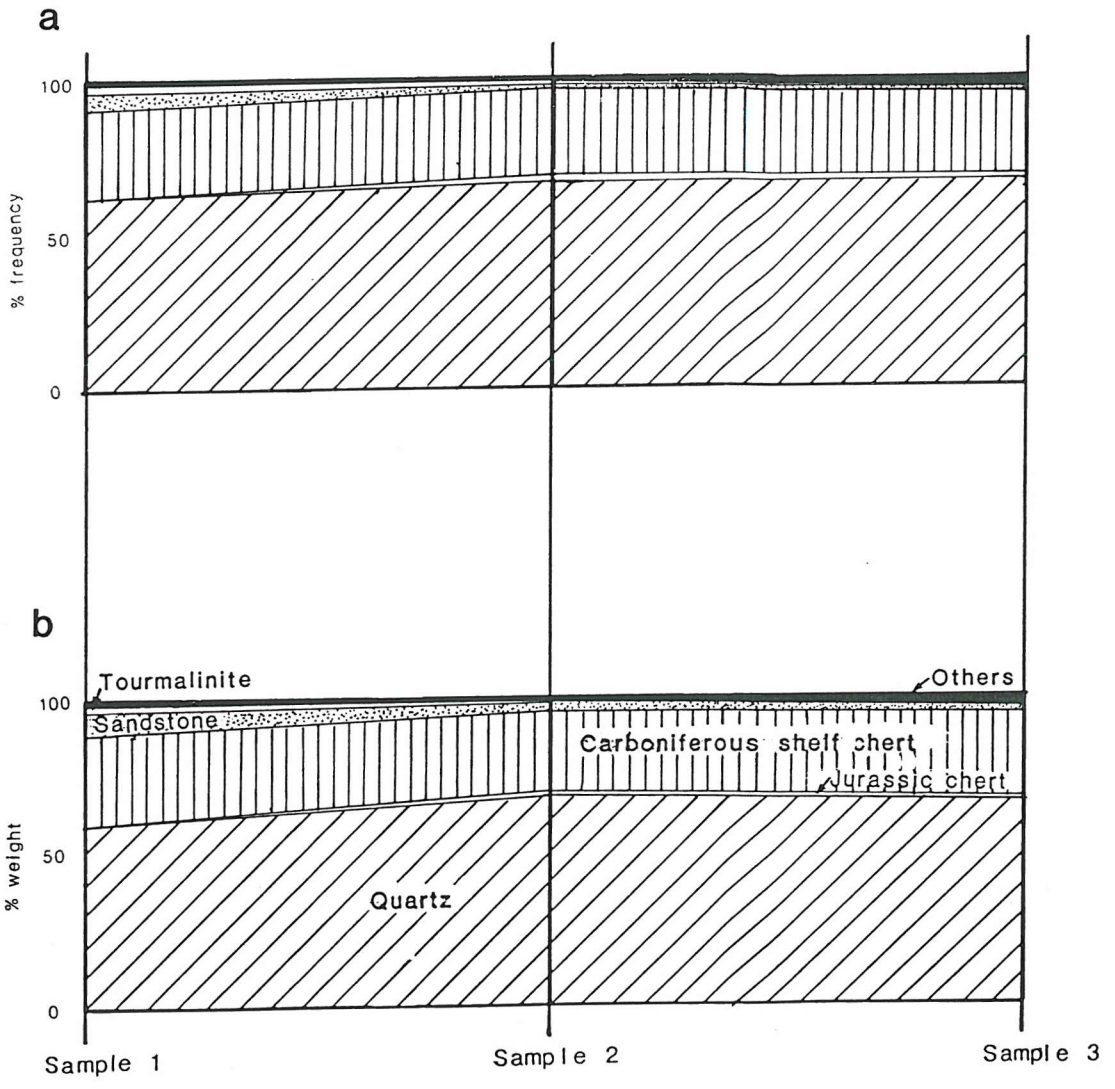


Figure 4.4 A composition-variation diagram for three samples from pebble bed CB5, Sandrock Formation, Compton Bay, Isle of Wight (-2.75 ø fraction).

Location: Compton Bay, Isle of Wight.
Horizon: Pebble bed CB5, Sandrock Formation.
Grain-size: -2.75 ø

Composition	% frequency			Mean	% weight			Mean
	10sr6/1 Sample 1	10sr6/2 Sample 2	10sr6/3 Sample 3	$\bar{X}$	10sr6/1 Sample 1	10sr6/2 Sample 2	10sr6/3 Sample 3	$\bar{X}$
Quartz	62.0	66.5	66.5	65	58.5	68.0	66.0	64
Jurassic chert	-	2.0	1.0	2	-	0.5	1.0	1
Carboniferous shelf chert	29.0	27.0	28.0	28	30.0	26.0	27.0	28
Radiolarian chert	0.5	-	-	<0.5	0.5	-	-	<0.5
Sandstone	6.0	3.0	1.0	3	8.0	4.0	2.0	5
Ironstone	-	0.5	0.5	<0.5	-	0.5	0.5	<0.5
Tourmalinite	1.5	0.5	-	1	2.0	0.5	-	1
Silicified volcanic	1.0.	-	3.0	1	1.0	-	3.5	2
Jasper	-	0.5	-	<0.5	-	0.5	-	<0.5
Number of clasts	180	170	180		180	170	182	
Q:C index	68	70	71	70	63	72	71	70
Q:S index	91	96	99	95	88	95	97	93
S:C index	17	10	3	10	21	13	6	13

Table 4.3 Compositions of three samples from the Sandrock Formation (pebble bed CB5) at Compton Bay, Isle of Wight, as percentage frequencies (a) and weight percentages (b).

operator-bias are expected to have been approximately the same for each sample. The development and refinement of techniques, however, probably did effect the results.

3. The third type of error encountered resulted from the natural variation in a sample. An example is given in Table 4.3 (Fig. 4.4), where three samples from the Sandrock Formation were examined by identical techniques over a short period of time.

For the manipulation of compositional data of a pebble suite, Griffiths (1967) expected clast-populations, for samples from a single locality and horizon, to follow a binomial frequency distribution if sufficiently large.

In the present study, single samples were processed in many cases and therefore it had to be assumed that these approximated to the population-composition. Clearly, such a method is susceptible to anomalous variations and therefore, the significance of minor variations in the phenoclast-assemblage populations needs to be rigorously tested before being accepted.

An interesting feature of the Sandrock Formation samples (Table 4.3) is the difference between the percentage abundances calculated from clast frequencies (the number of clasts of each type) and those calculated from weight of clasts (the weight of clasts of each type). Compositional estimates calculated from clast frequencies deviate from the mean to a lesser extent than estimates calculated by weight of clasts. Weight abundance, therefore, may be a more suitable method for the estimation of the pebble-suite composition in large samples, but in general, is a less sensitive measure of composition. Krumbein & Rasmussen (1941) detected similar variations in the investigation of heavy mineral detrital suites.

4.1.2 Chi-squared testing and the significance of geographical and stratigraphical variations in detrital assemblages

Detrital assemblages from different locations or horizons are commonly sufficiently different to allow rapid subjective assessment of variations. However, this is not always the case and an objective

means of comparison is necessary. In the absence of data suitable for the calculation of population means and standard deviations, comparisons were made of the whole population using the chi-squared test. The chi-squared method tests the probability of a number of samples having been drawn from a single population at random. In the present example, an estimate of the population composition is calculated from the mean of the samples under investigation. The number of degrees of freedom is set at the number of classes minus one for the mean calculated for each sample set. Examples of this common statistical test are described by Griffiths (1967) and Davis (1973).

A problem encountered in the present study was the degree of variation between localities. Pebble assemblages were typically dominated by between two and four phenoclast types (Sect. 3.3). Other minor phenoclast groups occur in low abundance (c. less than 1% to 10%). Cochran (1954) showed that classes with frequencies of less than five needed to be grouped for the chi-squared statistic to hold true. In the pebble assemblages therefore, the principal classes were quartz and Carboniferous shelf chert, with sandstones, phosphorites, ironstones and Jurassic cherts being locally major constituents in the pebble suites. The samples were treated in three ways by chi-squared testing:

1. bulk samples were examined,
2. lithotype abundances recalculated for the exclusion of detritus derived from Jurassic or Cretaceous sources (e.g. phosphorites, ironstones, cherts and limestones) were examined to study the types of detritus derived from the basement massifs,
3. Carboniferous shelf chert suites were tested in some cases to examine whether differences exist in this apparently mature group.

4.1.3 Variations in the composition of the phenoclast assemblages with grain size

A restriction of the clast-size range examined was made since, in a number of cases, the composition of the fine and coarse-grained pebble fractions for the same sample varied significantly. Differences in compositional abundance with grain size probably result from the physical properties of the phenoclast types. Examples of composition/grain size variations are given (Table 4.2).

A negative correlation between grain-size and quartz abundance and a positive correlation between grain-size and Carboniferous shelf

chert abundance is common for the Lower Cretaceous phenoclast assemblages examined. Such trends are recognised from the study of the frequency-percentage data (Tables 4.2a,b,c), but may be obscured by the difference in abundance of other components of the pebble suites. The same variations are recognised more clearly by examination of the quartz-chert index (Table 4.2c). These phenoclast types are the dominant phases in the phenoclast assemblages and they are present in approximately equal abundances. Hence, the variation may be caused by either one or other or both of the components. In this case, the variation probably results from the greater susceptibility of polycrystalline quartz than chert to fracture when grains are undergoing attrition from other pebbles. This is likely to have been the case in coarser grained pebbly sediments. In addition polycrystalline quartz may be less susceptible to abrasion by sand-grade material. This is likely to be the case in finer grained pebbly sediments.

The proportion of ironstone in the samples tends to correlate positively with grain size, in contrast to phosphorite abundance (Tables 4.2e,f,g). This is interpreted as resulting from the larger initial size of the ironstone clasts and the greater susceptibility of phosphorites to abrasion.

4.2 THE COMPOSITION OF THE PHENOCLAST SUITES

The pebble suites are discussed with respect to the six regional divisions recognised in the field investigation (Chap. II). Phenoclast assemblages in each area are described in stratigraphical order.

4.2.1 The phenoclast suites of the Dorset area

The pebble beds of the southwest of England differ in the clast-abundance, clast-morphology and the associated sedimentary facies. The composition of the phenoclast suites from each horizon are also distinct.

4.2.1.1 The Preston Grit Member phenoclast suite

The scarcity of phenoclasts in this bed (Sect. 2.2.1.1)

inhibited the collection of large samples. Pebbles are small, typically less than 8mm in length. Compositionally, the coarse-grained detritus suite is dominated by Carboniferous shelf chert and quartz (Table 4.4).

The cherts are dark rounded silicified limestones and include bioclastic types with foraminifera, crinoids, brachiopods and bryozoa (Sect. 3.2.1.8). Oolitic (Sect. 3.2.1.9) and rhombic-pseudomorph (Sect. 3.2.1.10) cherts are also present. Quartz pebbles are predominantly rounded, granoblastic types (Sect. 3.2.14.1). Fibrous quartz is very sparse.

The chert is of Carboniferous origin and its source probably existed on the Anglo-Brabant or Welsh Massifs. Quartz pebbles could have been derived from any of the surrounding massifs, but their textural maturity indicates that reworking from older pebble beds is likely. The sandstone pebbles may also have been reworked.

4.2.1.2 The middle Purbeck Formation phenoclast suite

Sampling of the middle Purbeck Formation coarse-grained detrital suite was hindered by the scarcity of clasts (Sect. 2.2.1.2). Siliceous extrabasinal clasts are scarce (Pl. 1-6) and large samples cannot be collected with ease. In addition, limestone clasts are present in the pebble-bearing beds and therefore, acid-dissolution is not a feasible method of sample extraction.

The limestone pebbles are dominated by micritic clasts, principally of algal limestone, but include scarce ostracod, gastropod and serpulid bioclastic packstones. These limestone clasts are of intraformational origin.

Two suites of extrabasinal clasts exist in the middle Purbeck Formation:

1. small pebbles and granules (less than 8mm in length) of dark chert and white or translucent quartz. The cherts are of the silicified Carboniferous shelf limestone types (Sect. 3.3.4) and the quartz pebbles are of rounded granoblastic types (Sect. 3.3.1),
2. phosphorites, partially-silicified limestones and silicified-wood pebbles form the second suite. These clasts are exceptionally

Location: Redcliff, Dorset.

Horizon: Preston Grit Member, Corallian Group.

Grain-size: <-1.00 ø

% frequency

Composition	Sample 219pg2
Quartz	43
Carboniferous shelf chert	50
Sandstone	2
Phosphorite	1
Silicified volcanic	2
Jasper	2
Number of clasts	98
Q:C index	46
Q:S index	95
S:C index	4

Location: Harden's Quarry, Acton, Dorset.

Horizon: Intermarine Member, Purbeck Formation.

Grain-size: <-1.00 ø

% frequency

Composition	Sample 253mp22/1
Quartz	8
Carboniferous shelf chert	80
Sandstone	6
Phosphorite	-
Silicified volcanic	6
Jasper	-
Number of clasts	51
Q:C index	9
Q:S index	57
S:C index	7

Table 4.4 Composition of the Preston Grit Member pebble suites, Corallian Group, Redcliff, Dorset (a) and the Intermarine Member pebble suite, Purbeck Formation, Harden's Quarry, Dorset (b).

sparse and very few examples were collected.

A pebble of partially silicified limestone was collected from the Intermarine Member at Worbarrow Bay (Bed 41c of El-Shahat, 1977; Bed WB 145 of Ensom, 1985b). This clast was a partially silicified bioclastic grainstone (Sect. 3.2.6.3), with a fauna indicating derivation from the Portland or Corallian Group limestones.

Silicified wood (Sect. 3.2.4.2) was collected from the Scallop Member, Worbarrow Bay (Bed 52 of El-Shahat, 1977; Bed WB 153 of Ensom, 1985b) and from the New Vein (Bed DB 101, Clements, 1969) at Durlston Bay. These clasts are dissimilar to the silicified wood of the basal Purbeck Formation (Dr. Francis, pers. comm., 1985). However, the state of preservation suggests that a local source is probable.

The clast of phosphorite was 14mm in length and although worn had the form of a Protocardia. The sample was collected from the Chief Beef Member (Bed WB 176 of Ensom, 1985b). A report of a rolled pavlovid ammonite cast from the same bed was made by Ensom (1985a). Both casts resemble the phosphatised fauna of the Kimmeridge Clay Formation and are probably derived from the pallasioides or rotunda nodule beds.

The cross-stratified sands of the Intermarine Member at Harden's Quarry (Sect. 2.2.1.2) contain scarce small extra-basinal pebbles, but do not include limestone clasts. A sample obtained from this locality provided small pebbles up to 6mm in length (Table 4.4). The suite is composed principally of Carboniferous shelf cherts (Sect. 3.3.4.), with lesser amounts of quartz and sandstone. The sample size taken from this locality was necessarily small because of sampling conditions. Hence, errors are likely to be large. The siliceous volcanic clasts are microcrystalline quartzose clasts with a weak lamination (Sect. 3.2.13.1). Similar clasts are present in many of the Lower Cretaceous pebble beds of southern England. Their anomalously high abundance in the Purbeck Formation is probably an artefact of errors in the assessment of composition from a small sample size and the relatively fine grain size of the suite.

4.2.1.3 The upper Purbeck Formation phenoclast suite

The pebble bed in the "Unio" Member described by West & Hooper (1969) was not exposed at the time of this study, but samples in the

collection of Dr.I.M.West were examined. Without knowledge of the original form of the bed and the subsequent history of the samples, it was considered that a quantitative analysis was inappropriate.

The pebble bed in the "Unio" at Friar Waddon contains Portland Limestone Formation and Kimmeridge Clay Formation detritus (West & Hooper, 1969). Samples of Portland limestone are predominantly of bioclastic packstones and wackestones, including calcitized Rhaxella spiculites. Oolitic and bioclastic grainstones were not observed. A number of the limestone clasts were partially silicified and Portland Limestone Formation cherts were also present in the suite. The abundance of low-energy lithotypes (e.g. mudstones and wackestones) and the absence of high-energy lithotypes (e.g. oolites and coarse-grained bioclastic grainstones) suggests that the phenoclasts were derived from the western basin-type facies of the Portland Limestone Formation described by Townson (1975; open lagoon area, Fig. 3.2).

The clast of chert with a possible Aptyxiella portlandica gastropod described by West & Hooper (1969) differs from the cherts of the top Winspit Member (Roach Beds) on the Isle of Portland, the horizon at which such gastropods are common. It contains neither ooids nor coarse-grained bioclastic matter. Derivation from the south of Friar Waddon is therefore uncertain.

The phosphorite clasts described by West & Hooper (1969) are reminiscent of those noted in phosphate nodules in the upper Kimmeridge Clay Formation at Ringstead Bay (Arkell, 1947a; p.82), but sources probably existed in other parts of southern Dorset.

Evidence for derivation of coarse-grained detritus from sources other than the Kimmeridge Clay and Portland Limestone Formations is scarce. Coarse-sand grains of structureless, spherulitic lutecite are present in the bed, but these are dissimilar to the siliceous replacements of evaporites in the basal Purbeck Formation. They are possibly silicified bioclast fragments from a Portland Limestone Formation source. Rare goethite ooids are present in the "Unio" Beds at Friar Waddon and are conceivably an important provenance indicator. Goethite and berthierine ooids are present in a number of horizons in the Jurassic rocks of Dorset, for example the Inferior

Oolite (Penn et al., 1980) and in the basal Kimmeridge Clay Formation (Brookfield, 1973a). The association of oolitic goethite grains with clasts of Portland and Kimmeridgian detritus suggest that a local exposure of the Abbotsbury Ironstone, which outcrops a short distance to the west and south of Friar Waddon, was a probable source horizon.

The sands associated with the Friar Waddon "Unio" Bed are feldspar- and tourmaline-rich. Exotic extrabasinal phenoclasts, other than polycrystalline quartz, are scarce but grains of quartz with acicular tourmaline (Sect. 3.2.11.1) have been found. The "Unio" Member sands differ distinctly from the quartz arenites of the Scallop Member (middle Purbeck Formation) and have a distinctly Cornubian "air". Pebbles of dark silicified limestone of the types present in the Corallian Group and middle Purbeck Formation were not found.

The "Unio" Member at Stair Hole contains very few pebbles, but clasts of oolitic grainstone and packstone (Sect. 3.2.7.4) and silicified Rhaxella packstone (Sect. 3.2.1.3) have been found. The clasts resemble lithotypes typical of the Portland Limestone Formation and the oolites were probably derived from the Winspit Member.

4.2.1.4 The Wessex Formation phenoclast suite

The coarse-grained horizons in the Wessex Formation of Dorset differ distinctly from those of the Purbeck Formation and Corallian Group. Pebbles are abundant and range in size from 4-45mm. The composition of the suites also differs from that of the older pebble beds. Kirkaldy (1947a) and P.Allen (1972) both examined the Wessex Formation pebble beds of this area and demonstrated that the pebble-grade detritus was of western origin. In an examination of the lateral variations in the Coarse Quartz Grit (Wessex Formation) from Durdle Door to Worbarrow Bay, only minor compositional differences in the pebble suites occur over this short distance (Fig. 4.5; Table 4.5).

The Wessex Formation pebble suites are distinguished from those of the Corallian Group and Purbeck Formation pebble beds by the high proportion of quartz and the presence of tourmalinite pebbles. The

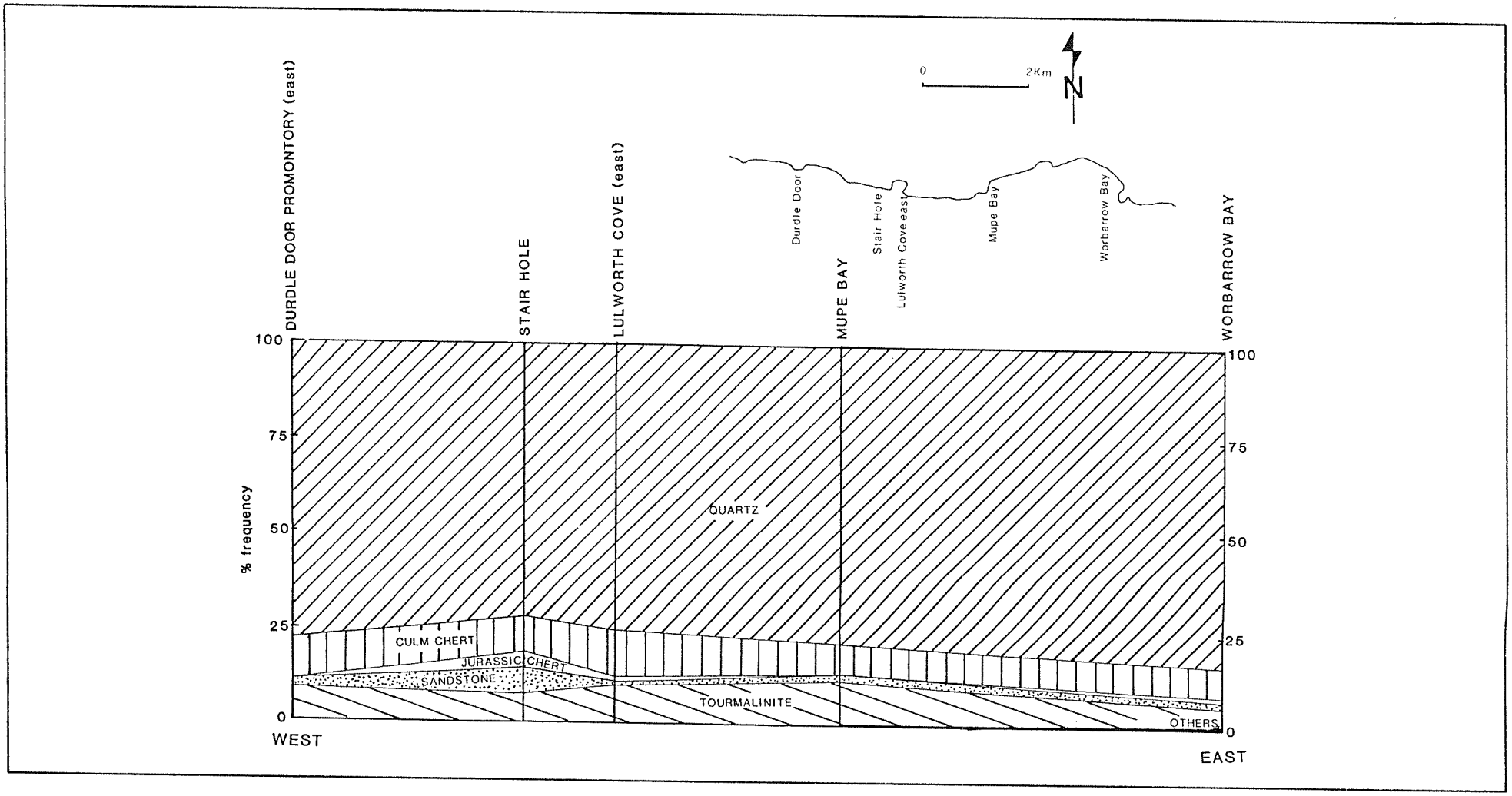


Figure 4.5 A geographical-variation diagram for the composition of the Coarse Quartz Grit, Wessex Formation, Dorset (-2.75 ø fraction).

Location: East Dorset.
Horizon: Coarse Quartz Grit, Wessex Formation.
Grain-size: -2.75 ø
% frequency and % weight

Composition	D.D.P. 2cqg3	S.H. 54cqg1	L.C. 97cqg3	M.B. 5cqg3	W.B. * 6cqg3	Mean
Quartz	78.5	72	75	78.0	83	77
Jurassic chert	-	2	1	-	1	1
Radiolarian chert	10.5	9	12	8.0	8	10
Sandstone	2.0	6	1	2.0	2	3
Tourmalinite	9.0	11	10	12.0	5	9
Silicified volcanic	-	-	-	-	1	<0.5
Jasper	-	-	1	-	-	<0.5
Number of clasts	c.216	138	120	221	99	
Q:S index	98	92	99	98	98	97

where
D.D.P. = Durdle Door promontory east,
S.H. = Stair Hole,
L.C. = Lulworth Cove east,
M.B. = Mupe Bay,
W.B. = Worbarrow Bay.

* = -3.0 ø

Table 4.5 Compositions of the Coarse Quartz Grit pebble suite Wessex Formation in southern Dorset.

quartz is predominantly of white granoblastic type (Sect. 3.2.14.1), but fibrous quartz (Sect. 3.2.14.2) is a subordinate phase (5-10%). This is probably a good indicator of the immaturity of the detrital suites.

The chert pebbles are argillaceous and include radiolaria and rhombic pseudomorphs (Sect. 3.2.2), but benthonic bioclasts are rarely found. The detritus is similar to the silicified mudstones and cherts of Dinantian age in southwest England.

Tourmaline-bearing clasts are common and include foliated and unfoliated tourmalinized quartzites and cherts (Sect. 3.2.11.3), pneumatolitic breccias (Sect. 3.2.11.4) and quartz-tourmaline vein rocks (Sect. 3.2.11.2). The most distinctive of these are pebbles of quartz with fine, purple-blue tourmaline needles and rosettes (Sect. 3.2.11.1), which are reminiscent of luxullianite (Wells, 1946). Most of the tourmalinites were probably derived from the granitic Massifs of Cornubia and Armorica. Foliated-tourmaline rocks, also noted by P.Allen (1972), are not similar to the pneumatolitic tourmalinites of southwest England and are probably of metamorphic origin. An Armorican source is likely for such clasts. P.Allen (1969) suggested possible derivation of tourmalinites from Galicia (Spain) or the Appalachians (U.S.A.), but there is little conclusive evidence of such far-travelled detritus.

Clasts of red chert or jasper (Sect. 3.2.15) are relatively common in the Wessex Formation pebble beds of Dorset (1-2%), but are present as a minor phase. These include colloform and spherulitic forms, but more commonly the jaspers are composed of micro-quartz cut by veins of colourless quartz. The jaspers are similar to cherts found in association with volcanics (Hein et al., 1983). Jaspers are reported from Devon and Cornwall (Selwood et al., 1984), but such lithotypes are not common in southwest England. An Armorican source is more probable.

Weathered chert pebbles are present in trace or minor amounts (1-5%) in the Wessex Formation. The chert clasts are present in both the Coarse Quartz Grit and in channel-sands and are generally larger than the quartz and tourmalinite pebbles. The weathered cherts include silicified oolitic grainstones and packstones (Sect.

3.2.1.2), bivalve, Pachastrella and Rhaxella packstones and wackestones (Sects. 3.2.1.1, 3.2.1.3) and are derived from a variety of horizons in the Portland Limestone Formation. The abundance of oolitic and coarse-grained bioclastic cherts indicates that a significant proportion of the detritus was derived from the swell facies of the Portland Limestone Formation (Fig. 3.2). This is supported by the presence of a clast with a silicified gastropod, probably Aptyxiella portlandica, in the Coarse Quartz Grit at Stair Hole (Pl. 9-3).

4.2.1.5 The Gault Clay Formation phenoclast suite

The pebble beds at the base of the Gault Clay Formation in Dorset differ distinctly between the exposures in the east and those in the west of the area. In the east of Dorset, the suites are bimodal, and include:

1. small rounded siliceous pebbles of quartz, dark chert, tourmalinite and sandstone, and
2. a coarse-pebble to cobble-grade fraction of pale, weathered cherts and dark phosphorites.

In the west, the pebble suite is composed only of small rounded siliceous clasts of the first group (Fig. 4.6; Table 4.6).

The pebble beds at Golden Cap (Sect. 2.2.1.4) and the finer grained fraction from east Dorset have a high quartz content (65-80%), which includes subordinate fibrous quartz (Sect. 3.2.14.2). The cherts are silicified mudstones which include radiolaria and rhombic-pseudomorphs (Sect. 3.2.2) and are veined by quartz. The cherts resemble silicified mudstones from the Lower Carboniferous rocks of southwest England. The tourmalinites are predominantly of microcrystalline quartz and tourmaline (tourmalinized mudstones or cherts; Sect. 3.2.11.3), but pebbles of tourmalinized breccia and coarsely crystalline granoblastic quartz with acicular tourmaline (Sect. 3.2.11.1) are also present. Sandstone clasts are typically of quartzites (Sect. 3.2.8.1) and lithic arenites (Sect. 3.2.8.2). Deformed quartzites are moderately common (Sects. 3.2.8.1, 3.2.14.3).

The coarse-grained phenoclast suite is composed almost entirely of pale, weathered chert. Rhaxella cherts (Sect. 3.2.1.3) predominate, but oolitic and coarse-grained bioclastic cherts (Sects.

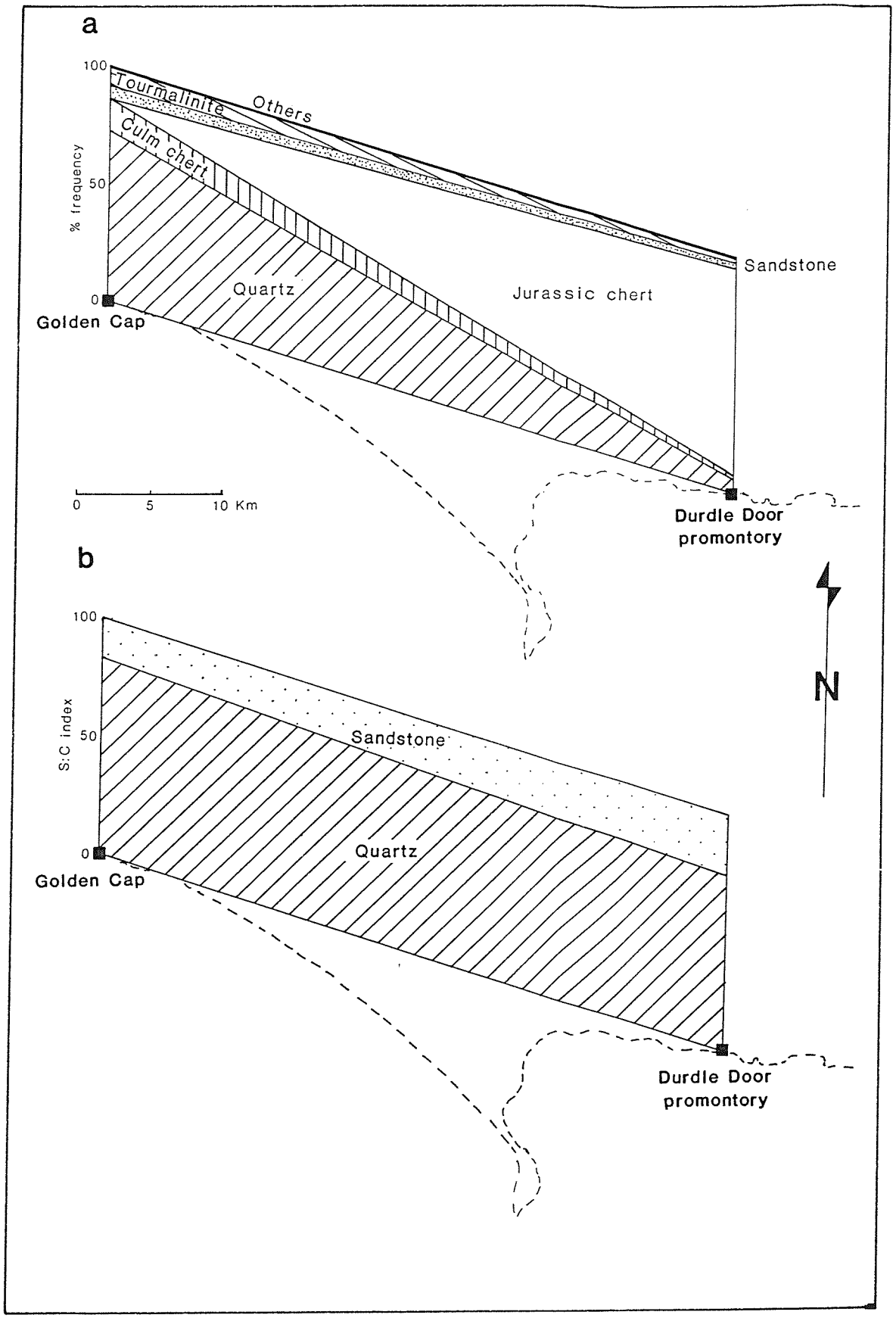


Figure 4.6 A geographical-variation diagram for the composition of the basal Gault Clay Formation pebble bed in Dorset (less than -2.00 ø fraction).

Location: Dorset.
Horizon: Basal Gault Clay Formation pebble bed.
Grain-size: < -2.00 ø
% frequency and % weight

Composition	West 17g1,2,3,4	East 3g8	Mean
Quartz	72.0	6	39
Jurassic chert	-	88	44
Radiolarian chert	7.0	2	5
Sandstone	15.0	2	9
Ironstone	-	1	1
Tourmalinite	6.0	1	4
Number of clasts	414	c.126	
S:C Index	83	77	80

where
West = Golden Cap,
East = Durdle Door promontory.

Table 4.6 Compositions of the basal Gault Clay Formation pebble suite at Durdle Door promontory and Golden Cap, Dorset.

3.2.1.1, 3.2.1.2) are also present. This suite covers the range of chert types present in the Portland Limestone Formation, but the abundance of oolitic and coarse-grained bioclastic cherts implies derivation of the clasts from the swell facies. Purbeck Formation cherts are less common as detrital clasts, forming 10-20% of the Jurassic chert. The Purbeck Formation cherts include silicified evaporites from the basal Purbeck Formation and silicified fresh-water limestones from the Cherty Freshwater Member. Pebbles of phosphorite are scarce (1-4%) and are rounded to subangular. The phosphorites include bivalve (Protocardia) and ammonite casts and are likely to have been derived from the upper Kimmeridge Clay Formation.

4.2.1.6 Comparison of the phenoclast suites from the Dorset area

The pebble beds of southern Dorset fall into two categories, those of the Corallian Group and the middle Purbeck Formation and those of the Wessex and Gault Clay Formations (Fig. 4.7). The "Unio" Member pebble suite has similarities to the second category.

The similarity of the extrabasinal suites from the Corallian Group and the middle Purbeck Formation is striking. Both contain chert clasts derived from Carboniferous limestones. Source areas with Carboniferous limestones probably outcropped on the Welsh and Anglo-Brabant Massifs to the north of Dorset. The compositional difference between the Corallian Group and middle Purbeck Formation extrabasinal pebble suites suggests that they are of differing origins. However, the small sample populations studied from each horizon probably have large errors. A clear distinction between the two suites has not been confirmed.

The extrabasinal detritus of the Wessex and Gault Clay Formations do not include chert clasts from Carboniferous limestones and much of the detritus is of western origin. The abundance of radiolarian cherts and poorly rounded pneumatolitic clasts suggests that the bulk of Wessex Formation coarse-grained detritus in Dorset was derived from the Cornubian Massif. A significant but smaller component of clasts in these suites was probably reworked from Armorica. The scarcity of quartzite pebbles suggests that Triassic pebble beds did not contribute significantly to the Cretaceous pebble suites.

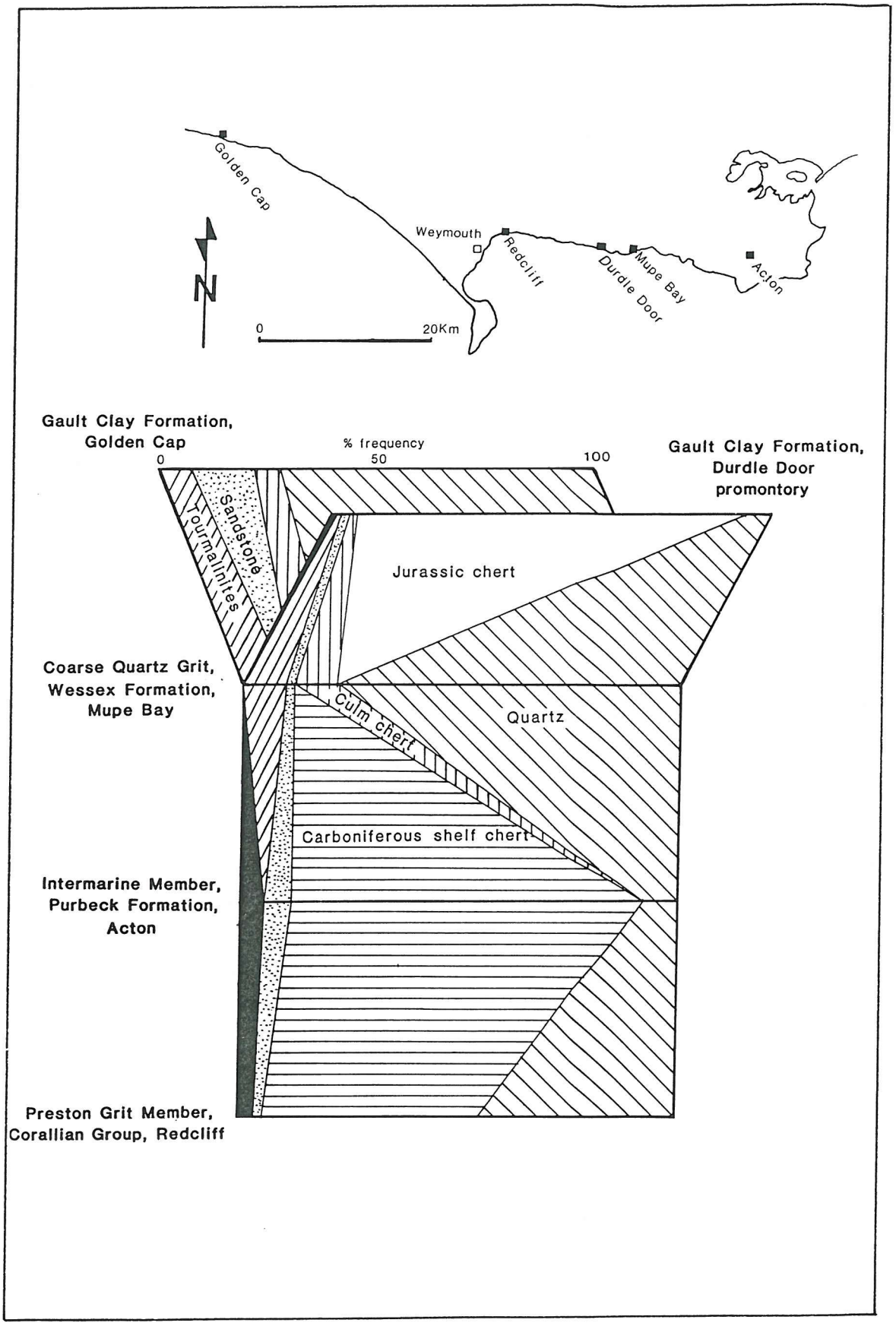


Figure 4.7 A stratigraphical-variation diagram for the composition of Upper Jurassic and Lower Cretaceous pebble beds in Dorset (less than -2.00 ø fraction).

The two pebble-suite categories in Dorset are also distinguished by the abundance and composition of locally derived clasts. The Corallian Group pebble bed studied contains minor amounts of phosphorite of indistinguishable origin. The middle Purbeck Formation contains minor quantities of detritus derived from Upper Jurassic source rocks, but it is not until the deposition of the upper Purbeck Formation that such material was locally common. The Lower Cretaceous pebble beds contain Upper Jurassic clasts principally of chert and phosphorite. Limestone pebbles have not been recorded from the Wessex and Gault Clay Formation phenoclast suites.

4.2.2 The phenoclast suites of the Isle of Wight area

The Late Aptian and Early Albian Lower Greensand Group pebble beds of the Isle of Wight have been studied and although they are of similar age, they differ significantly in appearance, clast-morphology and composition. The pebble beds are separable into those of the Ferruginous Sands Formation, Sandrock Formation and Carstone Member.

4.2.2.1 The Ferruginous Sands Formation phenoclast suite

The pebble beds of the Ferruginous Sands Formation (Sect. 2.2.2.1a) are notable for their high ironstone and phosphorite contents. Siliceous clasts are present as subordinate or minor phases (1-30%) and are of dark silicified limestones of Carboniferous origin and quartz. Pale weathered chert clasts are present, but are scarce in most horizons.

Four Ferruginous Sands Formation pebble beds have been sampled at Redcliff (Fig. 4.3, Table 4.1). Pebble beds RC 1, RC 2, RC 3, RC 4 in the Redcliff section are 16m, 15m, 11m and 10m respectively below the base of the Sandrock Formation (Sect. 2.2.2.1b). Bed RC 1 is correlated by Casey (1961) with the pebble bed at the base of Fitton's Group XIII (Fig. 4.2) and is considered to be of earliest nutfieldiensis Zone age.

The ironstone clasts of the Ferruginous Sands Formation are composed of microcrystalline, homogeneous and laminated goethite, or goethite-cemented quartz arenite (Sect. 3.2.9.5). The subangular clast-morphology of these clasts is consistent with minimal transportation and local derivation. Phosphorite phenoclasts are

less angular than the ironstones, but well preserved bioclast casts (Sect. 3.2.10.4) are abundant. The phosphorites are composed of microcrystalline phosphate, with or without glauconitic quartz sand (Sects. 3.2.10.1, 3.2.10.2). Bioclast casts include fragments of perisphinctid ammonites (Pavlovia) and are from an upper Kimmeridge Clay Formation source. Other perisphinctid ammonites have also been found and casts of the bivalves Pleuromya and Protocardia are common (Pl. 20-1). The association of ironstones and phosphorites in the pebble beds suggests derivation of both from a similar source area.

Pale chert phenoclasts similar to those in the Redcliff pebble beds are also found in the Ferruginous Sands Formation at Compton Bay (Sect. 2.2.2.1a). At both localities, the pebbles are predominantly of spherulitic lutecite (Sect. 3.2.3.3, Pl. 8-2), but clasts of microquartz with lenticular pseudomorphs (Sect. 3.2.3.1) are also found. The clasts are dated, using pollen grains, as Jurassic in age. Their micro-lithofabrics are consistent with derivation from silicified evaporites in the Purbeck Formation. Portland Limestone Formation cherts have not been recognised in these horizons.

The dark cherts are of silicified limestone and have a Carboniferous fauna. A variety of lithotypes are recognised, including bioclastic, oolitic, intraclastic and peloidal types (Sect. 3.3.4). Rhombic pseudomorphs are common in many of the cherts (Sect. 3.2.1.10). The detritus was derived from partially dolomitized shallow marine limestones of Carboniferous age and sources probably existed on either the Welsh or Anglo-Brabant Massifs, or both.

The quartz clasts are rounded to well rounded and predominantly of equant polycrystalline, "milky" or translucent types (Sect. 3.2.14.1). The scarcity of fibrous quartz or quartz with inclusions indicates that the extrabasinal phenoclast suites are mature and unlikely to be a first-cycle deposit.

4.2.2.2 The Sandrock Formation phenoclast suite

The pebble beds of the Sandrock Formation are commonest in the northwestern part of the Lower Greensand Group outcrop on the Isle of Wight and have been studied at Compton Bay and Coombe Farm (Sect. 2.2.2.1b). Granules and small pebbles are present in sands with

large-scale cross-sets, but are more common as concentrated lags. The phenoclast suites exhibit a greater maturity than those of the Ferruginous Sands Formation and contain little phosphorite or ironstone. The Sandrock Formation pebble suites are dominated by quartz and dark silicified limestones, but also contain minor amounts of sandstone.

The pebble beds of the Sandrock Formation are mature and are principally composed of hard, small siliceous pebbles. Quartz is typically present in greater abundance than chert which is commonly more abundant than sandstone (Fig. 4.8a, Table 4.7). Compositionally the quartz, dark chert and sandstone phenoclast assemblage of the Sandrock Formation is similar to that of the Ferruginous Sands Formation (Sect. 4.2.2.1). The composition was also quartz-dominated, but sandstone clasts were less common. Chert derived from Carboniferous limestones occurs in moderate abundance (Fig. 4.8a).

The pebble bed CB 4 at the base of the Sandrock Formation in Compton Bay is an exception (Fig. 4.9a). In this bed, chert is present as a minor phase (2-3%), but sandstone pebbles are comparatively common (3-7%). The sandstone clasts are of quartz and lithic arenites (Sects. 3.2.8.1, 3.2.8.2) and include clasts cross-cut by thin quartz-veins. The quartz pebbles are rounded and of polycrystalline granoblastic quartz (Sect. 3.2.14.1). Fibrous quartz (Sect. 3.2.14.2) is present in minor amounts (2-4%). The pebbles of chert are of two types. The first and most common group consists of dark, rounded silicified limestones of Carboniferous origin (Sect. 3.3.4) and these are similar to those of the Ferruginous Sands Formation (Sect. 4.2.2.1). The second group of cherts are pale in colour, weathered and are scarce (less than 2.0%). These include clasts with possible lenticular pseudomorphs after gypsum and may be reworked from the basal Purbeck Formation. The pebble suite also includes rare jaspers and possible radiolarian cherts. The suite is distinct from the other Lower Greensand Group pebble beds on the Isle of Wight and is more reminiscent of the Cretaceous pebble beds of Dorset. However, in contrast to the Dorset pebble beds, tourmalinites are not common (less than 2%).

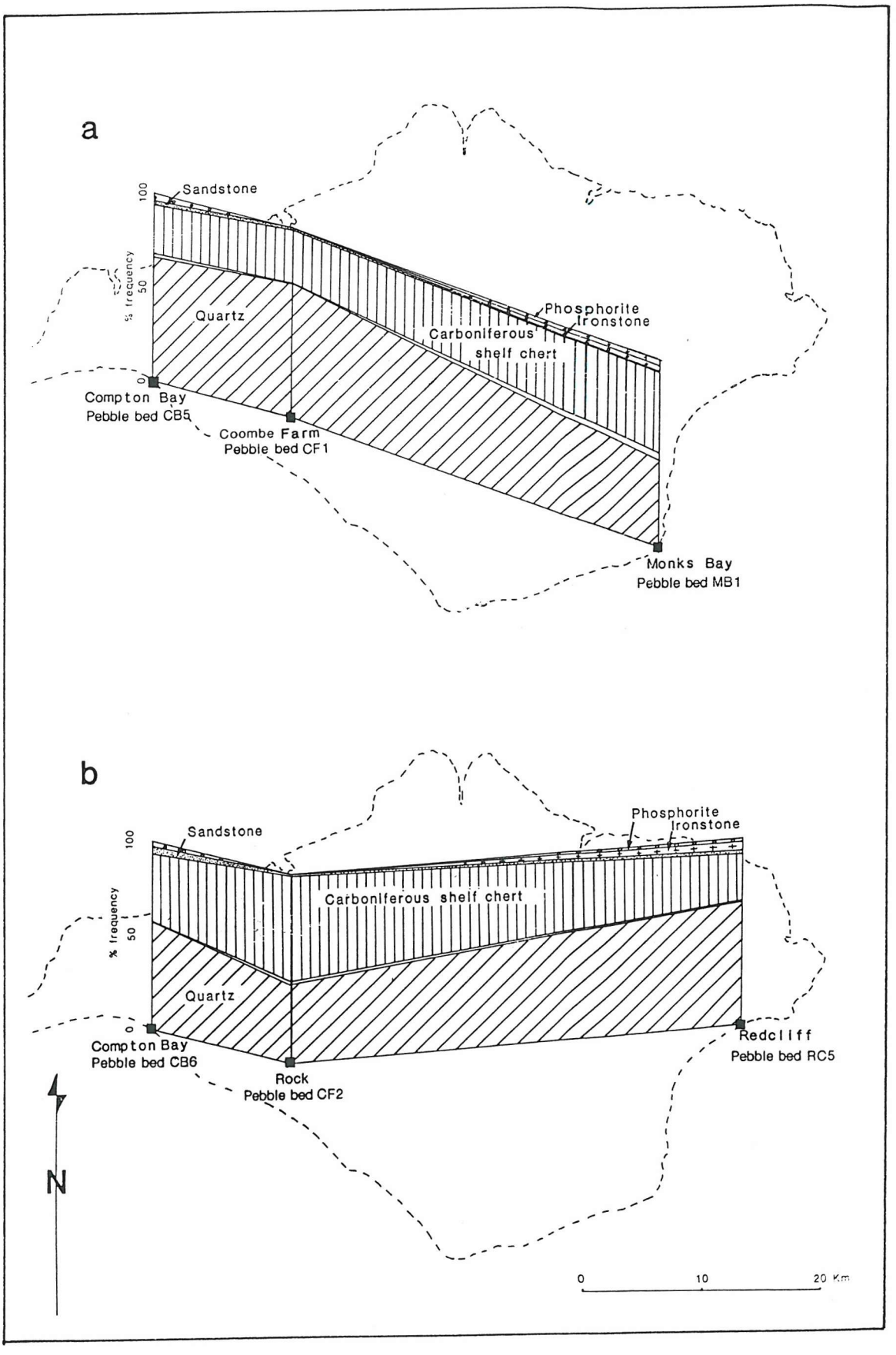


Figure 4.8 Geographical-variation diagrams for the composition of Sandrock Formation (a) and Carstone Member (b) pebble beds in the Isle of Wight (-2.75 ø fraction).

Location: Isle of Wight.
Horizon: Sandrock Formation.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% frequency

Composition	CB4 10sr13	CB5 10sr6/2	CF1 50sr1	MB1 59sr1	Mean
Quartz	93.0	80.0	69.0	63.5	76
Jurassic chert	1.0	0.5	-	4.5	2
Carboniferous shelf chert	1.5	15.5	28.0	25.5	18
Radiolarian chert	-	-	1.5	-	<0.5
Sandstone	4.0	2.0	1.5	1.0	2
Ironstone	-	0.5	-	1.0	<0.5
Phosphorite	-	-	-	4.0	1
Tourmalinite	0.5	1.0	-	-	<0.5
Silicified volcanic	<0.5	0.5	-	0.5	<0.5
Jasper	-	<0.5	-	-	<0.5
Number of clasts	726	1225	225	369	
Q:C index	98	84	71	71	81
Q:S index	96	98	98	98	98
S:C index	74	10	5	4	23

where
Pebble bed CB4 is 33m beneath the base of the Carstone Member at Compton Bay,
Pebble bed CB5 is 5m beneath the base of the Carstone Member at Compton Bay,
Pebble bed CF1 is 9m beneath the base of the Carstone Member at Coombe Farm,
Pebble bed MB1 is from Monks Bay.

Table 4.7 Compositions of Sandrock Formation pebble suites from Compton Bay, Coombe Farm and Monks Bay, Isle of Wight.

4.2.2.3 The Carstone Member phenoclast suite

The Carstone Member is composed of pebbly sands and thin pebble beds (Sect. 2.2.2.1c). The pebble suites are dominated by quartz and Carboniferous shelf chert (Figs. 4.3, 4.8b, 4.9, Table 4.8), but large variations in the proportions of the two major components occur (Q:C index = 45-85). The chert clasts are dark, unweathered or partially impregnated by goethite. They include a complete range of the Carboniferous shelf chert phenoclast types (Sect. 3.3.4). Oolitic cherts (Sect. 3.2.1.9) are present in trace or minor amounts (0.5-2.0% of the total population), but bioclastic and rhombic pseudomorph-bearing cherts (Sects. 3.2.1.8, 3.2.1.10) are common (50-85% of the chert population). Pebbles of quartz are rounded and have granoblastic fabrics (Sect. 3.2.14.1). Fibrous quartz is scarce (less than 1%). Clasts of pale weathered bioclastic chert are present at Rock and Redcliff. They include Pachastrella and Rhaxella cherts (Sects. 3.2.1.1, 3.2.1.3) from the Portland Limestone Formation. Phosphatic fossil casts are rare and Purbeck Formation cherts are not recognised.

4.2.2.4 Comparison of the phenoclast suites from the Isle of Wight area

The pebble beds in the Ferruginous Sands Formation, Sandrock Formation and Carstone Member all contain bimodal pebble suites with extrabasinal and intrabasinal detritus. However, they differ distinctly in composition and clast-morphology.

Extrabasinal phenoclasts: The extrabasinal clasts are composed of approximately equal proportions of quartz and Carboniferous shelf chert. The high Carboniferous shelf chert content and the abundance of rounded granoblastic quartz pebbles indicate that a significant proportion of the pebble suites were derived from the Welsh or Anglo-Brabant Massifs to the north.

An exception to the general pebble suite composition is the basal Sandrock Formation pebble bed at Compton Bay (Pebble Bed CB4). This bed has an immature phenoclast suite with high sandstone and low chert content. The compositional variation could have been produced by a number of conditions:

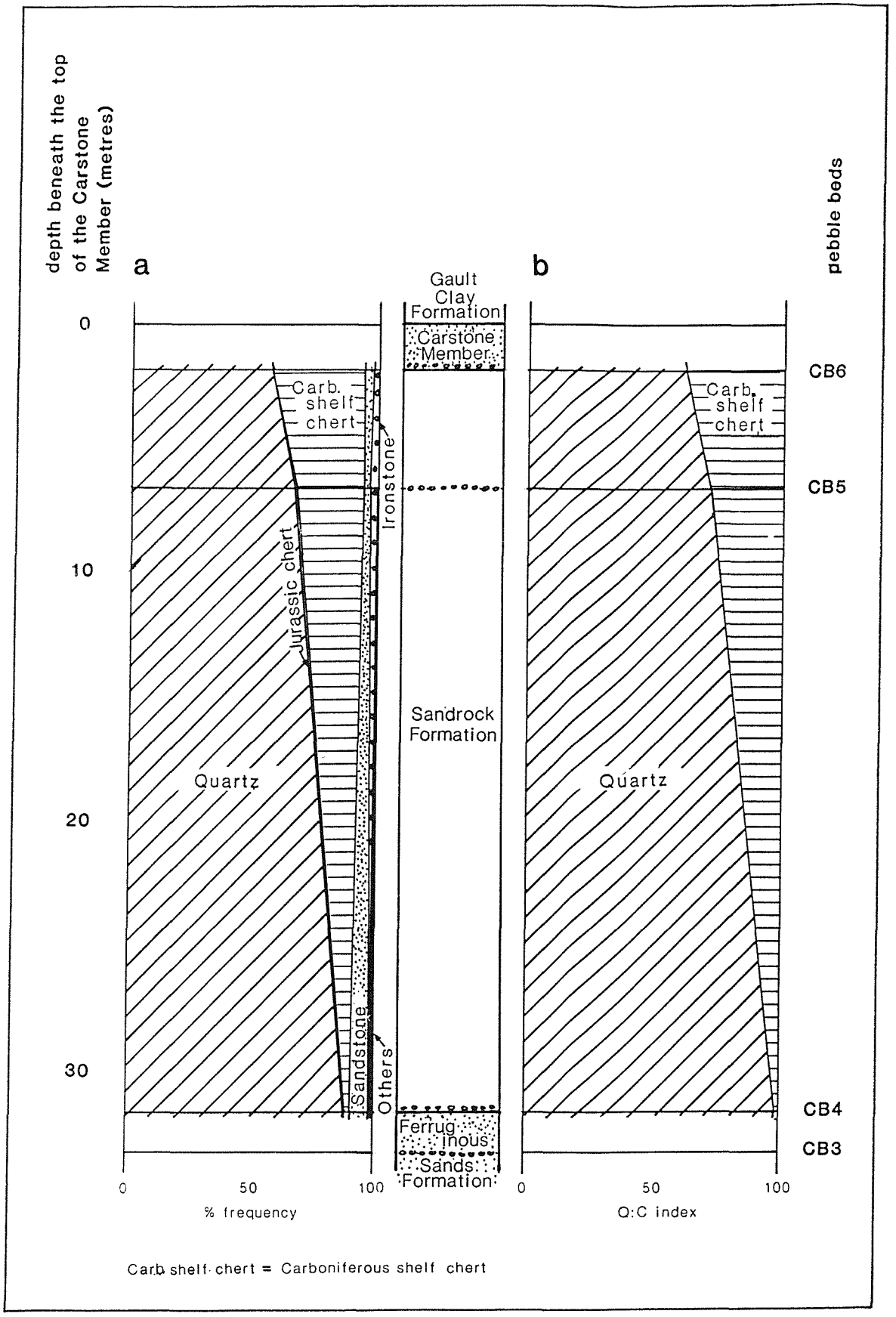


Figure 4.9 Stratigraphical-variation diagrams for the composition (a) and Q:C index (b) of Lower Greensand Group pebble beds at Compton Bay, Isle of Wight (-2.75 ø fraction).

Location: Compton Bay, Rock and Redcliff, Isle of Wight.
Horizon: Carstone Member.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% frequency and % weight

Composition	CB3 10c1	CF2* 50c1	RC5 12c4	Mean
Quartz	61	44.0	56.0	54
Jurassic chert	-	-	0.5	<0.5
Carboniferous shelf chert	33	54.5	37.5	42
Radiolarian chert	-	-	0.5	<0.5
Sandstone	4	1.5	2.0	3
Ironstone	-	-	2.0	1
Phosphorite	2	-	0.5	1
Tourmalinite	-	-	0.5	<0.5
Silicified volcanic	-	-	0.5	<0.5
Number of clasts	166	243	c. 798	
Q:C index	65	45	60	57
Q:S index	94	97	97	96
S:C index	10	2	5	6

where
pebble bed CB6 is at the base of the Carstone Member at Compton Bay,

pebble bed CF2 is at the base of the Carstone Member at Rock (Coombe Farm),

pebble bed RC5 is 19m above the base of the Carstone Member at Redcliff.

* -2.75 ø & -2.50 ø only

Table 4.8 Compositions of the Carstone Member pebble suite from Compton Bay, Rock and Redcliff, Isle of Wight.

1. the mechanical separation of clasts, with concentration of quartz and sandstone pebbles,
2. the destruction of chert pebbles through attrition or weathering,
3. an influx of quartz and sandstone-rich detritus into the basin.

The composition of the pebble bed does not vary significantly with grain-size. Therefore, there is no evidence for the distinct composition resulting from the introduction of clasts of a different size. Quartz and chert pebbles have similar specific densities and therefore separation of the two phases by mechanical processes is unlikely to have occurred.

Chert is less stable than quartz during burial (Folk, 1974) and some of the chert pebbles collected display evidence of post-depositional weathering. In the present study, it was found that Jurassic chert clasts were particularly susceptible to alteration and Carboniferous shelf chert pebbles in the Folkestone Beds Formation (Sect. 4.2.3.2) of the Weald and in the Carstone Member (Sect. 4.2.6.3) of the East Midlands were altered. However, the pebbles of Carboniferous chert in the basal Sandrock Formation pebble bed display little evidence of weathering. This process is unlikely, therefore, to have caused the scarcity of chert clasts in this case.

The possibility of a northern source of quartz and sandstone clasts for the pebbles may be discounted, because the Aptian and Albian phenoclast suites to the north of the Isle of Wight in Wiltshire, Oxfordshire, east Hampshire and west Surrey contain only minor amounts of sandstone pebbles (less than 3%) and high proportions of Carboniferous chert (30-70%).

The possibility of a western source is favourable considering that the Lower Cretaceous pebble beds of Dorset also have high quartz and moderate sandstone contents (Sect. 4.2.1). However, the basal Sandrock Formation pebble suite contains little tourmalinite and a small but significant quantity of Carboniferous shelf chert. This suggests either a mixing of western (quartz and sandstone-rich) and northern (Carboniferous shelf chert-rich) pebble suites, or an alternative source with all three lithotypes.

Derivation from an alternative source with a crystalline basement and deformed sedimentary cover cannot be discounted. Suitable source areas are not known, however. The Albian pebble suites of Normandy were derived from the Cotentin High (Juignet et al., 1973) and are similar compositionally to the Dorset pebble suites. They are distinguished from the basal Sandrock Formation pebble bed, however, by their higher proportion of deformed cherts and quartz clasts. A Cotentin source is therefore improbable, but other crystalline basement sources possibly existed in the English Channel to the south of the Isle of Wight.

The distinctive composition of the basal Sandrock Formation pebble suite probably resulted from the introduction of quartz and sandstone-rich detritus into the Isle of Wight area and mixing with a northern pebble suite. The precise source of the quartz and sandstone pebbles is still in question, but derivation from the west (Cornubia) or the south (Cotentin/Armorica or another high) is probable.

Intrabasinal phenoclasts: Whereas the extrabasinal phenoclast subsuites in the Lower Greensand Group pebble beds in the Isle of Wight are generally uniform in composition, the intrabasinal subsuites differ significantly.

The apparent absence of Portland Limestone Formation chert in the Ferruginous Sands Formation provides an interesting problem as to the source of the Purbeck Formation and Kimmeridge Clay Formation detritus in the beds. The physical separation of detritus from a source with both Portland Limestone Formation and Purbeck Formation cherts is improbable and does not occur in the basal Gault Clay Formation pebble bed in Dorset. It is likely that the Ferruginous Sands Formation detritus was derived from an area with both cherty Purbeck Formation limestones and phosphate nodule-bearing Kimmeridge Clay Formation, but without chert-bearing Portland Group limestones. A suitable source area exists to the north of the Isle of Wight in the Portsdown area (Taitt & Kent, 1958). This indicates a northern provenance for part of the Ferruginous Sands Formation detritus.

The scarcity of Purbeck Formation chert and the presence of silicified Portland Limestone Formation clasts in the Carstone Member

implies a different source from the Ferruginous Sands Formation for these younger pebble beds. Suitable sources for the intrabasinal detritus in the Carstone Member probably existed to the west and northwest of the Isle of Wight in Dorset and Southern Wiltshire.

4.2.3 The phenoclast suites of the Weald area

Samples have been collected from the Bargate Beds, the Folkestone Beds and the Gault Clay Formations in the Weald (Sect. 2.2.3). Only lateral variations in composition of the Folkestone Beds Formation pebble suites have been examined in detail.

4.2.3.1 The Bargate Beds Formation phenoclast suite

The samples examined from the Bargate Beds Formation contain a distinctive pebble suite with a high proportion of goethite fossil casts (Sect. 3.2.9.3). The pebble suite (Fig. 4.2, Table 4.9) is composed of ironstone (18-45%), dark cherts (25-40%), quartz (0-8%) and phosphorite (20-45%).

The ironstone clasts include a small, but distinctive, proportion of bioclast casts (Sect. 3.2.9.3). The remainder of the ironstone pebbles are of angular, goethite-cemented quartz arenites (Sect. 3.2.9.5), laminated microcrystalline goethite (Sect. 3.2.9.4) and scarce oolitic ironstones (Sect. 3.2.9.2). The bioclast casts are predominantly of ammonite whorls, the size of which suggests that they are part of the ammonite protoconchs (Pl. 20-8). The ammonites are well-preserved and generic identification is relatively simple. They include specimens of Cardioceras, Creniceras and Quenstedtoceras and are derived from the Oxford Clay Formation (Arkell, 1939b).

The cherts are of dark unweathered silicified Carboniferous shelf limestones (Sect. 3.3.4). The quartz is of granoblastic polygranular grains (Sect. 3.2.14.1). The roundness of the clasts and the maturity of the pebble suite indicates that the siliceous pebbles were unlikely to have been derived directly from their sources and reworking from older pebble beds is possible.

The phosphorite clasts of the Bargate Beds Formation included rolled and rounded teeth and ammonite chamber casts. The latter resemble the phosphatized ammonites of the Kimmeridge Clay Formation,

Location: Compton, Surrey.
Horizon: Bargate Beds Formation.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% frequency

Composition	Sample 176bb1	Sample 176bb2	Mean
Quartz	5.5	5.5	6
Carboniferous shelf chert	27.5	25.5	27
Sandstone	0.5	0.5	1
Ironstone	41.5	42.0	42
Phosphorite	25.0	25.5	25
Silicified volcanic	-	1.0	1
Number of clasts	995	1188	
Q:C index	16	18	17
Q:S index	91	96	94
S:C index	2	<0.5	1
I:P index	63	62	63

Table 4.9 Compositions of two samples from the Bargate Beds Formation pebble suite at Compton, Surrey.

but are rarely identifiable. Pebbles of phosphorite are composed of quartz and glauconitic sand grains, supported in a matrix of microcrystalline phosphate (Sect. 3.2.10.2).

Palaeocurrent indicators in the Bargate Beds Formation imply dominant sediment transportation from the northwest into the Weald Basin (Narayan, 1963, 1971; Sobey, 1975). The sediment source therefore lay on the margins of the Anglo-Brabant massif where Jurassic strata cover Palaeozoic basement rocks. The association of the quartz and chert with Jurassic detritus indicates that derivation from the Lydite Beds (Sects. 2.2.4.1, 2.2.4.2), or possibly from Corallian Group pebble beds on the margin of the Anglo-Brabant Massif is likely. The lack of Jurassic chert pebbles indicates that Upper Jurassic cherty limestones were absent in the source area. This is consistent with the known Jurassic geology of the area northwest of the Weald (Arkell, 1933a).

4.2.3.2 The Folkestone Beds Formation phenoclast suite

The pebble beds of the Folkestone Beds Formation are commonly lag deposits within tidal sandwave complexes. Precise correlation of the pebbly horizons has not been attempted, but all the samples were taken from the upper Folkestone Beds Formation of tardefurcata Zone age (Sect. 2.2.3.1). From the examination of the pebble beds and comparison of detritus of similar grain size, it is possible to demonstrate that the detrital suite of the upper Folkestone Beds Formation displays a distinct lateral variation in composition (Figs. 4.10, 4.11a,b,c; Table 4.10).

In the west of the Weald at Huntingford Bridge (Sect. 2.2.3.1b), the pebble suite is composed of quartz and dark chert in approximately equal proportions. Both lithotypes are present as rounded pebbles, the latter consisting of Carboniferous shelf chert and includes foraminiferal wackestones and packstones, crinoidal packstones, oolitic grainstones and rhomb-bearing mudstones (Sect. 3.3.4). Quartz pebbles are generally of white granoblastic types (Sect. 3.2.14.1). Pebbles of subrounded to angular, goethite-cemented quartz arenite (Sect. 3.2.9.5) and laminated microcrystalline goethite (Sect. 3.2.9.4) are common in the suite.

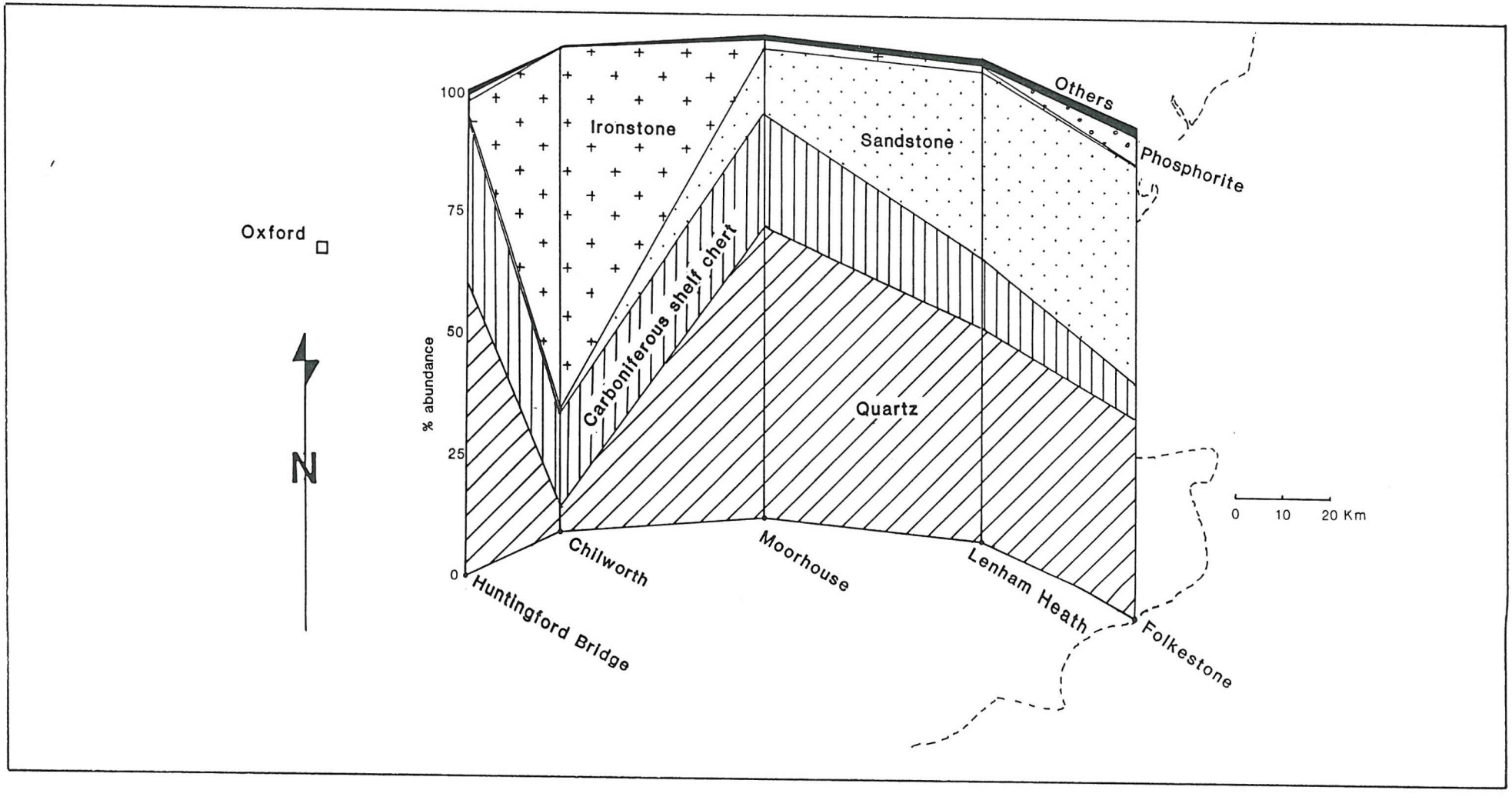


Figure 4.10 A geographical-variation diagram for the composition of Folkestone Beds Formation pebble suites in the Weald (less than -2.00 ø fraction).

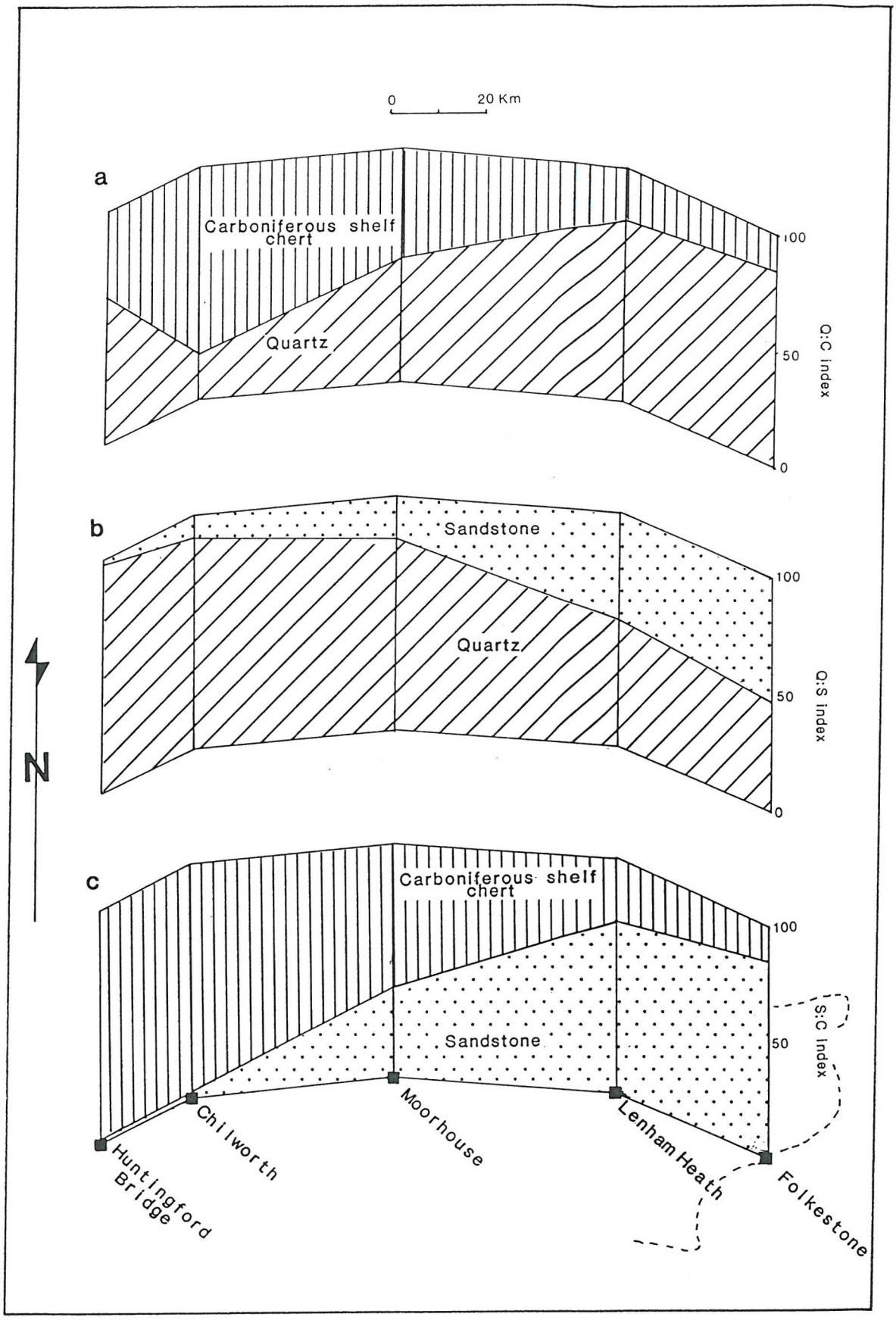


Figure 4.11 Geographical-variation diagrams for the Q:C index (a), Q:S index (b) and S:C index (c) of the Folkestone Beds Formation pebble suites in the Weald (less than -2.00 ø fraction).

Location: Hampshire, Surrey and Kent.
Horizon: Folkestone Beds Formation.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% frequency

Composition	Hunt. 92fb5	Chil. 183fb2	Moor. 186fb6	Lenham 189fb1,2	Folke. 174fb1/8,9	Mean
Quartz	58.0	4.5	68.0	44	41	43
Carboniferous shelf chert	34.5	15.0	22.0	13	7	18
Sandstone	0.5	0.5	8.5	39	44	19
Ironstone	5.0	79.5	1.0	2	-	18
Phosphorite	1.0	-	-	-	6	1
Tourmalinite	-	-	<0.5	-	-	<0.5
Silicified volcanic	1.0	0.5	0.5	2	2	1
Number of clasts	214	343	779	163	118	
Q:C index	63	24	76	77	84	65
Q:S index	99	89	89	53	48	76
S:C index	1	4	28	74	85	38
I:P index	85	-	-	-	-	-

where
Hunt. = Huntingford Bridge, Hampshire,
Chil. = Chilworth, Surrey,
Moor. = Moorhouse, Kent,
Lenham = Lenham Heath, Kent,
Folke. = Baker's Gap, Folkestone, Kent.

Table 4.10 Compositions of Folkestone Beds Formation pebble suite samples from the Weald.

At Chilworth, in the northwest Weald (Sect. 2.2.3.1b), the Folkestone Beds Formation contains a pebble suite with appreciably greater proportions of chert and ironstone than the suite at Huntingford Bridge. Ironstone clasts are particularly abundant in the fine-pebble fractions. Although differing in abundance, the dark chert and quartz are essentially similar to those at Huntingford Bridge.

In west Kent (Moorhouse; Sect. 2.2.3.1b), the proportion of chert clasts in the Folkestone Beds Formation pebble suite is less than in the pebble beds to the west and sandstone clasts form a greater proportion of the pebble suite (Fig. 4.10). The sandstone clasts are subrounded, very fine- to medium-grained quartz arenites (Sect. 3.2.8.1), very fine- to fine-grained micaceous arenites (Sect. 3.2.8.3), quartz siltites (Sect. 3.2.8.4) and lithic arenites (Sect. 3.2.8.2). The quartz pebbles are of white, granoblastic quartz (Sect. 3.2.14.1) and are subangular to rounded in form. Fibrous quartz is scarce (less than 1%). Chert pebbles are of the dark, rounded Carboniferous shelf types (Sect. 3.3.4). Weathering of the chert clasts is advanced. In some examples, the cherts are white and powdery, and disintegrate on extraction. Some of the sandstone and quartz pebbles appear to be first-cycle clasts and derivation from the Devonian or Lower Palaeozoic rocks of the Anglo-Brabant Massif is probable. Many of the pebbles, in particular the altered cherts, are reddened. This apparently results from weathering and is not an indication of derivation from the Devonian or Triassic source rocks.

Between Maidstone and Ashford (Lenham Heath; Sect. 2.2.3.1b), sandstone pebbles are the main component of the Folkestone Beds Formation pebble-suite and the Q:C index is higher than in the west (Fig. 4.11a). The cherts are of Carboniferous shelf varieties (Sect. 3.3.4), but a relatively high proportion of silicified volcanics or silicified mudstones (c. 2%; Sect. 3.2.13.1) is also present in this suite. The pebbles of silicified volcanics are rounded to subrounded and reworking from older pebble beds is possible. J.R.L.Allen (1974) noted similar pebbles in the Devonian Brownstones of the Welsh Borders. The Lenham Heath pebbly sandstones are similar to those at Moorhouse and are also likely to have been derived from Palaeozoic sedimentary rocks on the Anglo-Brabant Massif.

In the pebble suite at Folkestone (Sect. 2.2.3.1b), the sandstone pebble content is slightly greater and Carboniferous chert abundance is lower than at Lenham Heath. Pebbles of silicified volcanics are still moderately common. Pebble horizons are rare in the Folkestone Beds Formation and the pebble fraction is generally finer than 8mm (c. -2.5 ø). The samples examined were of a finer grain-size than the other Folkestone Beds Formation pebble suites examined and this possibly accounts for the high quartz content in the compositional analysis (Table 4.10).

4.2.3.3 The Gault Clay Formation phenoclast suite

The pebble and granule concentrate at the base of the Gault Clay Formation in the southwest Weald differs in appearance between the exposure at Petersfield and those further to the east at Burton School and Fittleworth Station (Sect. 2.2.3.2). However, the pebble suites at the different locations are essentially the same. Granoblastic white quartz (Sect. 3.2.14.1) and dark, crinoidal, foraminiferal, oolitic and rhombic-pseudomorph Carboniferous shelf cherts (Sect. 3.3.4) form the main components of the pebble suite. Q:C indices range between 56 and 74 (Table 4.11). Minor quantities of ironstone and sandstone are also present in these suites. The sandstones are of rounded, fine- to medium-grained quartz arenites (Sect. 3.2.8.1.).

In the basal Gault Clay Formation pebble bed at Aldersnapp Farm (Sect. 2.2.3.2), a clast of porcellanous chert with lenticular pseudomorphs after gypsum was found. The clast is larger and differs texturally from the other chert pebbles in the bed. This suggests that it is not a Carboniferous shelf chert type. The pebble does not contain pollen grains, but lithologically resembles chert from the basal Purbeck Formation (Sect. 3.2.3.1).

4.2.3.4 Comparison of the phenoclast suites from the Weald area

The pebbles of the Folkestone Beds Formation are dominantly of Palaeozoic origin and were derived from the Anglo-Brabant Massif to the north of the Weald Basin. The east-west variation in the detrital suite reflects the known pre-Cretaceous geology of the Anglo-Brabant Massif (P.Allen, 1967a; Kirkaldy, 1947a).

Location: Hampshire and Sussex.
Horizon: Basal Gault Clay Formation pebble bed.
Grain-size: <-2.00 ø
% frequency

Composition	Ald. 104g3	Burton 107g1,2	Mean
Quartz	69	52	61
Jurassic chert	1	-	1
Carboniferous shelf chert	25	42	34
Sandstone	1	6	4
Ironstone	2	-	1
Phosphorite	1	-	1
Silicified volcanic	1	-	1
Number of clasts	152	67	
Q:C index	74	56	65
Q:S index	99	90	95
S:C index	3	13	8

where
Ald. = Aldersnapp Farm, Hampshire,
Burton = Burton School, Sussex.

Table 4.11 Compositions of the Gault Clay Formation pebble suite at Aldersnapp Farm, Hampshire and Burton School, Sussex.

The pebble suites of the Bargate Beds and the Folkestone Beds Formations in the northwest Weald have low Q:C indices and are compositionally similar (Fig. 4.12a). It is considered likely that they were derived from similar source rocks. The higher proportion of locally derived Jurassic detritus in the Bargate Beds Formation, relative to the Folkestone Beds Formation, suggests that the less resistant ironstones and phosphorites were destroyed prior to the reworking of resistant clasts during the Early Albian transgression.

The pebbly detritus at the base of the Gault Clay Formation in the southwest Weald is similar in composition and grain-size to the pebble suites of the Folkestone Beds Formation in the area (Fig. 4.12b) and reworking of material from the top of the older formation is probable.

The Gault Clay Formation and Folkestone Bed Formation phenoclast-suites of the southwest Weald have higher Q:C indices than the pebble beds in the northwest Weald. This reflects either lateral variation in the composition of Jurassic pebble beds sourcing the Albian sediments, or the introduction of quartz-rich detritus into the west of the Weald Basin. A similarly high Q:C index for the Lower Greensand Group pebble suites in the Isle of Wight and Wiltshire is consistent with an influx of quartz-rich detritus into Wiltshire, Hampshire, West Sussex and the Isle of Wight during the Aptian and Albian Stages.

The pebble beds of the Lower Greensand Group examined in the Weald contain three groups of clast:

1. rounded pebbles of quartz and Carboniferous shelf chert are the dominant type and are present throughout the area. The distribution of known Carboniferous limestone with chert is restricted to the margins of the Welsh and Anglo-Brabant Massifs and on the highs of northern and central England. Derivation is, therefore, considered to be from the north. The Anglo-Brabant Massif would appear to be the most suitable source in view of its close proximity to the Weald Basin. The rounding of the cherts, however, indicates that direct derivation from source was unlikely to have occurred and reworking from older pebble beds was possible. The association of a texturally and compositionally

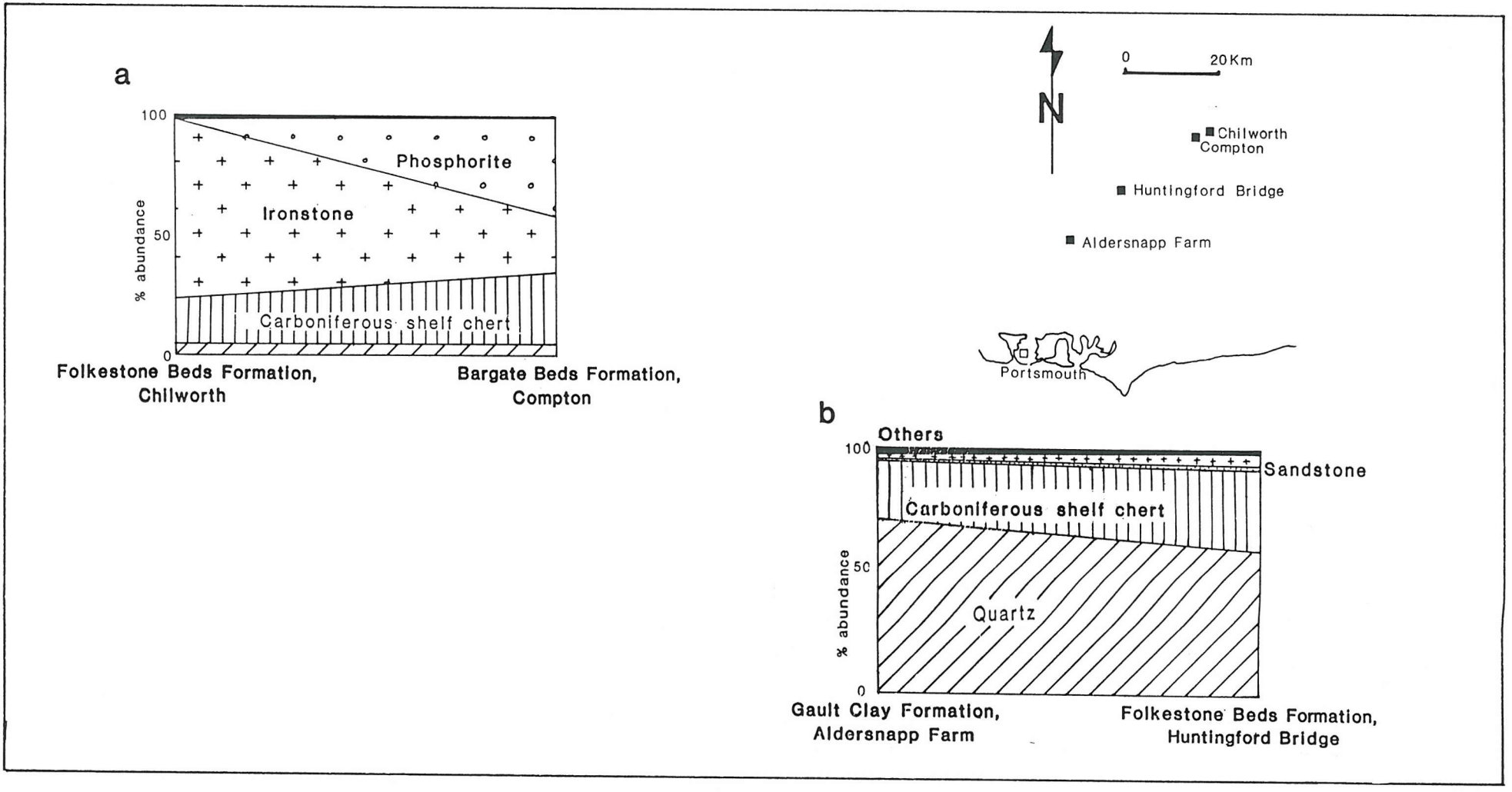


Figure 4.12 Stratigraphical-variation diagrams for the compositions of the Bargate Beds Formation and Folkestone Beds Formation pebble suites in the northwest Weald (a; -2.75 ø fraction) and the Folkestone Beds Formation and the Gault Clay Formation pebble suites in the southwest Weald (b; less than -2.00 ø fraction).

mature subsuite of Carboniferous chert clasts with pebbles of Jurassic origin, is consistent with reworking of Upper Jurassic pebble beds, in particular the Lydite Beds (Fig. 4.13; see section 4.2.4.2 for details of Lydite Bed compositions).

2. subangular to subrounded pebbles of quartz and sandstone form the second suite. Clast roundness and the pebble suite immaturity suggest that much of this group was derived directly from its source. The composition of the diagenetic fabrics and sandstones suggest that the pebbles were probably derived from Lower Palaeozoic or Devonian strata, which are known to subcrop beneath the Cretaceous cover on the Anglo-Brabant Massif (Wills, 1973; Whittaker, 1985).
3. clasts derived from the Upper Jurassic source rocks are common in the northwest Weald. These include ironstones reworked from the Oxford Clay Formation or contemporaneous sources, and phosphorites from the Kimmeridge Clay Formation. The clast of probable Purbeck Formation chert is also included in this group, but is possibly from a different source area. The greater abundance of these clasts in the northwest Weald implies that the source rocks were on the margins of the Anglo-Brabant Massif.

4.2.4 The phenoclast suites of the Wiltshire and Oxfordshire area

The area between the Vale of Wardour and Oxford contains a number of pebbly horizons of Late Jurassic and Early Cretaceous age (Sect. 2.2.4). Samples from the Lydite Beds, the Lower Greensand Group and the Gault Clay Formation have been examined.

4.2.4.1 The basal Swindon Clay pebble bed phenoclast suite

The pebble bed at the base of the Swindon Clay in the old railway cutting at Swindon (Sect. 2.2.4.1) contains dark, rounded chert pebbles, with lesser amounts of quartz and sparse phosphorite pebbles (Table 4.12).

The cherts of the pebble bed are predominantly of fine-grained types, commonly with rhombic pseudomorphs after dolomite/ankerite (Sect. 3.2.1.10). Bioclasts present in the chert are of Palaeozoic age and the chert is similar to those of Carboniferous limestones (Sect. 3.3.4). The rounding and textural maturity of the chert

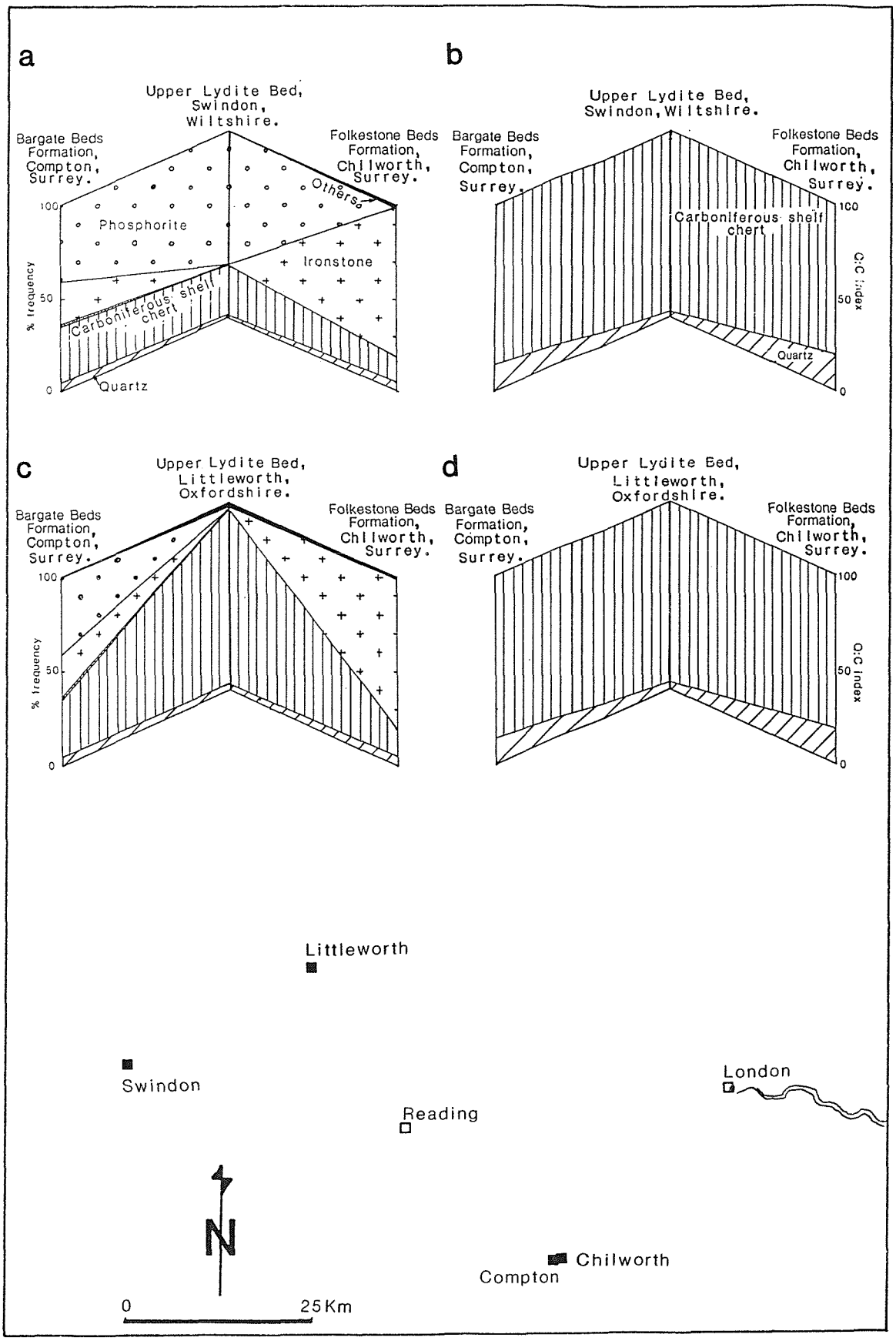


Figure 4.13 Stratigraphical-variation diagrams for the compositions of the Upper Jurassic pebble beds in the Wiltshire and Oxfordshire area (Upper Lydite Beds) and the Lower Greensand Group pebble beds of the northwest Weald.

Location: Wiltshire and Oxfordshire.
Horizons: Basal Swindon Clay pebble bed and Upper Lydite Bed.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% weight

Composition	71bscpb1 Swindon	71ulb2 Swindon	193ulb3 Little.	Mean
Quartz	7	2	7.0	5
Carboniferous shelf chert	93	28	88.5	70
Sandstone	-	<0.5	-	<0.5
Phosphorite	<0.5	70	3.0	24
Silicified volcanic	-	-	1.5	1
Number of clasts	c.60	137	421	
Q:C index	7	6	7	7
Dolo-chert index	10	3	20	11
Bio-chert index	18	10	11	13

where
71bscpb1 Swindon = basal Swindon Clay pebble bed, Swindon,
71ulb2 Swindon = Upper Lydite Bed, Swindon,
193ulb3 Little. = Upper Lydite Bed, Littleworth.

Table 4.12 Compositions of the basal Swindon Clay pebble bed and the Lydite Bed pebble suites from the Wiltshire and Oxfordshire area.

pebbles indicates that reworking from older pebble beds is possible. The quartz pebbles have a granoblastic fabric (Sect. 3.2.14.1) and fibrous quartz is scarce. The clasts of phosphorite are rounded but include internal casts of bivalves (Sect. 3.2.10.4), principally Protocardia.

Chatwin & Pringle (1922) and Arkell (1947b) reported the Lower Lydite Bed to contain appreciable quantities of phosphorite and therefore, the samples may not be from the same horizon. The oyster bed above the pebbly sands is probably the "Exogyra" nana Bed described by Arkell (1947b). The pebbles would, therefore, be at the top of the Pectinatus Sands.

4.2.4.2 The Upper Lydite Bed phenoclast suite

This horizon was examined at Swindon and at Littleworth, near Oxford (Sect. 2.2.4.2). The two pebble beds are compositionally distinct. At Swindon, the suite is dominated by phosphorite clasts, with lesser amounts of chert and rare quartz pebbles. To the east at Littleworth, phosphorite clasts are rare, the suite being composed of chert and accessory quartz (Fig. 4.14, Table 4.12).

The Q:C indices for the two localities are similar (Fig. 4.15), suggesting that the suites are derived from the same or related sources. The fauna of the chert clasts indicates derivation from Carboniferous rocks and the phenoclast types imply that they are silicified limestones (Sect. 3.3.4.). Oolitic and bioclastic cherts appear to be more common in the east, but the variations were not statistically significant. The quartz pebbles are of coarse-grained granoblastic types (Sect. 3.2.14.1), with small proportions of deformed quartz (Sect. 3.2.14.3). Phosphorite pebbles, abundant at Swindon, display little evidence of abrasion and are probably locally derived. They are principally bivalve and burrow casts (Sect. 3.2.10.4). Ammonite fragments are rare. The bivalves are predominantly Protocardia, but fragments of larger bivalves are also found. Rod-like structures, probably burrow fills, are common. The rods are 1mm to 2mm in diameter and up to 8mm long. The preservation of such fragile clasts indicates that transportation was limited. The phosphorite pebbles in the Upper Lydite Bed were probably derived from the underlying Swindon Clay.

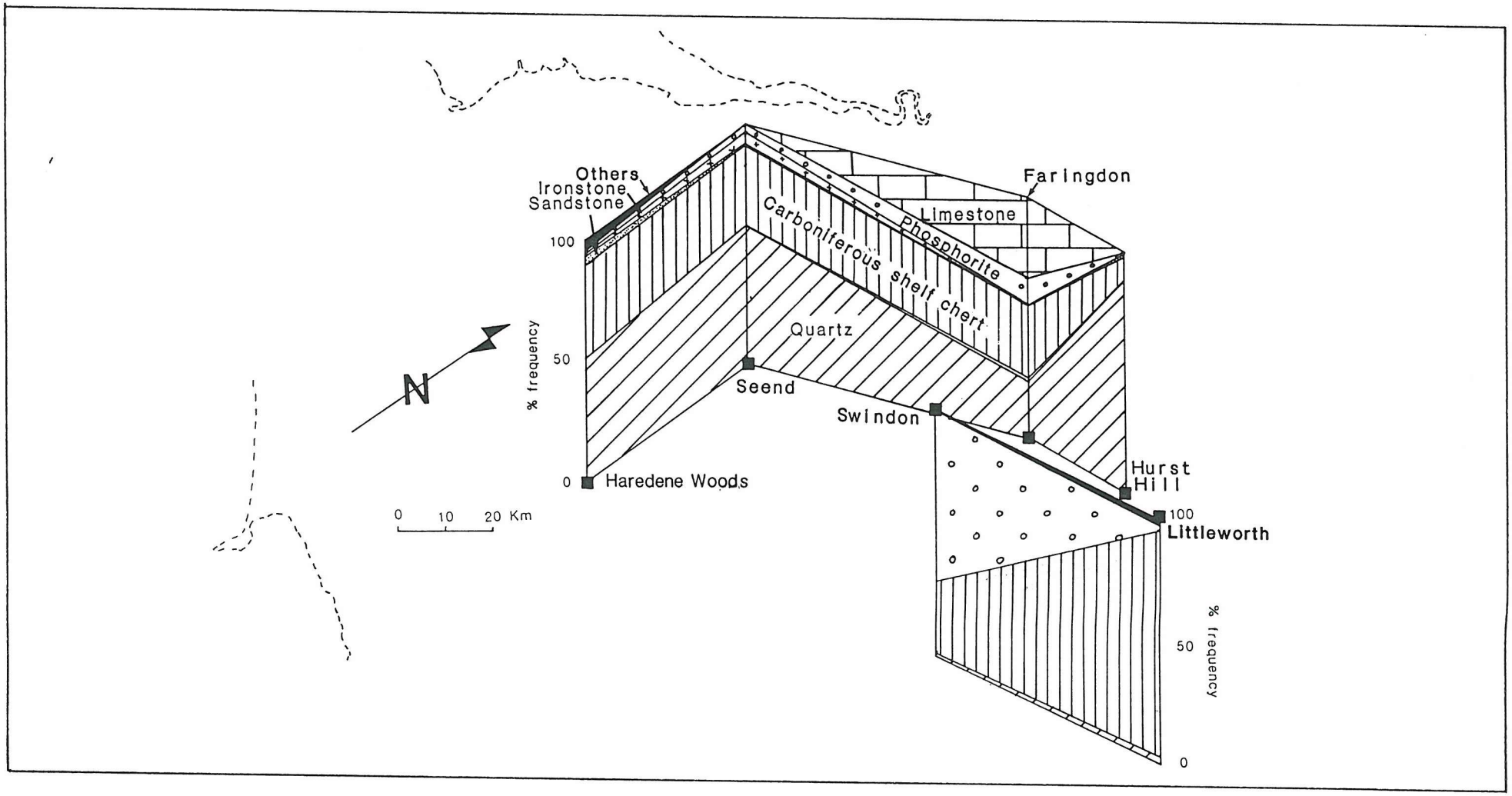


Figure 4.14 Geographical-variation diagrams for the composition of the Upper Jurassic and Lower Cretaceous pebble beds in the Wiltshire and Oxfordshire area.

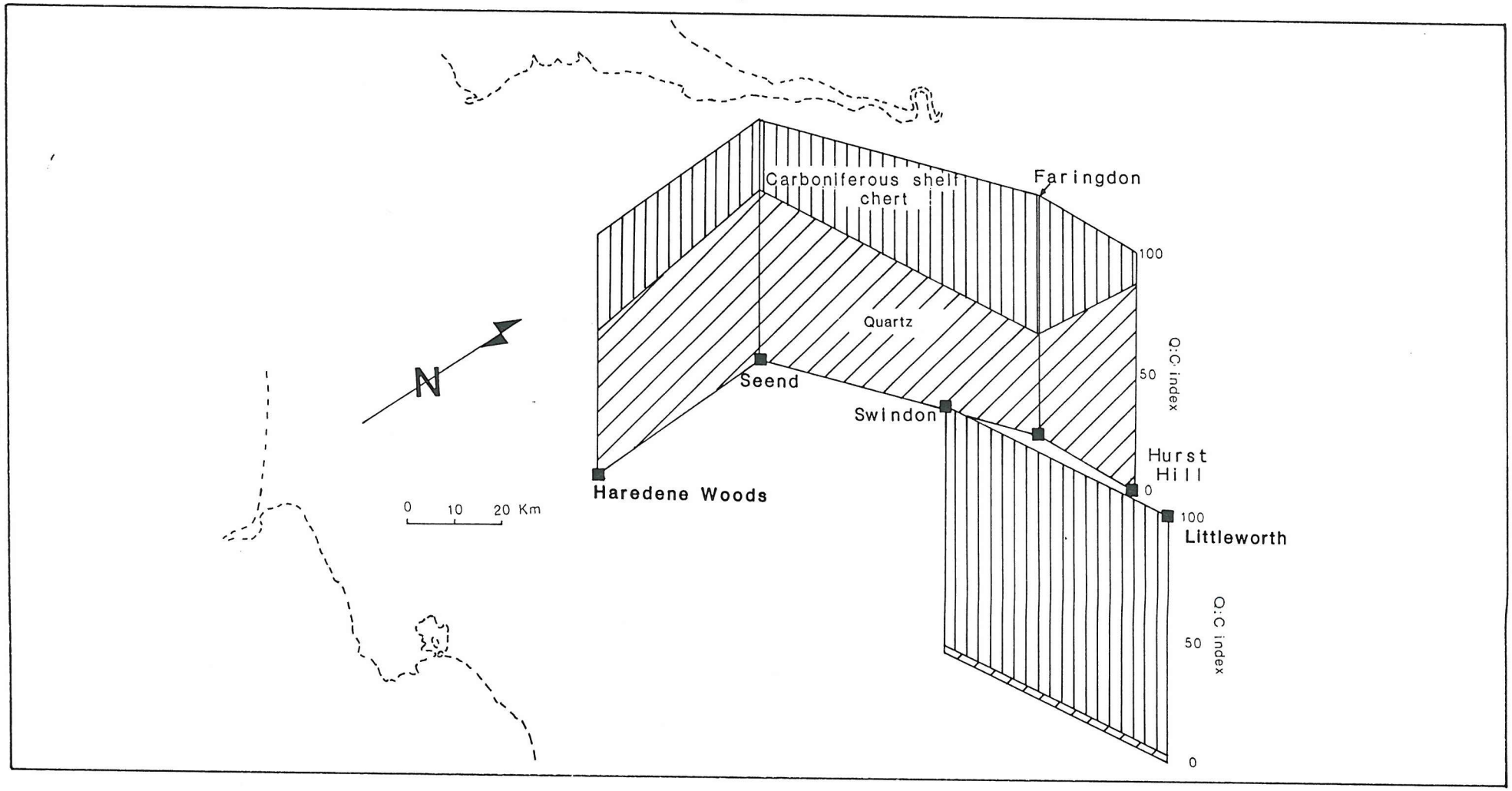


Figure 4.15 Geographical-variation diagrams for the Q:C index of the Upper Jurassic and Lower Cretaceous pebble beds in the Wiltshire and Oxfordshire area (less than -2.00 ø fraction).

4.2.4.3 The Faringdon Sponge Gravel phenoclast suite

The pebble beds of the Faringdon Sponge Gravel are distinct (Sect. 2.2.4.3), differing from all the other pebble beds examined. The pebble suite is composed of two groups of phenoclasts (Fig. 4.14, Table 4.13):

1. locally derived intrabasinal limestones, cherts and phosphorites, and
2. exotic extrabasinal dark cherts, quartz and sandstone.

The intrabasinal detritus in the Faringdon Sponge Gravel Formation is notable for the abundance of limestone (Sect. 3.2.7) and partially silicified limestone (Sect. 3.2.6) phenoclasts. The limestones include bioclastic and oolitic packstones and grainstones (Sect. 3.2.6.1), fossiliferous mudstones and wackestones (Sect. 3.2.7.1) and glauconitic sandstones with microspar matrices (Sect. 3.2.7.2). Rolled scleractinid corals and perisphinctid ammonite whorls, filled with calcite-cemented sandstone, are relatively common. The lithotypes of the limestone pebbles resemble those of the Calcareous Grit, "Trigonia" Beds and Coral Rag in the Corallian Group in the Faringdon area. Some of the micritic limestone clasts are possibly derived from the Kimmeridge Clay Formation.

Porous and vitreous chert and partially silicified limestone clasts are subrounded to rounded. They include bioclastic and oolitic grainstones and sandy-pellet packstones. The fauna of the cherts is consistent with a Jurassic (probably Corallian Group) source.

Pebbles of phosphorite include fossil casts and rounded sandy phosphorites (Sect. 3.2.10.4, 3.2.10.2). The phosphatic bioclast casts are rounded and poorly preserved, but include ammonite camerae and bivalves. Derivation from the Kimmeridge Clay Formation is probable.

Rounded pebbles of dark Carboniferous shelf chert (Sect. 3.3.4) and quartz (Sect. 3.3.1) are the most common exotic extrabasinal clasts in the Faringdon Sponge Gravel. The Q:C indices for these beds are between 40 and 60. Pebbles of sandstone are moderately

Location: Wiltshire and Oxfordshire.
Horizon: Lower Greensand Group and Gault Clay Formation.
Grain-size: < -2.00 ø
% weight

Composition	Far.* 130fsg3	Seend[x] 58si1	Hurst[†] 129hs2	Hare.[‡] 63g2	Mean
Quartz	20.5	58.0	85	57	55
Jurassic chert	0.5	-	-	-	<0.5
Carboniferous shelf chert	31.0	25.5	9	34	25
Sandstone	<0.5	0.5	4	3	2
Ironstone	-	4.5	-	<0.5	1
Phosphorite	17.5	2.0	2	1	6
Limestone	30.5	-	-	-	8
Tourmalinite	-	-	-	3	1
Silicified volcanic	-	9.5	-	1	3
Mylonite	-	-	-	1	<0.5
Number of clasts	268	c.200	32	155	
Q:C index	40	70	90	63	66
Q:S index	99	99	96	95	97
S:C index	<1	<1	29	8	9
Dolo-chert index	15	8	-	9	-
Bio-chert index	7	28	-	24	-

where
Far. = Faringdon Sponge Gravel, Faringdon, Oxfordshire,
Seend = Seend Ironsand, Seend, Wiltshire,
Hurst = Hurst Hill Sands, Hurst Hill, Oxfordshire,
Hare. = Gault Clay Formation, Haredene Woods, Wiltshire.
* = -2.75 ø, -2.50 ø, -2.00 ø. x = <-2.00 ø. † = -2.50 ø, -2.00 ø.
‡ = -3.00 ø, -2.75 ø.

Table 4.13 Compositions of the Lower Greensand Group and Gault Clay Formation pebble suites from the Wiltshire and Oxfordshire area.

abundant and are principally of rounded quartzites (Sect. 3.2.8.1). The induration of the quartzites indicates that they are probably of Palaeozoic origin.

Sparse tourmalinite clasts composed of equigranular quartz and fine-bladed tourmaline (possibly tourmalinized quartzites; Sect. 3.2.11.3) are present in the Faringdon Sponge Gravel Formation. They are rounded and more abundant in the coarser pebble fractions, but never form a significant proportion of the phenoclast suite (App. I). Primary sources of quartz-tourmaline are not exposed in the south Midlands and tourmaline-bearing lithotypes are more common in southwest England and Armorica. The majority of the extrabasinal clasts in the Faringdon Sponge Gravel (Carboniferous shelf chert and quartz) are presumed to have been derived from the massifs of central England and Wales and it is therefore improbable that the tourmalinites were derived directly from Cornubia. Triassic pebble beds outcrop in the Midlands (Kidderminster Conglomerate Formation and the Nottingham Castle Conglomerate Formation) and reworking from such sources is possible.

4.2.4.4 The Seend Ironsand phenoclast suite

Pebbles in the Seend Ironsand (Sect. 2.2.4.3) are predominantly of quartz and chert. Phosphorite and ironstone clasts are present in low abundance (Fig. 4.14, Table 4.13).

The siliceous clasts are rounded and resemble those of the other pebble beds of the south Midlands. Quartz grains are of white or translucent granoblastic types (Sect. 3.2.14.1) and were derived from basement sources. The maturity of the quartz (absence of fibrous quartz and quartz with inclusions) indicates that significant reworking probably occurred. Devonian, Carboniferous or Triassic pebble beds to the west or northwest of Seend were potential sources. The absence of quartzite clasts in the Seend Ironsand suite possibly precludes a significant input from Triassic source conglomerates, which are reported to contain up to 80% quartzite clasts (Wills, 1956). The cherts are dark in colour and include foraminiferal, crinoidal, bryozoan and brachiopodal packstones and wackestones (Sect. 3.2.1.8), oolitic grainstones (Sect. 3.2.1.9) and rhomb-bearing mudstones (Sect. 3.2.1.10). Packstones and wackestones

are more common than grainstones in the chert suite. Pebbles of dark chert are derived from Carboniferous limestones.

Pebbles of phosphorite contain quartz and glauconite sand grains (Sect. 3.2.10.2) and resemble the nodules in the Kimmeridge Clay Formation. Bioclast casts were not found, but derivation from Jurassic sources is probable.

4.2.4.5 The Hurst Hill Sands phenoclast suite

The coarse-grained fraction in the sands at Hurst Hill (Sect. 2.2.4.3) is composed of small pebble and granule-grade clasts. The phenoclast-suite is dominated by quartz, with lesser amounts of dark chert. Sandstone and phosphorite clasts are rare and ironstone pebbles were not found (Fig. 4.14, Table 4.13).

The high proportion of quartz in the sample is probably in part an artefact of the fine-grain size of the pebble suite. However, the high Q:C index is probably real. The microcrystalline chert clasts present in the suite include bioclastic (Sect. 3.2.1.8) and rhomb-bearing (Sect. 3.2.1.10) varieties of Carboniferous shelf chert. Pebbles of silicified tuff or lava (Sect. 3.2.13.1) are present in low abundance.

4.2.4.6 The Gault Clay Formation phenoclast suite

Samples from the basal Gault Clay Formation were collected from Haredene Woods, near Tisbury, Wiltshire (Sect. 2.2.4.4). The pebble suite is composed of quartz and chert with minor quantities of sandstone. Phosphorite and ironstone pebbles were found in low abundance (Fig. 4.14, Table 4.13).

The chert pebbles are predominantly of the types derived from Carboniferous limestones (Sect. 3.3.4), but possible radiolarian chert pebbles (Sect. 3.3.5) are also present in the bed. Both types of chert are rounded and derivation from older pebble beds is possible. The quartz pebbles are of polygranular, granoblastic types (Sect. 3.2.14.1), with little fibrous quartz or tourmalinite. Sandstone pebbles are typically quartzites (Sect. 3.2.8.1), but deformed quartzites are also found. The former were probably derived

from the Lower Palaeozoic rocks of the English Midlands or South Wales, but might have been reworked from older pebble beds (e.g. Devonian or Triassic age). The phosphorite pebbles were not found to include bioclast casts and their source cannot be ascertained. Derivation from Jurassic sources is probable.

4.2.4.7 Comparison of the phenoclast suites from the Wiltshire and Oxfordshire area

The pebble beds of Oxfordshire and Wiltshire can be separated into two compositional groups; those with low Q:C indices and those with moderate to high Q:C indices (Fig. 4.15). Q:S indices are high throughout the area. The Lydite beds constitute the former, the Lower Greensand Group and basal Gault Clay Formation pebble beds the latter. The difference between the two pebble suites suggests either completely different detrital sources or mixing of detritus from the Lydite Beds suites with quartz-rich material. The presence of phosphorite pebbles in the basal Gault Clay Formation, the Seend Ironsands Formation and also the presence of Jurassic limestones and cherts in the Faringdon Sponge Gravel suggests that mixing must have occurred.

4.2.5 The phenoclast suites of the Bedfordshire and Cambridgeshire area

The area on the northwestern margin of the Anglo-Brabant Massif contains pebble and remanié beds of Aptian and Albian age. The top of the Woburn Sands Formation and the junction beds between the Woburn Sands and the Gault Clay Formation have been sampled.

4.2.5.1 The Woburn Sands phenoclast suite

The coarse-grained detritus in the Late Aptian and Early Albian marine sandstones of Bedfordshire and Cambridgeshire contain similar pebble suites which are only distinguished by the presence or absence of ironstone clasts. Ironstones form a significant proportion of the pebble suite in the large-scale cross-stratified sets (Sect. 2.2.5.1) at Leighton Buzzard (30-35%; Billington Crossing sandpit) and are also found in the Woburn Sands at Haddenham (5-10%). The small-scale cross-stratified upper Woburn Sands in the Double Arches sandpit at Leighton Buzzard contain sparse ironstone clasts (Fig. 4.16a; Table

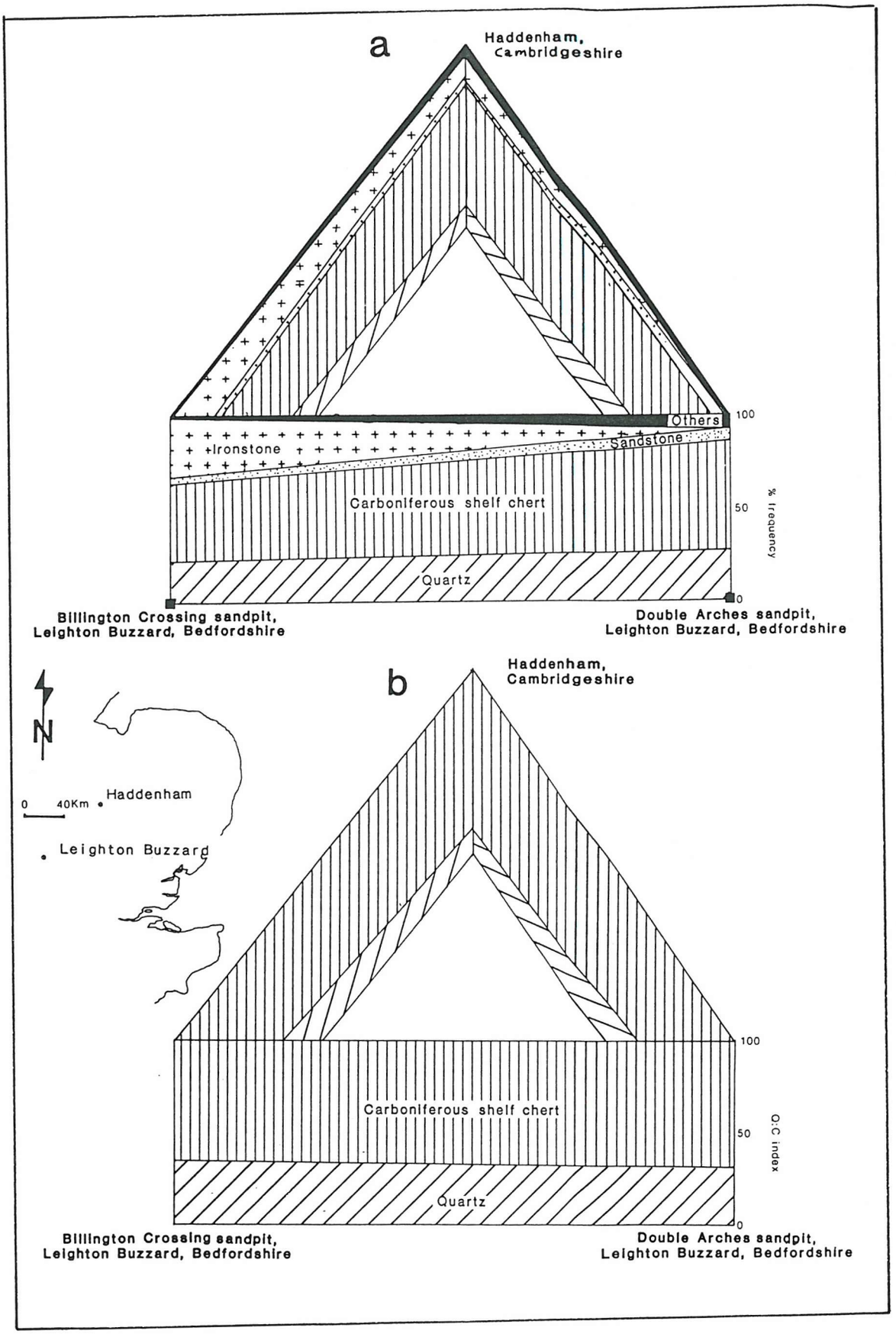


Figure 4.16 Geographical-variation diagrams for the composition (a) and Q:C index (b) of the Woburn Sands pebble suites in the Bedfordshire and Cambridgeshire area (less than -2.00 ø fraction).

4.14).

The ironstone pebbles of the Woburn Sands are composed predominantly of goethite-cemented quartz arenites (Sect. 3.2.9.5), with fewer clasts of laminated microcrystalline goethite (Sect. 3.2.9.4). The remainder of the pebble suite is composed of small rounded clasts of chert and quartz (Fig. 4.16a). The cherts are black or dark brown in colour and contain a Carboniferous fauna (Sect. 3.2.1.8), rhombic-pseudomorphs (Sect. 3.2.1.10) and silicified oolites (Sect. 3.2.1.9). The possibility of reworking of these clasts from older pebble beds is indicated by the maturity of the chert subsuite. The chert subsuites of the Woburn sands have moderate dolo-chert indices (9-21). Pebbles of quartz are predominantly of white granoblastic types (Sect. 3.2.14.1) and fibrous quartz forms less than 1% of the suites. Q:C indices for the beds are low (Fig. 4.16b).

The apparently high content of silicified volcanic clasts (Sect. 3.2.13.1) in the Double Arches pit (Fig. 4.16a) is probably a function of small sample size and greater abundance of such clasts in the coarser-grained fractions (see App. I).

4.2.5.2 The Gault Clay Formation phenoclast suite

The pebble suite of the junction beds is composed principally of Carboniferous shelf chert and quartz (Fig. 4.17a,b; Table 4.15). Sandstone and phosphorite clasts are scarce. The abundance of ironstone clasts varies and such clasts are present in the Gault Clay Formation where the pebble suite of the underlying Woburn Sands also contains ironstone clasts (Fig. 4.17a,b). The pebbles of ironstone are more common in the coarser-grained fractions and are angular to subangular. The other lithotypes of the pebble suite are of quartz and Carboniferous shelf chert. Q:C indices are low (Fig. 4.18c,d) and the cherts include a high proportion of microcrystalline types with rhombic pseudomorphs (Sect. 3.2.1.10).

4.2.5.3 Comparison of the phenoclast suites from the Bedfordshire and Cambridgeshire area

The pebble suites of the Woburn Sands and the Gault Clay

Location: Bedfordshire and Cambridgeshire.
Horizon: Woburn Sands.
Grain-size: -2.75 ø, -2.50 ø, -2.00 ø
% frequency

Composition	Bill.* 195ws1	D.A. 196ws2	Hadd. 198ws2	Mean
Quartz	22.5	62.5	32.5	39
Carboniferous shelf chert	39.0	36.0	60.5	45
Radiolarian chert	0.5	-	-	<0.5
Sandstone	4.0	0.5	<0.5	2
Ironstone	32.5	0.5	6.0	13
Phosphorite	-	-	<0.5	<0.5
Silicified volcanic	1.5	0.5	1.0	1
Number of clasts	211	411	520	
Q:C index	37	63	35	45
Q:S index	86	99	99	95
S:C index	9	2	<1	4
Dolo-chert index	9	18	21	16
Bio-chert index	35	31	22	29

where
Bill. = Billington Crossing Sandpit, Leighton Buzzard, Bedfordshire,
D.A. = Double Arches Sandpit, Leighton Buzzard, Bedfordshire,
Hadd. = Haddenham, Cambridgeshire.

* -2.75 ø only

Table 4.14 Compositions of the Woburn Sands pebble suites from the Bedfordshire and Cambridgeshire area.

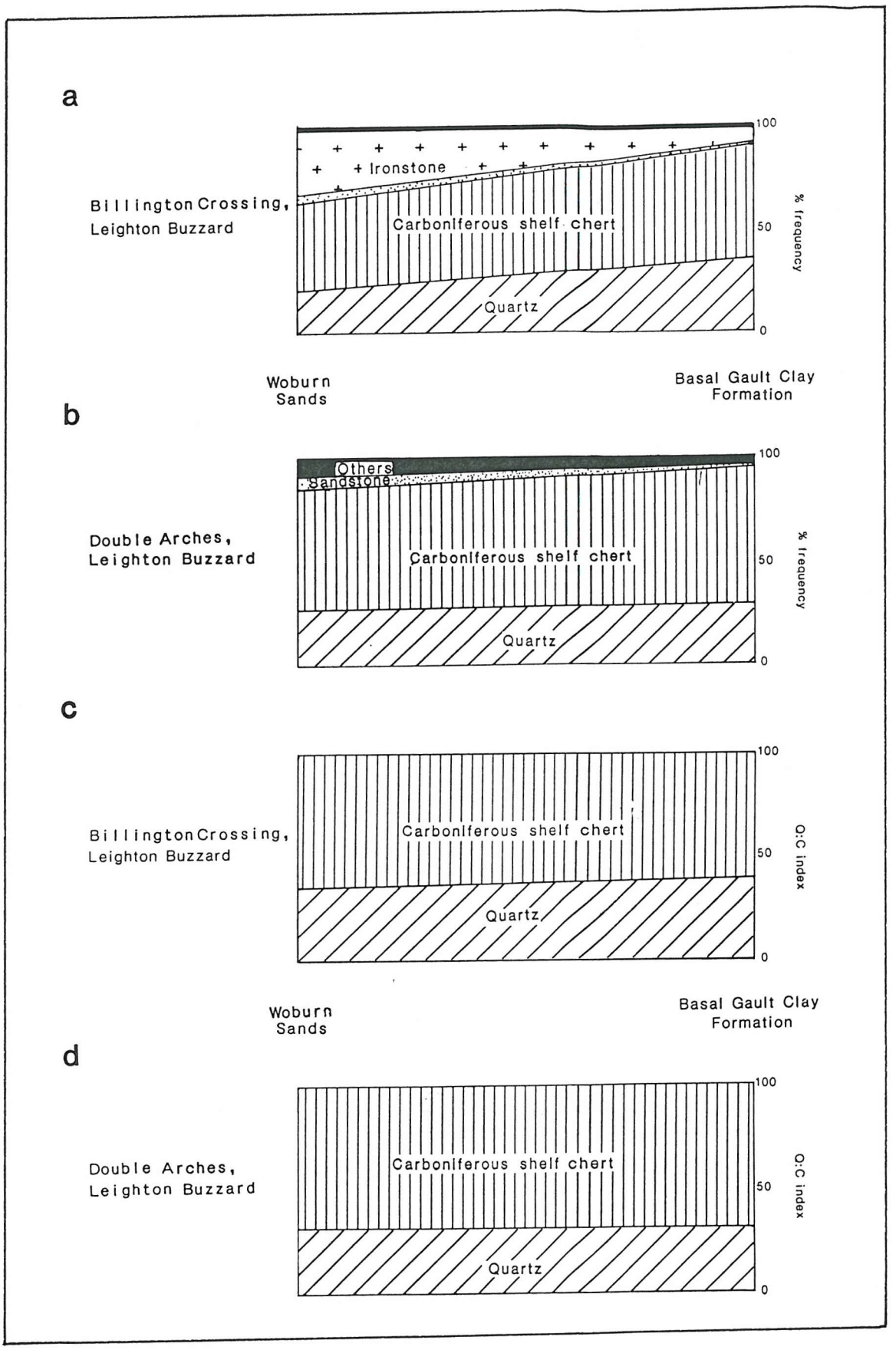


Figure 4.17 Stratigraphical-variation diagrams for the composition (a,b) and Q:C index (c,d) of the Woburn Sands pebble suite at Billington Crossing and Double Arches sandpits (c,d), Leighton Buzzard, Bedfordshire (-2.50 ø & -2.75 ø fraction).

Location: Bedfordshire.
Horizon: Basal Gault Clay Formation pebble bed.
Grain-size: -2.5 & -2.75 ø
% frequency

Composition	Bill. 195g1	D.A. 196g1	Mean
Quartz	34	31.0	33
Carboniferous shelf chert	59	65.0	62
Sandstone	1	1.0	1
Ironstone	5	-	3
Phosphorite	1	-	1
Silicified volcanic	-	3.0	2
Number of clasts	121	585	
Q:C index	37	33	35
Q:S index	98	97	98
S:C index	1	1	1
I:P index	75	-	-
Dolo-chert index	17	26	22
Bio-chert index	6	20	13

where
Bill. = Billington Crossing Sandpit, Leighton Buzzard, Bedfordshire,
D.A. = Double Arches Sandpit, Leighton Buzzard, Bedfordshire.

Table 4.15 Compositions of the Gault Clay Formation pebble suites from Billington Crossing and Double Arches sandpits, Leighton Buzzard, Bedfordshire.

Formation are similar but differ in two respects. Sandstone clasts are more abundant in the Woburn Sands and chert with rhombic-pseudomorphs is more abundant in the Gault Clay Formation. Both variations are small and differences in the pebble suites are not significant by chi-squared testing.

The similarity in the Q:C indices of the basal Gault Clay Formation and Woburn Sands phenoclast suites (Fig. 4.17c,d) and the similarity in clast size suggests that they are closely related. The basal Gault Clay Formation pebble suite was probably derived from the Woburn Sands without a significant fresh input of coarse-grained detritus. The restriction of ironstone pebbles in the basal Gault Clay Formation to locations where similar clasts are present in the Woburn Sands is consistent with reworking.

4.2.6 The phenoclast suites of the East Midlands area

Three pebble beds in the East Midlands have been sampled during the present study (Sect. 2.2.6).

4.2.6.1 The Mid-Spilsby Nodule Bed phenoclast suite

The pebble suite of this bed is dominated by small, rounded clasts of dark Carboniferous shelf chert (85-95%). Several chert lithotypes are recognised, including foraminiferal and crinoidal packstones and wackestones (Sect. 3.2.1.8), and crinoidal and oolitic grainstones (Sect. 3.2.1.9). Cherts with rhombic-pseudomorphs (Sect. 3.2.1.10) are particularly common. The faunal assemblage is that of Carboniferous limestones and the clasts are probably derived from the Anglo-Brabant Massif or possibly the Pennine High. Rounded white quartz pebbles (Sect. 3.3.1) are present in minor amounts (3-9%; Fig. 4.18a, Table 4.16).

4.2.6.2 The Claxby Ironstone Formation phenoclast suite

The basal Claxby Ironstone Formation phenoclast suite is compositionally and morphologically similar to the Mid-Spilsby Nodule Bed pebble suite. The basal Claxby Ironstone Formation pebble bed contains a phenoclast-suite composed principally of dark Carboniferous shelf chert and minor quantities of rounded quartz

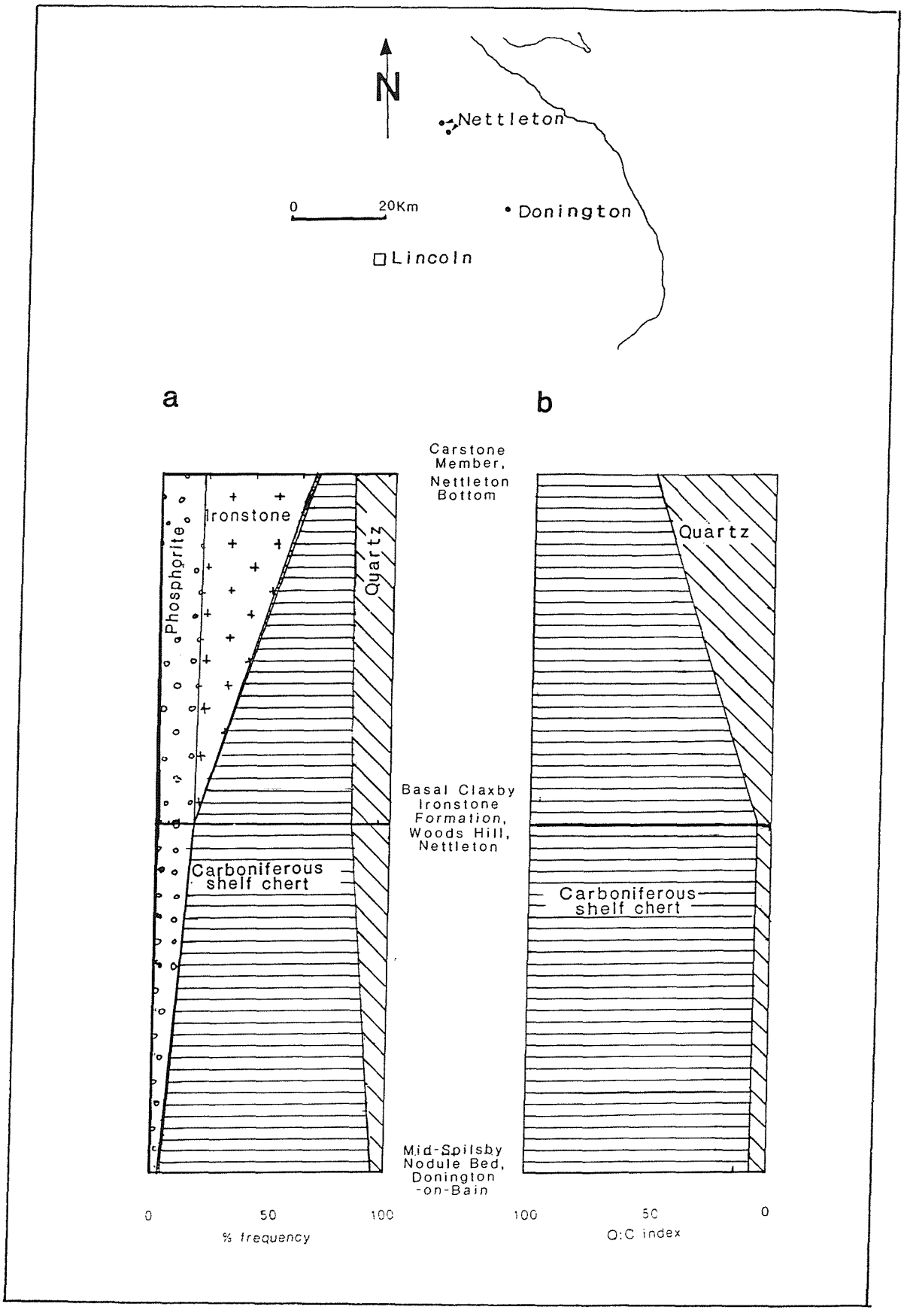


Figure 4.18 Stratigraphical-variation diagrams for the composition (a) and Q:C index (b) of the Lower Cretaceous pebble suites in Lincolnshire (less than -2.50 ø fraction).

Location: Lincolnshire.
Horizons: Mid-Spilsby Nodule Bed, Claxby Ironstone Formation and Clixby pebble bed.
Grain-size: -2.75 ø, -2.50 ø
% frequency

Composition	Doning. 206msnb2	Nettle. 204ci1	Clixby 202cpb2	Mean
Quartz	6.5	5.0	15.0	9
Carboniferous shelf chert	88.5	79.0	81.5	83
Sandstone	1.0	0.5	0.5	1
Phosphorite	3.0	14.0	2.5	7
Silicified volcanic	1.0	1.5	0.5	1
Number of clasts	179	343	428	
Q:C index	7	6	15	9
Q:S index	86	89	97	91
S:C index	1	<1	<1	<1
Dolo-chert index	22	33	27	27
Bio-chert index	18	11	8	12

where
Doning. = Mid-Spilsby Nodule Bed, Donington-on-Bain, Lincolnshire,
Nettle. = Basal Claxby Ironstone Formation pebble bed, Woods Hill, Nettleton, Lincolnshire,
Clixby = Clixby pebble bed, Clixby, Lincolnshire.

Table 4.16 Compositions of the pebble suites from the Mid-Spilsby Nodule Bed, basal Claxby Ironstone Formation pebble bed and the Clixby pebble bed in Lincolnshire.

(Fig. 4.18a, Table 4.16).

The chert clasts are of Carboniferous limestone types (Sect. 3.3.4) and are predominantly of fine-grained varieties. Rhombic-pseudomorphs are common in many of the chert clasts (Sect. 3.2.1.10.) and fine-grained cherts with rhombs form 25-30% of the pebble population (dolo-chert index: c.34). Reddening of the chert pebbles internally is moderately common, but the surfaces are typically dark grey or black. The clasts of phosphorite are not distinctive and their source cannot be determined.

4.2.6.3 The Carstone Member phenoclast suite

The Carstone Member pebble suite has been sampled at three localities in the East Midlands and the samples display a distinct compositional trend across the area. The pebble beds are composed of four principal components; quartz, dark Carboniferous chert, ironstone and phosphorite (Fig. 4.19, Table 4.17).

The Q:C index of the Carstone Member pebble beds increases to the north (Fig. 4.20a). The quartz clasts are of rounded granoblastic types (Sect. 3.2.14.1) and fibrous quartz is scarce (less than 0.5%). The chert clasts are commonly dark and rounded, but in some examples are altered and have a powdery texture. The cherts are of Carboniferous limestone type and include bioclastic packstones (Sect. 3.2.1.8) and oolitic grainstones (Sect. 3.2.1.9).

The ironstone and phosphorite pebbles are the dominant lithotypes on the north of the East Midlands Shelf (Fig. 4.20b). The ironstone clasts include laminated, oolitic and pelletal types and goethite-cemented sandstones (Sect. 3.2.9). Goethitic bioclast casts were not found. Ironstone pebbles in the Carstone Member are angular and are presumed to have been locally derived. In the basal Carstone Member at South Ferriby, the greater proportion of phosphorite clasts, relative to ironstones, could not be accounted for if the ironstones were reworked entirely from older deposits. Reworking of contemporaneous deposits during the mammillatum Zone to dentatus Zone transgression is therefore suggested.

In contrast to the ironstone phenoclast suite, phosphorite

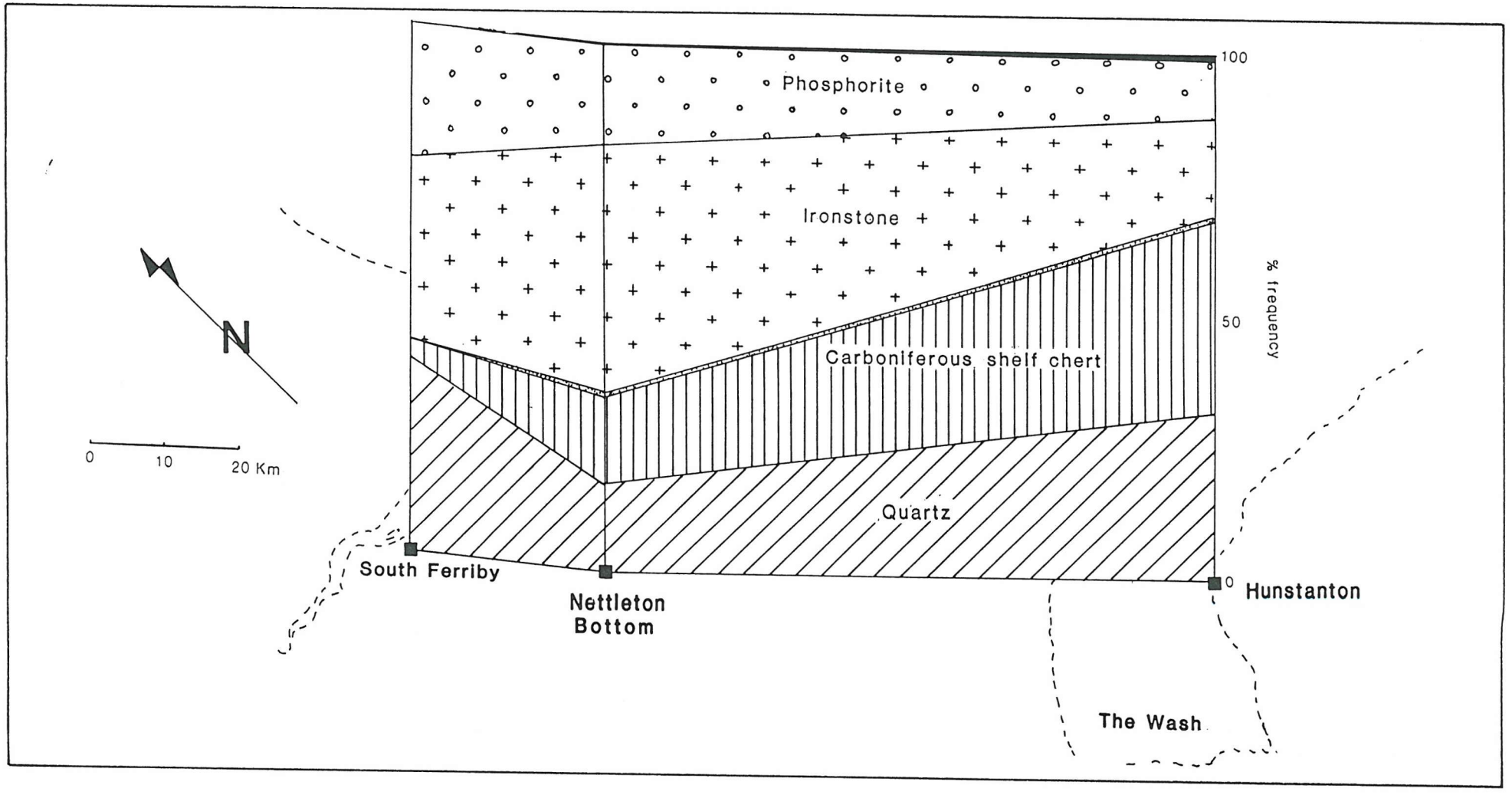


Figure 4.19 A geographical-variation diagram for the composition of the Carstone Member pebble suites in the Norfolk and Lincolnshire area (-2.75 ø fraction).

Location: Norfolk, Lincolnshire and Humberside.
Horizon: Carstone Member.
Grain-size: -2.75 ø
% frequency

Composition	Hunst. 199c1	Nettle. 205c2	S.Ferr. 203c1,2	Mean
Quartz	32.5	17.0	20	23
Carboniferous shelf chert	36.0	16.5	3	19
Sandstone	0.5	1.0	-	1
Ironstone	19.5	47.5	53	40
Phosphorite	10.5	18.0	24	18
Silicified volcanic	1.0	<0.5	-	<0.5
Number of clasts	206	935	89	
Q:C index	48	51	86	62
Q:S index	99	94	100	98
S:C index	1	6	-	2
I:P index	65	72	69	69
Dolo-chert index	15	8	-	-
Bio-chert index	27	28	-	-

where
Hunst. = Hunstanton, Norfolk,
Nettle. = Nettleton Bottom, Lincolnshire,
S.Ferr. = South Ferriby, Humberside.

Table 4.17 Composition of the Carstone Member pebble suites from Norfolk, Lincolnshire and Humberside.

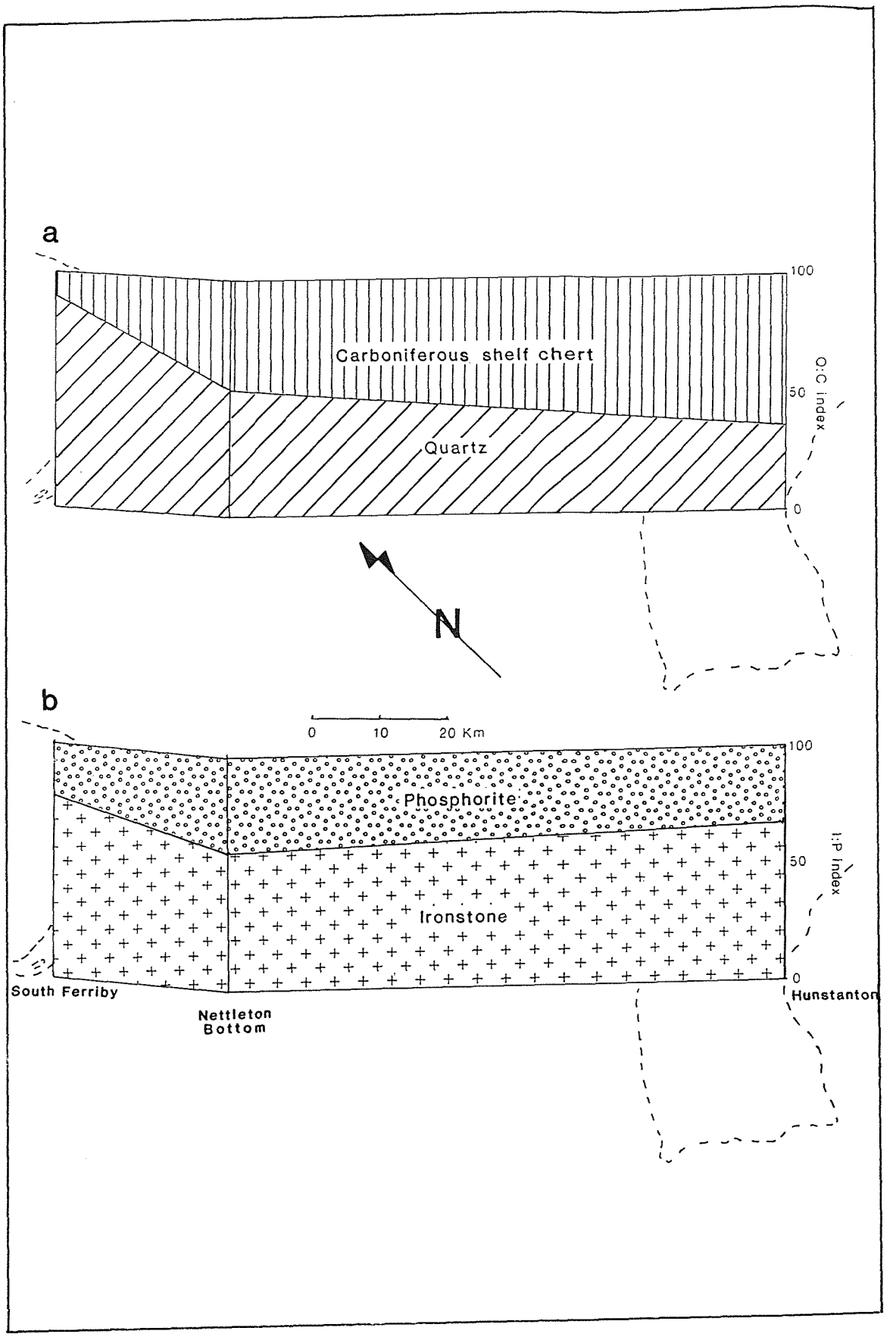


Figure 4.20 Geographical-variation diagrams for the Q:C index (a) and I:P index (b) of the Carstone Member pebble suites in the Norfolk and Lincolnshire area (-2.75 ø fraction).

fossil casts are present in the pebble suite, but are scarce (less than 1%). These include examples of belemnite phragmacones and a few bivalve and ammonite casts. Pleuromya casts were found but Protocardia casts were not recognised. Ammonite casts are very rare and those found are rounded and preserve little of the shell morphology. Clasts of phosphate-cemented sands and phosphatic oolites are moderately common. Many of the phosphate lithotypes are bored and partially replaced by goethite. Borings are filled by phosphate, goethite and occasionally calcite-cemented sand.

At South Ferriby, where the whole of the Carstone Member is exposed (Sect. 2.2.6.3), the base of the unit contains a greater proportion of phosphorite clasts than the top (App.I, Tables i.clxxxviii to i.cxcvii). Phosphorites were probably derived from Lower Cretaceous or Jurassic deposits, but have undergone a complex history of reworking and repeated phosphatization (Kelly, 1980).

4.2.6.4 Comparison of the phenoclast suites from the East Midlands area

In the East Midlands, the pebble-grade detritus from the Mid-Spilsby Nodule Bed and the basal Claxby Ironstone Formation is compositionally similar. However, both of these older pebble suites differ from the pebble suite of the Carstone Member (Fig. 4.18).

The Claxby Ironstone Formation overlies the Lower Spilsby Sandstone Member disconformably at Nettleton (Sect. 2.2.6.2) and reworking of the older pebble bed is probable. The similarity of the Mid-Spilsby Nodule Bed and the basal Claxby Ironstone Formation pebble suites also indicates that there was no fresh influx of coarse-grained detritus into the central and northern Lincolnshire area during the Ryazanian and Valanginian Stages.

In contrast to the older Cretaceous pebble beds, the composition of the Carstone Member pebble suite reflects a distinct change in the type of pebble-grade detritus transported into the area. The greater proportion of quartz in the Carstone Member relative to the Mid-Spilsby Nodule Bed and the basal Claxby Ironstone Formation pebble bed, indicates that the Albian deposits could not have been entirely reworked from the underlying pebble beds. However, the

degree of rounding of the Carstone Member quartz pebbles indicates that some reworking may have occurred. The Carstone Member chert suite is similar to that of the older pebble beds (Sects. 4.2.6.1, 4.2.6.2), but the range of clast sizes is greater. Potential sources for quartz pebbles in the south of the East Midlands Shelf are Devonian, Upper Carboniferous or Triassic pebble beds or perhaps the Precambrian and Lower Palaeozoic basement rocks of the Anglo-Brabant Massif (Whittaker, 1985, map 2). The scarcity of sandstone and tourmaline-bearing pebbles possibly implies that little coarse-grained detritus was reworked from the Triassic strata of the type present in the West Midlands.

The northward increase in abundance of quartz in the Carstone Member is in accordance with a northern source for some of the quartz pebbles. The quantity of quartz clasts in the pebble bed is not great and they are generally small. Possible sources include the middle Jurassic pebbly sands on the Market Weighton High, the Lower and Middle Jurassic sandstones of Yorkshire or the Millstone Grit of the Pennines. The rapid thinning of the Carstone Member over the Market Weighton High (Kent, 1980) and the absence of pebble beds to the north of the High, indicate that derivation from the north of the Market Weighton High was improbable and that Middle Jurassic pebble beds were a likely source.

4.2.6.5 The Clixby pebble bed phenoclast suite

The pebble bed at Clixby, Lincolnshire has not been dated and it has been questioned as to whether it is the Mid-Spilsby Nodule Bed, the basal Claxby Ironstone Formation pebble bed, the Carstone Member, Pleistocene till or some other bed (Kelly & Rawson, 1982). An examination of the pebble suite reveals that it is composed principally of dark Carboniferous shelf chert (78-88%), with subordinate quantities of quartz (12-16%), accessory sandstone (less than 1%) and phosphorite (2-3%; Fig. 4.21).

Research has revealed that the pebble suite is not that of the Carstone Member, since it contains little ironstone and phosphorite, and its Q:C index is low (Sect. 4.3.6.4). The absence of Upper Cretaceous detritus (e.g. flint) implies that a Pleistocene or recent origin is improbable. The pebble suite is very similar to that of

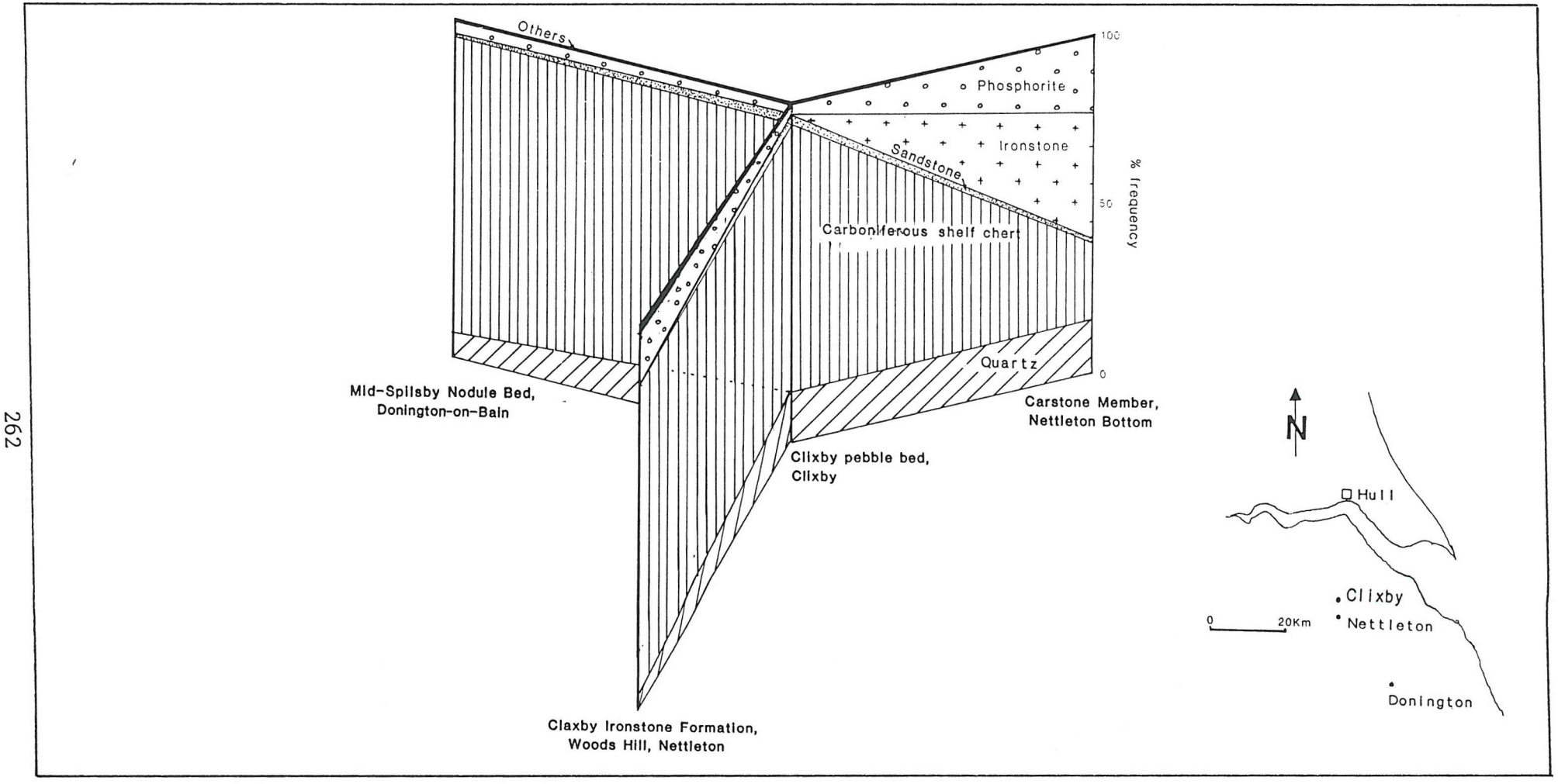


Figure 4.21 A variation diagram for the composition of the Clixby pebble bed and the Lower Cretaceous pebble suites of north Lincolnshire (less than -2.50 ø fraction).

the Mid-Spilsby Nodule Bed and the basal Claxby Ironstone Formation pebble bed and even contains a high proportion of rhombic-pseudomorph cherts. This is a characteristic of both these Lower Cretaceous pebble beds. The Clixby pebble bed could be either of these horizons. However, the increasing erosion below the Claxby Ironstone Formation northwards indicates that the Mid-Spilsby Nodule Bed is probably absent at Clixby and the bed is either the basal Claxby Ironstone Formation pebble bed or a younger pre-Carstone Member pebble bed.

4.2.7 The phenoclast suites of the Normandy area

Examination of the basal Gault Clay Formation and the Poudingue Ferrugineux pebble beds in Normandy reveals that they are within a petrographic province quite distinct from those of England.

4.2.7.1 The Poudingue Ferrugineux and Gault Clay Formation phenoclast suites

Pebble suites were collected from four localities (Sect. 2.2.7) and each is comparatively similar (Figs. 4.22, 4.23a, Table 4.18). However, a north-south variation is seen in the suite.

The pebble beds are quartz-rich (50-85%) and contain minor amounts of sandstone (2-12%). The quartz pebbles are of white, grey or pink granoblastic types (Sect. 3.2.14.1), with a significant proportion of fibrous quartz (5-11%; Sect. 3.2.14.2) and quartz with inclusions (chlorite and possibly pyrite; 0-4%). Chert pebbles are present in the beds and are of three types:

1. black or dark grey, rounded cherts of microcrystalline silica without bioclasts are present in minor amounts (2-5%). The cherts are veined by quartz and are occasionally laminated (Sect. 3.2.13.1). These cherts were derived from a deformed source area and are possibly of Brioverian or Lower Palaeozoic origin.
2. bioclastic chert with foraminifera, crinoids and brachiopods is present in the pebble suites (1-7%). The fauna of the cherts differs from those of the Carboniferous shelf cherts of Britain, but their source is possibly the Palaeozoic rocks of the Cotentin area (Doré et al., 1977 and Juignet et al., 1973).
3. angular to subangular pebbles of silicified bioclastic packstone

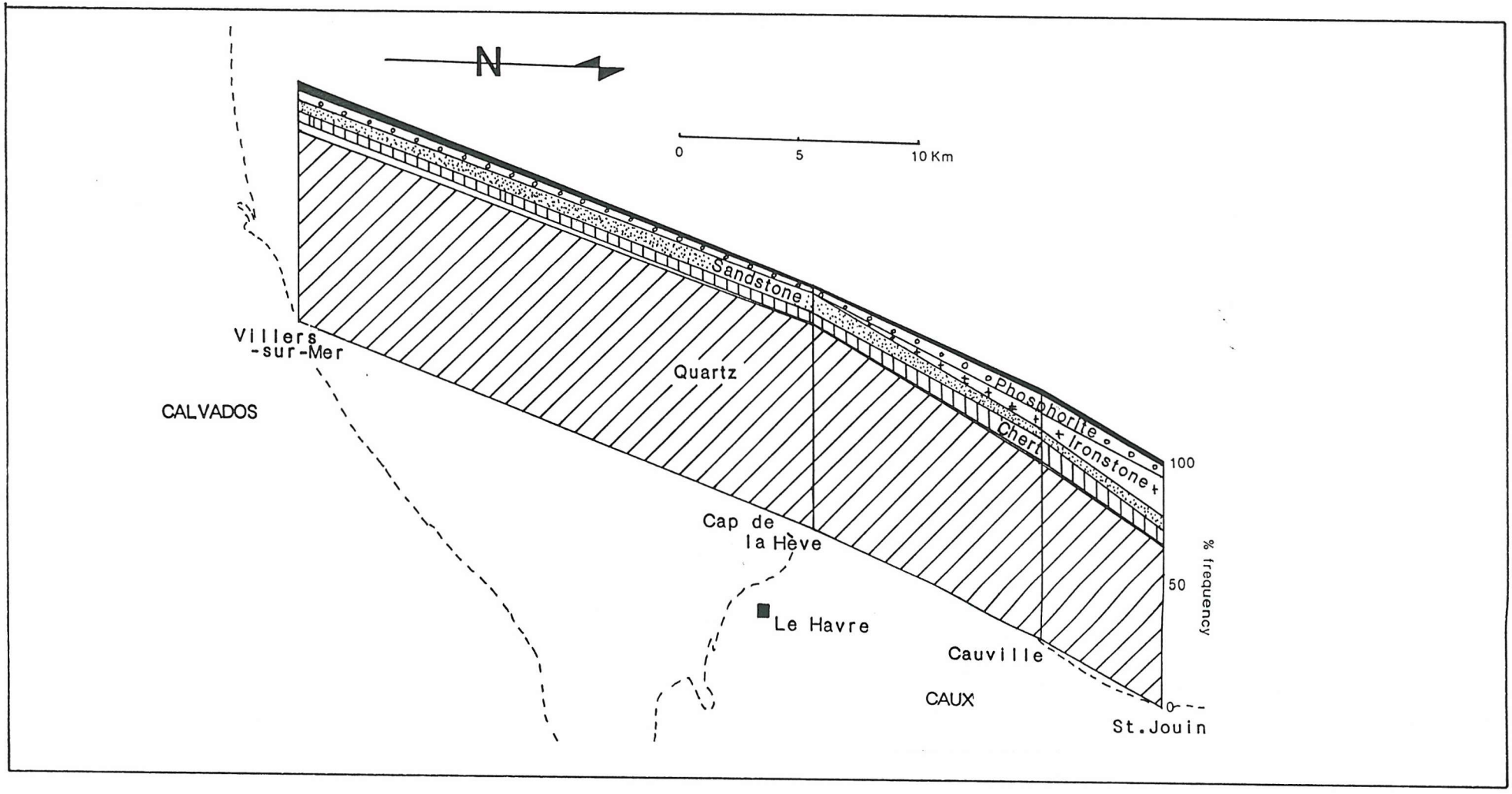


Figure 4.22 A geographical-variation diagram for the composition of the Poudingue Ferrugineux and basal Gault Clay Formation pebble suites in Normandy (-2.75 ø fraction).

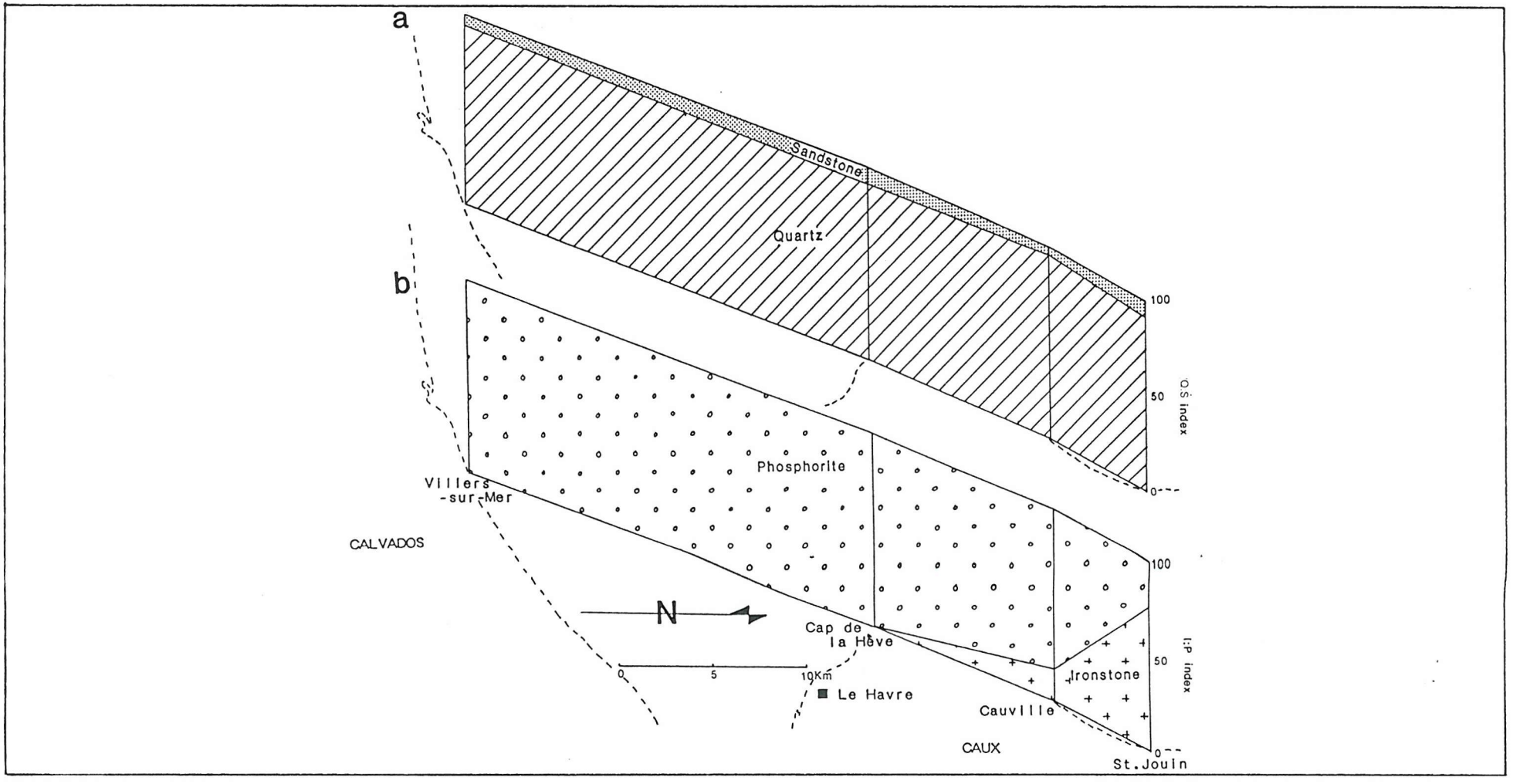


Figure 4.23 Geographical-variation diagrams for the Q:S index (a) and the I:P index (b) of the Poudingue Ferrugineux and basal Gault Clay Formation pebble suites in Normandy (-2.75 ø fraction).

Location: Normandy, France.
Horizons: Gault Clay Formation and Poudingue Ferrugineux.
Grain-size: -2.75 ø
% frequency

Composition	Vill. 220g2	Hève 221pf1	Cauv. 222pf1	St.Jou# 223pf1	Mean
Quartz	80.0	85.0	72	65	76
Jurassic chert	4.0	-	1	1	2
Palaeozoic chert	4.0	4.5	7	6	5
Sandstone	5.0	8.0	3	6	6
Ironstone	-	-	9	3	3
Phosphorite	4.5	2.0	7	17	8
Tourmalinite	0.5	0.5	-	-	< 0.5
Silicified volcanic	0.5	-	-	2	1
Jasper	0.5	-	-	-	< 0.5
Mylonite	1.0	-	1	-	1
Number of clasts	231	184	74	102	
Q:S index	94	91	96	92	93

where
Vill. = Basal Gault Clay Formation pebble bed, Villers-sur-Mer,
Hève = Poudingue Ferrugineux, Cap de Hève,
Cauv. = Poudingue Ferrugineux, Cauville,
St.Jou. = Poudingue Ferrugineux, St. Jouin.

-2.75 ø, -2.50 ø

Table 4.18 Composition of the basal Gault Clay Formation and Poudingue Ferrugineux pebble suites in Normandy.

and grainstones. The fauna of the clasts includes Rhaxella and Pachastrella spicules and bivalves (Sect. 3.2.1.1). This faunal assemblage is consistent with derivation of the cherts from the Oxfordian (Calcaire de Hennequeville), Bajocian (Maliere) or Bathonian (Calcaire de Caen and Calcaire de Bessin) limestones of Normandy.

Tourmalinites (tourmalinized cherts and quartzites; Sect. 3.2.11.3) are present in minor amounts (less than 1%). Clasts of quartz-mylonite and other deformed fine-grained siliceous lithotypes (Sect. 3.2.14.3) are also present in the pebble suites. These clasts were probably derived from the Brioverian or Pentevrian basement of the Cotentin High or possibly the Armorican Massif.

Most of the lithotypes are siliceous, indicating that the pebble suites are mature. The high proportion of fibrous quartz, however, suggests that some of the detritus is in its first-cycle of reworking.

Phosphorite and ironstone pebbles are present in the pebble beds. Microcrystalline phosphate-cemented glauconitic arenites (Sect. 3.2.10.2) are the most common type of phosphorite pebble, but oolitic phosphorites (Sect. 3.2.10.3) have also been found. Ironstone pebbles are of quartz arenites with a matrix of microcrystalline goethite (Sect. 3.2.9.5).

Examination of the lateral variations in these suites reveals an interesting trend. There is a slight decrease in the abundance of siliceous clasts and an increase in the abundance of ironstone pebbles from south (Calvados) to north (Caux; Fig. 4.23b). The abundance of phosphorite pebbles remains approximately constant throughout the area (Figs. 4.22, 4.23b). This is of significance in the interpretation of detrital provenance in this area. Juignet (1971), in a study of the mid-Cretaceous palaeogeography of the Normandy area, suggested that the Cretaceous shoreline retreated southwards during the mid-Albian transgression towards the detrital source area. The increase in abundance of ironstone pebbles northwards implies that they were not derived from pedogenic deposits which would presumably have been best developed to the south. It is probable that they were reworked from contemporaneous marine deposits

or eroded from local Jurassic source rocks.

4.3 REGIONAL VARIATIONS IN THE COMPOSITION OF THE UPPER JURASSIC AND LOWER CRETACEOUS PHENOCLAST SUITES OF ENGLAND AND NORMANDY

When contrasted, the Upper Jurassic and Lower Cretaceous pebble suites in southern Britain and Normandy are found to be separable both geographically and stratigraphically. The limited extent of pebbly lithofacies restricted the investigation of lateral provenance variations for single horizons and therefore, the pebble suites were considered as three chronological divisions: the Late Oxfordian to Early Berriasian division, the Late Berriasian to Barremian division, and the Aptian to Middle Albian division. Changes in the detrital suites probably occurred during the time-intervals considered, but in general were restricted to local variations.

4.3.1 The Oxfordian to Early Berriasian phenoclast assemblage

The pebble suites of the Corallian Group, the Lydite Beds, the Mid-Spilsby Nodule Bed and middle Purbeck Formation are included in this assemblage. In all these pebble suites, the extrabasinal pebble-grade detritus was dominated by chert clasts derived from Carboniferous limestones. Q:C indices are therefore low (2-15). The sandstone pebble content is similarly low. The dolo-chert indices for the pebble beds are moderately high (up to 28), indicating a high proportion of cherts with rhombic-pseudomorphs.

The scarcity of quartz and sandstone pebbles in these suites indicates that Lower Palaeozoic and Precambrian basement rocks and Triassic, Upper Carboniferous and Devonian pebble beds did not provide a significant amount of detritus to these suites. The source areas may be assumed therefore, to have had extensive sedimentary covers which, when eroded, provided few resistate clasts.

The intrabasinal detritus in the Lydite Beds and the middle Purbeck Formation was derived from Upper Jurassic sources. In the case of the Upper Lydite Beds, much of the detritus is derived from the underlying beds indicating only minor intrabasinal erosion. However, the presence of Kimmeridge Clay Formation and Portland Limestone Formation clasts in the middle Purbeck Formation indicates a more extensive phase of erosion, probably in association with local

tectonic movements.

4.3.2 The Late Berriasian to Barremian phenoclast assemblage

Pebble beds of this assemblage include those of the "Unio" Member and the Wessex Formation in Dorset and the basal Claxby Formation in the East Midlands. Clearly, the conclusions that might be drawn from data concerning three horizons in two widely separated localities are limited. However, the present study is of importance when considering variations in the type of coarse-grained sediment which entered the basins in Dorset and the East Midlands and also supplements earlier studies, in particular those studies of P.Allen (1949, 1960, 1961, 1967a, 1972, 1975).

Pebbles of Carboniferous shelf chert have not been recognised in the "Unio" Member and the Wessex Formation pebble suites of Dorset. The presence of western-derived detritus in these suites distinguishes them from the Corallian Group and middle Purbeck Formation pebble suites of this area. The majority of the Wessex Formation clasts were derived from Cornubia and Armorica and there is little evidence for a significant input of Triassic detritus in the suite. It is concluded therefore that a significant change in the provenance of coarse-grained detritus entering the western part of the Central Channel Basin occurred during earliest Cretaceous times.

The basal Claxby Ironstone Formation pebble bed differs from the Dorset pebble beds since it is compositionally similar to the older pebble beds in the area of deposition, the East Midlands Shelf. Chert pebbles derived from Carboniferous limestones are common and quartz is present in minor quantities. The clast suite is mature and the scarcity of silicified grainstones and coarse-grained cherts indicates that derivation direct from the primary chert source is improbable. The disconformable position of the Claxby Ironstone Formation above the Lower Spilsby Sandstone Member at the sample locality (Sect. 2.2.6.2), indicates that reworking of an older pebble bed was likely.

4.3.3 The Aptian and Early Albian phenoclast assemblage

This phenoclast assemblage is separated into two subassemblages;

the Aptian phenoclast subassemblage and the Early to Middle Albian phenoclast subassemblage.

4.3.3.1 The Aptian phenoclast subassemblage

The pebbly sands and thin pebble beds of Aptian age were deposited in shallow seas. The coarse-grained detritus is commonly associated with what have been recognised as sediments deposited during transgressive events (Casey, 1961). During Early Aptian times, sedimentation was generally restricted to the same deposition area as the Weald Clay Group and the Vectis Formation and it was probably not until the nutfieldiensis Zone transgression that the Aptian sea extended significantly beyond this area. The pebble deposits of Late Aptian age examined from the Isle of Wight (Ferruginous Sands Formation; Sect. 4.2.2.1), the Weald (Bargate Beds Formation; Sect. 4.2.3.1) and in the south Midlands (Faringdon Sponge Gravel and Seend Ironsand; Sects. 4.2.4.3, 4.2.4.4) are all compositionally distinct, but all contain both locally derived intrabasinal and exotic extrabasinal phenoclasts. The influx of locally derived clasts into the basins probably resulted from the transgression and the stranding of coarse-grained detritus on the shelf and also to erosion of areas of uplift (Casey, 1961).

4.3.3.2 The Early and Middle Albian phenoclast subassemblage

This phenoclast subassemblage has several regional variations (Figs. 4.24, 4.25, 4.26) and each of the Cretaceous basins may be considered as separate petrographic provinces or subprovinces.

Dorset and Normandy: the phenoclast suites of Dorset and Normandy both contain detritus of western origin, but are distinctly different. The majority of the Albian pebble suite in Dorset was derived from the Cornubian Massif, whereas much of the French detritus was from the Cotentin High. Locally derived detritus is present in both areas and is probably the result of tectonic activity within the basins and erosion of highs during the mammillatum Zone to dentatus Zone transgression.

The Isle of Wight: a western influence is also noted in the Albian pebble suites of the Isle of Wight. The bulk of the detritus in these

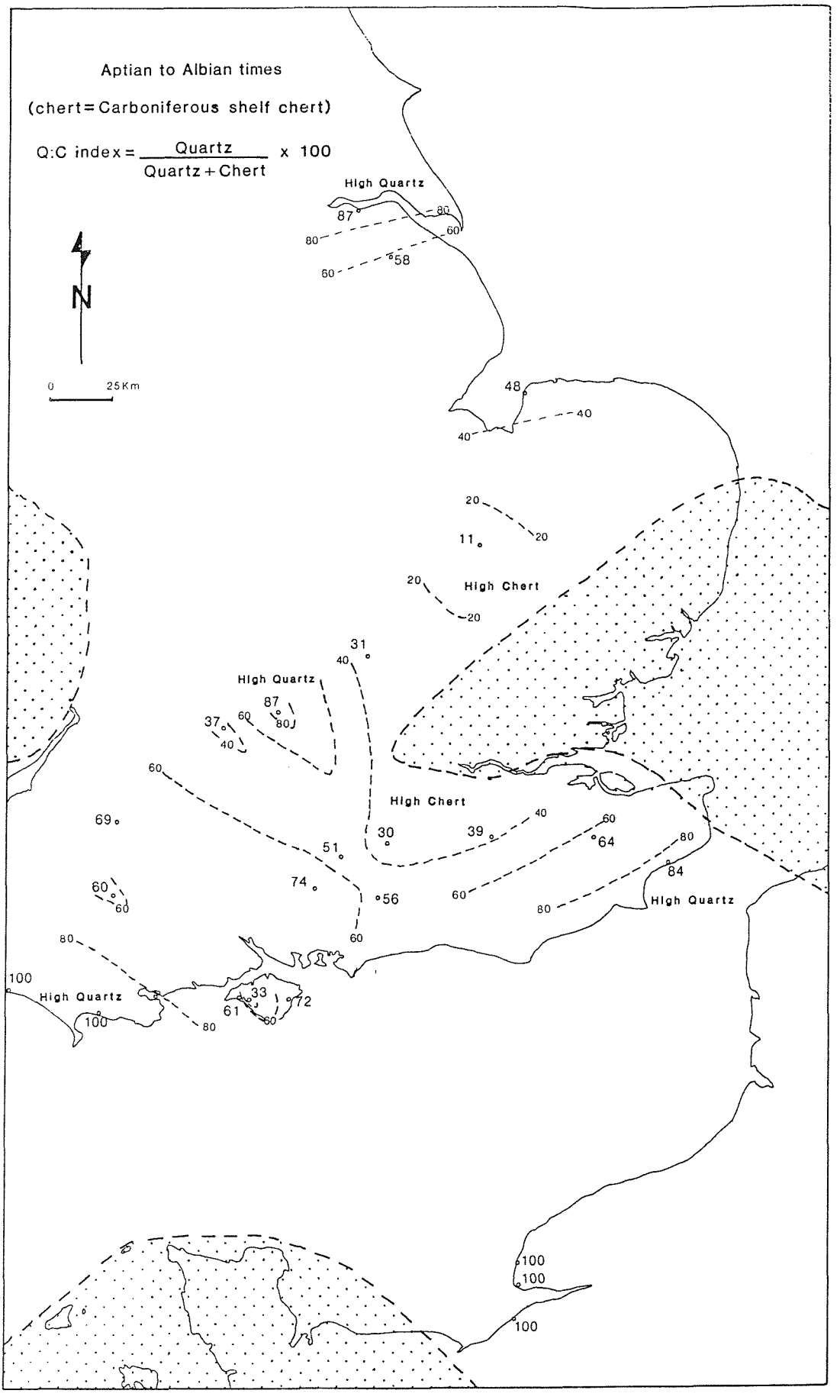


Figure 4.24 Contour map for the Q:C index of Lower Greensand Group and basal Gault Clay Formation pebble suites. The -2.75 ø fraction was selected where possible.

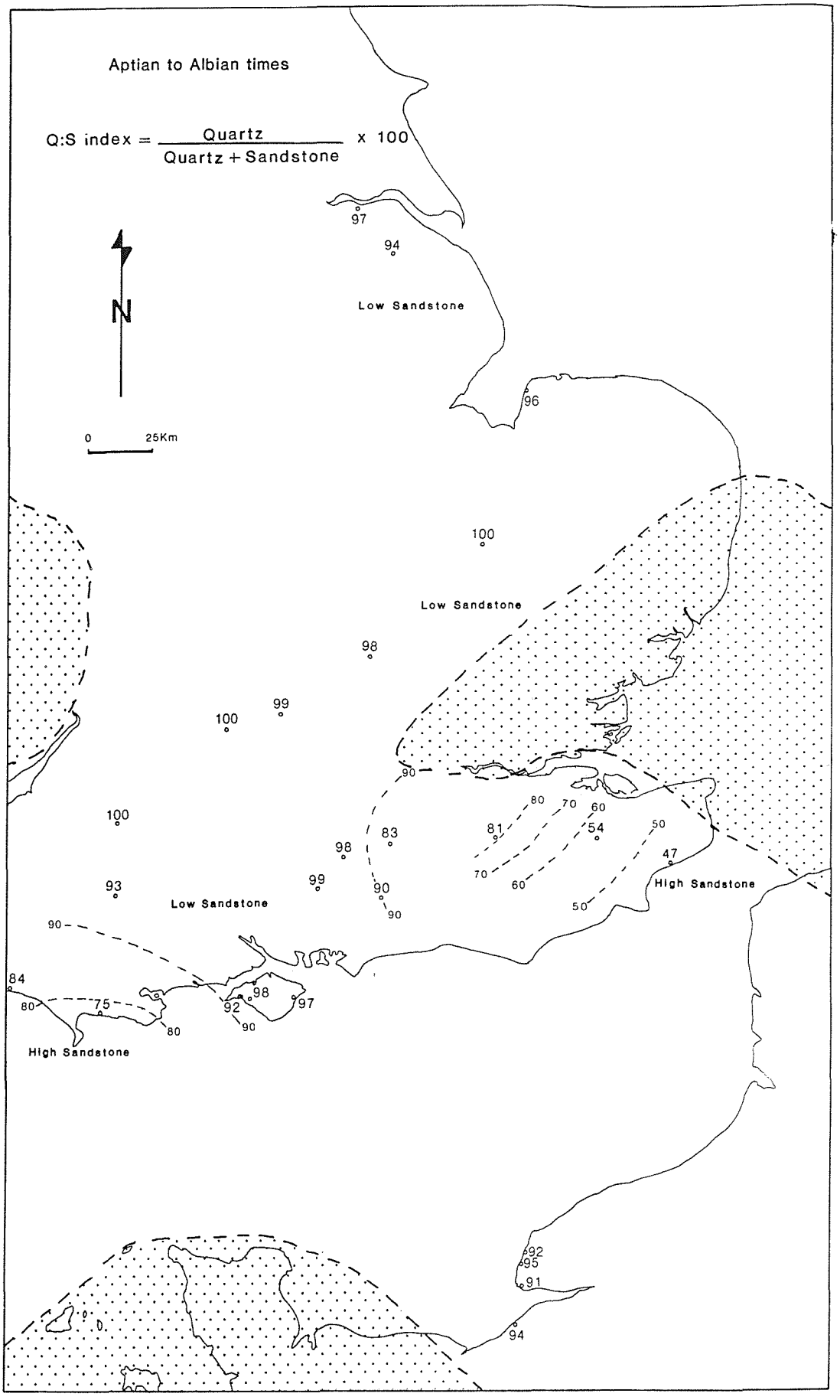


Figure 4.25 Contour map for the Q:S index of Lower Greensand Group and basal Gault Clay Formation pebble suites. The -2.75 ø fraction was selected where possible.

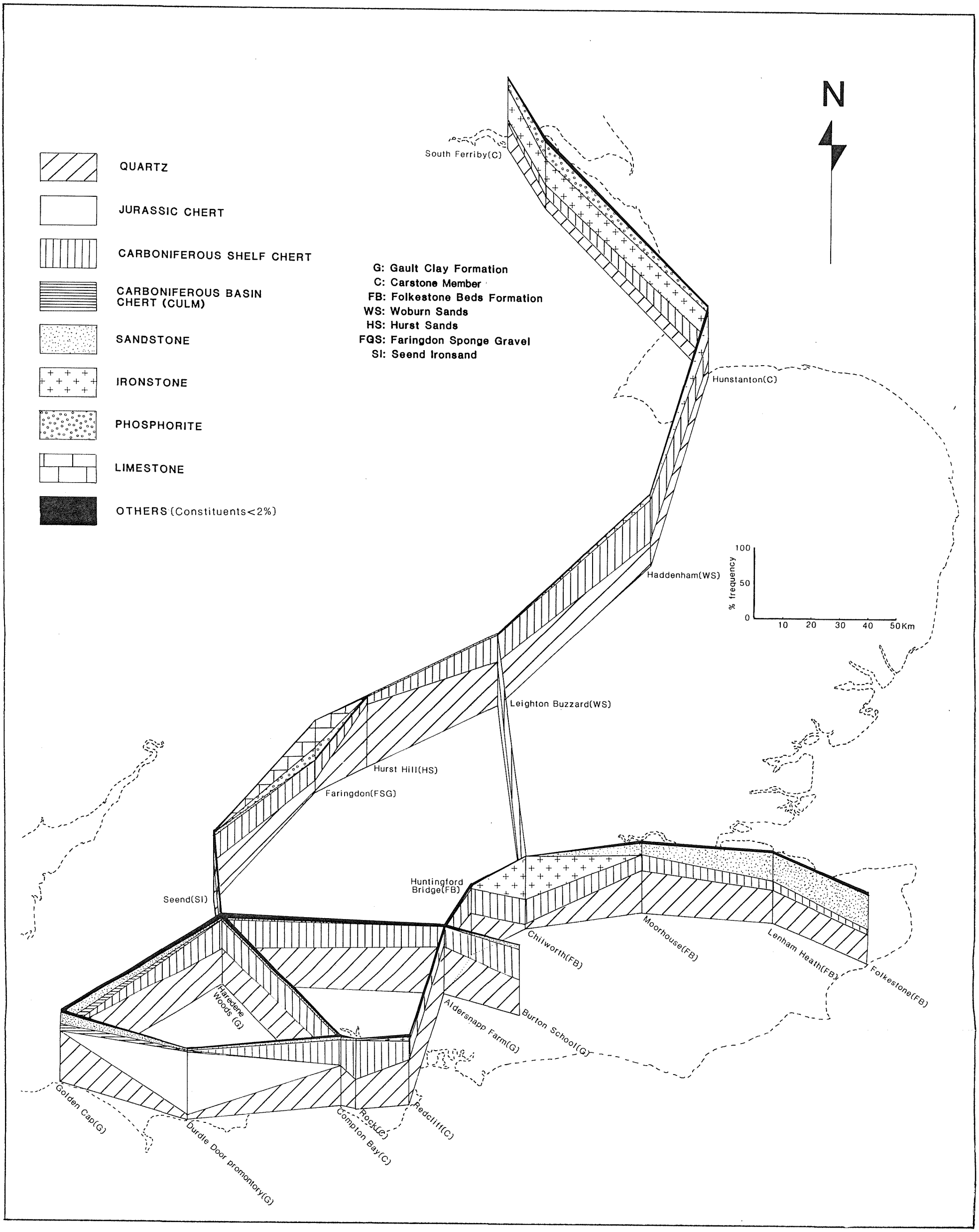


Figure 4.26 A fence diagram showing lateral variation in the composition of the Lower Greensand Group and basal Gault Clay Formation pebble suites in southern Britain. The -2.75 ø fraction was selected where possible.

pebble suites however was derived from northern sources. The Q:C indices of the Albian pebble beds (Carstone Member) are similar to those of the Late Aptian pebble beds. Jurassic detritus is relatively scarce.

The Weald: the Early and Middle Albian phenoclast suites of the Weald differ distinctly from those of Dorset. Cornubian-type detritus is not found and the suites are composed of detritus derived from the Anglo-Brabant Massif. On this massif, Palaeozoic and Upper Jurassic rocks subcrop below the Lower Greensand Group and Gault Clay Formation (Middlemiss, 1975).

Wiltshire and Oxfordshire: the Gault Clay Formation phenoclast suite from the Vale of Wardour has a similar constitution to that of the Isle of Wight pebble beds. It has intermediate Q:C indices (c. 63). Reworking of quartz-rich detritus from the margins of the Welsh Massif into the Wiltshire and Isle of Wight area is probable.

Bedfordshire and Cambridgeshire: the Woburn Sands and basal Gault Clay Formation phenoclast suites of Bedfordshire and Cambridgeshire have low to moderate Q:C indices (20-50). Clast-morphology indicates that derivation from the primary source rocks was unlikely. Clasts were probably derived from older pebble beds on the margins of the Anglo-Brabant Massif or the East Midlands Shelf.

East Midlands: the Early Albian pebble beds (Carstone Member) contain a pebble-suite distinct from those of the Bedfordshire and Cambridgeshire area. The high quartz contents in the Carstone Member phenoclast suites are interpreted as the result of an influx of quartz-rich detritus from the Anglo-Brabant Massif on the southern margin of the shelf and the introduction of minor quantities of detritus from Middle Jurassic sources on the Market Weighton High.

CHAPTER V

TECTONIC AND EUSTATIC CONTROLS ON LATE JURASSIC AND EARLY CRETACEOUS SEDIMENTATION IN SOUTHERN BRITAIN

5.1 GENERAL

Pebble beds are commonly associated with unconformities or non-sequences, with the coarse-grained detritus having been derived from elevated areas which formed in response to a complex inter-relationship of sedimentary, tectonic and eustatic controls. Changes in the rates of sea-level rise and fall, sediment influx and subsidence/uplift would all have affected conditions in the sedimentary environment, thereby making it possible for coarse-grained detritus to have been transported. Falls in sea-level, increases in the detrital input or decreases in the rate of subsidence would favour the formation of pebble beds, but a subsequent change in conditions may have been necessary to preserve such deposits.

Pebble-grade detritus examined during this study was transported by both fluvial and shallow marine processes (Chap. II). The pebble beds are frequently thin lags at the tops or bases of sedimentary sequences and are assumed to have been formed in response to distinct changes in the gross sedimentary environment. Deposition during the Jurassic and Cretaceous Periods occurred at a time of relative tectonic quiescence, but sedimentological evidence of localized tectonic movements implies that some structural control on sedimentation existed. Coarse-grained detritus reworked from uplifted areas may therefore provide an important indication of a disturbance otherwise unrecorded in the sediments in a basin. Pebble beds and pebbly sands in the Upper Jurassic and Lower Cretaceous rocks of southern England and northern France are in general compositionally mature. Coarse-grained clastic deposits commonly occur in proximity to structural highs, but their presence or absence cannot be used directly to indicate the presence of such structures.

5.2 EUSTATIC CONTROLS ON SEDIMENTATION

Changes in the basin geometry and depositional environment may have been caused by both regional tectonics and eustatic sea-level changes. However, the effects of the two processes can rarely be distinguished satisfactorily, and hence, before an interpretation of the tectonic development of a basin may be made, the effects of

eustatic movements must first be considered.

5.2.1 Mechanisms for eustatic sea-level change

Facies changes, unconformities and diastems in sedimentary sequences deposited under marine conditions frequently appear to be unrelated to tectonic events and may be traced across basins and in some cases between basins (e.g. the mid-Albian transgression). These features have been interpreted as resulting from changes in relative sea-level (i.e. eustatic sea-level changes). Attempts have been made to recognise such sea-level fluctuations in the stratigraphical record (Vail et al., 1977; Cooper, 1977; Hallam, 1978).

The influence of global sea-level changes on sedimentation is potentially significant, since fluctuations in sea-level affect the positions of the strandline, depth of water in the basins and the size and relief of syn-depositional highs. Each of these features has in turn an important control on the distribution of coarse-grained detritus in a basin.

The importance of eustatic sea-level fluctuations was first realised by Suess (1906) and the concept was later advanced by Stille (1924), Kuenen (1954) and others. It was not until the development of plate-tectonic theories (e.g. Hays & Pitman, 1973), however, that eustatic models were considered in detail. In a review of the problem, Donovan & Jones (1979) concluded that there were four principal controls on eustasy:

1. changes in the volume of land ice,
2. changes in sediment accumulation rates,
3. desiccation of isolated oceanic basins,
4. changes in the volume of the oceanic ridges.

No evidence of major Jurassic or Cretaceous ice sheets has been found and the climate during this period was notably equable (Hallam, 1985). Sea-level changes resulting from the development of ice sheets during the Mesozoic Era are therefore considered improbable.

If the volume of sediment accumulating in marine basins is greater than the volume of sedimentary rock being uplifted from sedimentary basins, then the global sea-level will rise. Global

sea-level rise and fall, as a result of sediment accumulation, may have occurred during the Mesozoic Era but has not as yet been demonstrated satisfactorily enough to be regarded as proven. Donovan & Jones (1979) attributed small-scale variations in sea-level to this mechanism.

Desiccation of sedimentary basins and formation of evaporites occurred during the Late Jurassic times, but Gordon (1975) has noted that evaporites are less common in Lower Cretaceous rocks. Evidence for the complete desiccation of large basins has not, however, been recognised in Upper Jurassic sediments. The sediments of Late Jurassic evaporite basins were probably products of low sea-level. Basin evaporation is unlikely to have been the cause of this sea-level fall.

The possibility that alterations in the volume of oceanic ridges might cause sea-level changes was recognised by Hallam (1963a). This mechanism found favour following the development of plate-tectonic models. Volume-change may occur by two mechanisms:

1. the volume of the ridge may increase as a result of heating during episodes of increased sea-floor spreading rates (Hays & Pitman, 1973);
2. the ridge length itself may increase in association with ocean-basin formation.

Donovan & Jones (1979) considered the latter to be of more importance. In connection with this, it has been suggested that the opening of the Atlantic Ocean may have controlled global sea-levels during the Mesozoic Era (Hallam, 1978). Donovan & Jones (1979) questioned, however, whether changes in the volume of ocean ridges could account for the small-scale sea-level changes recognised in many sedimentary basins. Such fluctuations may have resulted from changes in the global rate of sedimentation, desiccation or alternatively, and more plausibly, by local tectonic events.

5.2.2 Proposed Late Jurassic and Early Cretaceous eustatic events

Eustatic changes in sea-level during the Jurassic and Cretaceous Systems have been proposed as the controlling factors on facies changes in Britain (Hallam, 1961, 1963b, 1978; Sellwood, 1970; Brookfield, 1973b; Talbot, 1973; Townson, 1975; Donovan et al., 1979;

Hancock & Kauffman, 1979; Rawson & Riley, 1982). The use of eustatic changes to account for facies-variations in sedimentary basins arose partially as the result of the studies of sediments deposited in epicontinental basins unaffected by orogenic events. However, the areas were commonly affected by minor (epiorogenic) tectonic events, and it was recognised that tectonic and eustatic events could potentially have similar effects on sedimentation. Changes in the rate of sedimentation and basin-subsidence would also affect sea-level. For these reasons, Vail et al. (1977) suggested that only if an apparent sea-level change could be demonstrated to have occurred contemporaneously in three regionally isolated basins, could such an event be considered as eustatic in origin. Details of interbasinal correlations and the controlling factors were discussed by Donovan & Jones (1979), Vail & Todd (1981) and briefly by Watts (1982).

The development of eustatic sea-level and coastal onlap curves for the Mesozoic Era by Vail et al. (1977), together with the curves of Hallam (1978, 1981) for the Jurassic System and Cooper (1977) for the Cretaceous System provide a mechanism by which interpretation of the distribution and composition of the coarse-grained detrital suites might be made. The curves are superficially similar, but differ significantly in detail (Fig. 5.1). This indicates the uncertainty which still remains in the interpretation of eustatic sea-level changes.

Three methods have been developed to calculate the effects of eustatic change during the Mesozoic Era:

1. Vail et al. (1977) and Vail & Todd (1981) produced estimates of sea-level change and relative coastal onlap from the interpretation of seismic-reflection data and it is their interpretations that have been most widely used;
2. sea-level changes may also be calculated by estimation of changes in the position of shore-lines or the changing depth of deposition of marine sediments through time (Suess, 1906);
3. the final method involves calculation of changes in the surface area of a basin covered by marine sediments during a defined episode (Cooper, 1977; Hallam, 1978, 1981; Hancock & Kauffman, 1979). Rawson & Riley (1982), in an examination of facies-variations and unconformities in the North Sea, developed a

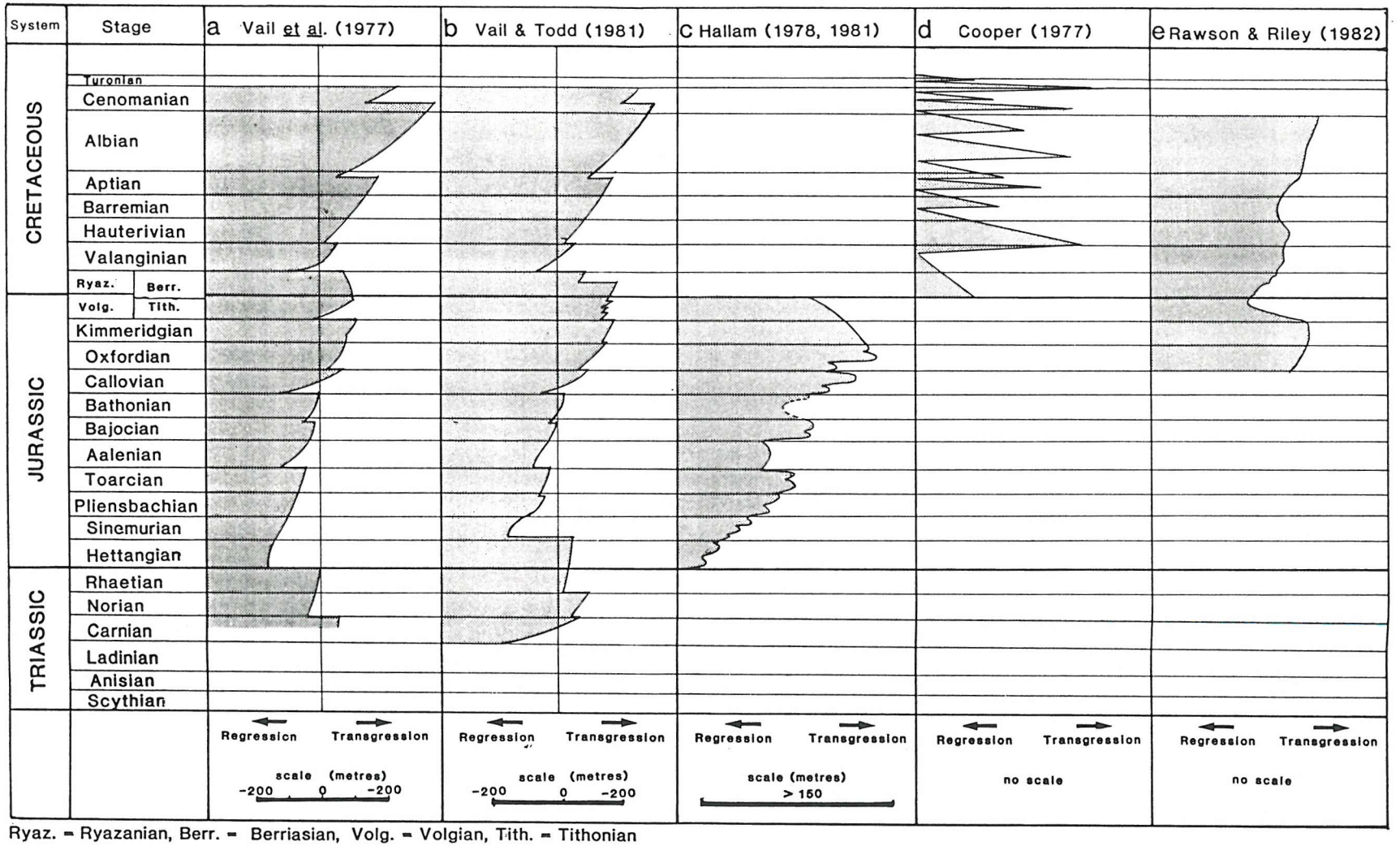


Figure 5.1 Global sea-level curves for the Mesozoic Era (after Vail et al., 1977; Vail & Todd, 1981; Hallam, 1978, 1981; Cooper, 1977; Rawson & Riley, 1982).

sea-level curve for the Mesozoic Era, but did not attempt to correlate their curve with others from outside this area.

From the studies of earlier workers a number of trends are recognised. The curves developed for the Jurassic System are detailed, but those of the Cretaceous System and in particular Early Cretaceous times are less precise (Fig. 5.1).

During the Jurassic Period, sea-level is considered to have risen progressively (Vail et al., 1977; Hallam, 1978), but important Aalenian and Bathonian to Callovian regressions occurred.

Details of Cretaceous eustatic events were not published by Vail & Todd, (1981); only the major eustatic cycles were described (Fig. 5.1b). A progressive coastal onlap is considered to have occurred during Early Cretaceous times, lasting until Late Aptian times, when an offlapping event may have resulted in worldwide unconformities. The Aptian event was also recognised by Kent (1976), but was ascribed by him to tectonic effects. Vail & Todd (1981) proposed a further transgressive event from latest Aptian until the mid-Cenomanian times.

Cooper (1977), in a study of worldwide Cretaceous facies-variations recognised fifteen major eustatic events (Fig. 5.1d). However, his work was criticised by Hancock & Kauffman (1979) for lacking quantified estimates of the extent of regressive phases. Cooper's "curves" differ from those of Vail et al. (1977) and Vail & Todd (1981) in that he considered there to have been a major transgression during Late Volgian times, with subsequent transgressions during the Late Barremian, earliest Aptian, Late Aptian and Early Albian times (compare Figs 5.1a,b and 5.1d).

From studies in the North Sea, Rawson & Riley (1982) recognised four major eustatic 'cycles' during the Cretaceous System (Fig. 5.1e). The oldest was a continuation of the Late Jurassic regression which persisted until Early Ryazanian times. The following Late Ryazanian to Late Hauterivian interval was marked by a general transgression with minor regressive events. A 'mildly' regressive phase occurred from Late Hauterivian to Early Aptian times and was succeeded by a strongly transgressive phase. These episodes are in

general agreement with the scheme developed by Vail et al. (1977) and modified by Vail & Todd (1981) for the North Sea (compare Figs. 5.1a,b and 5.1e).

5.2.3 Late Jurassic and Early Cretaceous eustatic controls on sedimentation in southern Britain

Eustatic events during the Jurassic and Cretaceous Systems are least well demonstrated for the Late Oxfordian to Early Albian interval. The lack of clarity results principally from the marine regression in many areas, particularly in northwest Europe.

Oxfordian events: the 'cyclic' sedimentation pattern recognised in the Corallian Group of southern England by Arkell (1933a) was interpreted by Talbot (1973) as resulting from eustatic changes in sea-level. The sediments deposited during the transgressive phase were thin and were succeeded by a thicker sequence of shallowing-upwards deposits. The studies of Wilson (1968), Talbot (1973) and Brookfield (1973b) demonstrated that during the Oxfordian Stage in southern England sea-level was relatively low. The pebble-bearing limestones of the Corallian Group in Dorset, at the base of Talbot's second and third cycles, were interpreted as having formed during transgressive phases.

Kimmeridgian and Portlandian events: the Kimmeridgian Stage is considered by Vail et al. (1977) and Vail & Todd (1981) to have been a time of regionally high sea-level. Hallam (1978), however, did not depict the Kimmeridgian sea-level to be significantly higher than that of the Oxfordian Stage and tentatively suggested a progressive fall in sea-level during the Kimmeridgian Stage. Similarly, Townson (1975) identified three Late Kimmeridgian to Early Portlandian sedimentary cycles in southern England and concluded that they resulted from fluctuations in sea-level during an episode of progressive sea-level fall. Rawson & Riley (1982) also considered this time to be one of marine regression, but noted the importance of contemporaneous rifting in the North Sea. They suggested that the Lydite Beds were deposited during an episode of major uplift and erosion which caused marine regression and isolation of the Wessex and Southern North Sea Basins. However, the effect of tectonic movements on apparent sea-level change or coastal onlap has not been

defined satisfactorily.

Berriasian to Barremian events: the Late Jurassic and Early Cretaceous retreat of the seas from the basins of southern England hinders recognition of eustatic sea-level changes in this area. On the East Midlands Shelf, however, marine conditions persisted and the Late Ryazanian (Late Berriasian) to mid-Hauterivian interval is reported to have been a transgressive phase (Cooper, 1977; Vail & Todd, 1981; Rawson & Riley, 1982) marked by repeated breaks in sedimentation (e.g. breaks at the bases of the Claxby Ironstone Formation and the Tealby Clay Member). The erosion surfaces and pebble lags at the base of the Upper Spilsby Sandstone Member (Late Ryazanian) and Claxby Ironstone Formation (Early Valanginian) were both considered to result from coastal onlap (Rawson & Riley, 1982).

In the Purbeck Formation of the Weald, Morter (1984) recognised five (locally six) major salinity 'events' which he correlated with intervals of marine influence. The most extensive marine inundation was the Cinder Bed Member transgression (Casey, 1963). The development of oyster banks and a larger faunal diversity associated with this transgression indicates near-marine salinities to have been present in the Wessex Basin of southern England. Casey (1963) correlated the Cinder Bed Member in southern England with the pebble-bearing Mid-Spilsby Nodule Bed on the East Midlands Shelf.

An increase in climatic humidity, coupled with the probable tectonic rejuvenation of highs and massifs from Berriasian to Barremian times resulted in influxes of coarse-grained detritus into the basins of southern England (P.Allen, 1975, 1981; Stewart, 1981b). P.Allen (1975) commented on the possibility of eustatic events affecting lake levels in the area but did not recognise definite eustatic influences on sedimentation.

Aptian and Albian events: the absence of earliest Aptian sediments in the Weald and Central Channel Basins (Table 1.7) was considered by Cooper (1977) to indicate a minor, but widespread, regressive phase. However, the recognition of folding prior to the earliest Aptian transgression in southern England (Casey, 1961) implies that the break may have resulted locally from minor tectonic movements.

Rawson & Riley (1982) considered that four minor transgressive events occurred in England during Early Aptian and Middle Albian times, each being part of a major mid-to-late Cretaceous transgressive phase resulting from eustatic sea-level rise. The transgressive events occurred during:

1. the late fissicostatus Zone (Early Aptian),
2. the nutfieldiensis Zone (Late Aptian),
3. the tardefurcata Zone (Early Albian) and
4. the dentatus Zone (Middle Albian).

1. The late fissicostatus Zone transgression resulted in the inundation of the Barremian lakes in southern Britain. The basal beds (the Perna Beds) are locally marked by pebble lags.
2. The nutfieldiensis Zone transgression is similarly marked by pebble beds in the Weald, the Isle of Wight and the south Midlands, but the sea extended beyond the earlier basin margins and possibly connected the Wessex Basin and the East Midlands Shelf.
3. The tardefurcata Zone transgression is marked by an influx of coarse-grained and pebbly sands into the Weald and Central Channel Basins.
4. The dentatus Zone transgression resulted in extensive overstep beyond the former basin margins. This event greatly reduced the amount of arenaceous and rudaceous detritus entering the basins by submerging many of the source areas.

These phases all succeed local tectonic events (Kirkaldy, 1933b; Casey, 1961; Middlemiss, 1967) and a tectonic influence on the transgression cannot be discounted. Cooper (1977) concluded that Middle Albian times were marked by a regressive episode globally. However, in Britain and the surrounding area it was clearly transgressive (Owen, 1971a) and postdated an important phase of basin rifting in southern England.

5.3 TECTONIC CONTROLS ON SEDIMENTATION

A number of unconformities overlain by onlapping sediments are recognised in the Upper Jurassic and Lower Cretaceous rocks of northwest Europe. Although Vail et al. (1977) and Vail & Todd (1981) interpreted these features as being of eustatic origin, Watts (1982),

Beach (1984) and Miall (1986) have questioned this interpretation. Evidence of local folding or faulting prior to onlap indicates that tectonic contols are probably of equal if not of greater importance than eustatic controls (Watts, 1982).

5.3.1 Mechanisms for basin development

Subsidence in the Jurassic and Cretaceous basins of southern Britain was in general passive and there is little evidence of sedimentation directly related to tectonic events. In early studies, facies-variations, thickness-changes and local or regional unconformities provide almost the only indication concerning the position and form of the intrabasinal structures controlling sedimentation. Further information on the mechanisms controlling basin development has become available as a result of detailed sedimentological investigations (Hallam, 1958; Drummond, 1970; Sellwood & Jenkyns, 1975; Townson, 1975; West, 1975). Advances in geophysical techniques have provided a knowledge of subsurface geology and enabled detailed models for modes of basin-formation to be developed.

The interpretation of Mesozoic basin-development mechanisms for southern Britain has advanced in three stages:

1. the axes of uplift model (Arkell, 1933a),
2. the basin-and-swell model (Hallam, 1958),
3. the extensional-rifting model (McKenzie, 1978).

1. The axes of uplift model

This school of thought was stimulated by the exploration for coal during the latter part of the last century and first half of this century. It was recognised that in certain areas of the British Mesozoic basins, unconformities were more common and the sedimentary sequences preserved were relatively thin. Studies of structural axes were made by Buckman (1901) in the Cotswolds; Baker (1917) in Kent; Cox & Trueman (1920); Rastall (1925) and Thompson (1925) in the Midlands; and Versey (1929) in south Yorkshire. Arkell (1933a) proposed that Mesozoic sedimentation in southern Britain occurred in basins between three major axes (Mendips, Moreton-in-the-Marsh and Market Weighton) and a number of smaller structures.

It was recognised that the structures present in the Jurassic and Cretaceous strata paralleled trend-lines identified in the surrounding Palaeozoic and Precambrian basement rocks. Four dominant orientations were recognised:

a. an east-west (Variscan) trend,

b. a north-south (Malvernian) trend,

c. a northwest-southeast (Charnian) trend and

d. a northeast-southwest (Caledonian) trend.

The three main structural axes were considered to be traceable laterally into Palaeozoic anticlinal structures and therefore it was assumed that the Mesozoic axes overlay Palaeozoic fold crests (Buckman, 1901).

2. The basin-and-swell model

When examined in detail, sedimentary facies variations were found not to correspond closely to the axes of uplift. As a result, Hallam (1958) preferred to consider the areas of deposition in southern Britain as swells or basins. Basins were areas of relatively rapid downwarping and sediment-accumulation and swells were areas of slow subsidence, forming submarine shallows or land. Swells were subject either to uplift or reduced rates of subsidence, which caused breaks in sedimentation, erosion surfaces and condensed sequences. A fault-control on the swells was implied by Sellwood & Jenkyns (1975) and Hallam & Sellwood (1976). Sedimentological investigations in southern Britain are restricted by the lack of exposure and therefore identification of the controlling structural mechanisms is difficult.

3. The extensional-rifting model

Geophysical and sedimentological studies have demonstrated that many basins on passive continental plate margins have followed a similar sequence of development (McKenzie, 1978). In this sequence, an initial phase of crustal rifting and sediment accumulation in fault-bounded basins is followed by post-rifting, thermally induced subsidence. Sedimentation continues during the latter phase, draping older rift structures and infilling the former lows. During its development, a basin may be affected by a number of rifting events and subsequent periods of subsidence (Chadwick, 1985a; Watts & Thorne, 1984).

Several models have been put forward to account for this sequence of development in sedimentary basins. The early model of Sleep (1971) has been surpassed by the two-stage model of McKenzie (1978) which has been generally accepted, although commonly modified to account for local detail (e.g. Royden & Keen, 1980; Jarvis & McKenzie, 1980; Le Pichon and Sibuet, 1981; Cochran, 1983; Wernicke, 1985; Rowley & Sahagian, 1986). The various models are described below.

Thermal-updoming model: the recognition of a two-phase development within many sedimentary basins, resulting in a thinning of the crust beneath the basins led Sleep (1971) to propose a model for their development. He postulated that heating the crust causes uplift, which in turn causes rifting of continental plates, followed by thermal subsidence as the crust cools. No mechanical stretching of the crust is involved (cf. McKenzie, 1978). A number of problems were found to exist with such a model (McKenzie, 1978; Dewey, 1982). A space problem exists because for a basin to form, it has initially to be uplifted by many kilometres without involving compressional strain. The uplifted crust is then eroded prior to subsidence. In this model, detritus eroded from the uplifted areas would be deposited on the future basin-margins and the area of greatest erosion prior to basin subsidence would be the future basin-centre. These features are rarely recognised, but it has been suggested that a similar thermal uplift model may account for Late Jurassic basin inversion in the southern North Sea (Badley & Price, in press).

Uniform pure-shear instantaneous-stretching model: a model in which crustal thinning resulted from uniform stretching was proposed by McKenzie (1978). In this model, thinning of the crust creates a disequilibrium in the upper lithosphere and causes upwelling of hot asthenosphere. As rifting ceases and the mantle-lithosphere thickens through heat conduction, cooling of the crust causes thermal subsidence. The Viking Graben of the northern North Sea was taken as an example by McKenzie (1978) and the model has been generally accepted for the development of epi-continental Mesozoic basins in northwest Europe (Donato & Tully, 1981; Dixon et al., 1981; Watts, 1982; Chadwick, 1985a, 1986). Watts (1982), however, noted that although this model provides a general explanation of the features observed in many sedimentary basins it does not satisfactorily

account for all the basin-features.

Mafic-intrusion model: in a review of plate and basin-tectonics, Dewey (1982) considered that McKenzie's model or a modification of it, was suitable for basins with extension factors of two or less. Where the extension factor exceeds two, however, the model of Royden et al. (1980) was considered more applicable. Royden et al. (1980) proposed that subsidence rates of basins on passive continental margins were consistent with those expected for partially attenuated crusts intruded by mafic or ultramafic mantle diapirs. In their model, therefore, ultramafic intrusion into the lower lithosphere is envisaged to cause subsidence and extensional faulting. In basins on the margins of the European continental plate, the model of Royden et al. (1980) may be more applicable than the model of McKenzie (1978).

Non-uniform pure-shear instantaneous-stretching model: observations of rift margin structural highs and subsidence of areas beyond that of obvious crustal thinning resulted in the proposition that thinning of the crust and the mantle-lithosphere was not uniform. Greater stretching of the mantle-lithosphere than the crust was suggested as causing upwelling of hot asthenosphere beneath cool unthinned continental crust (Royden & Keen, 1980; Leeder, 1983). This would result in uplift of the crust during the stretching phase.

Uniform pure-shear non-instantaneous-stretching model: the McKenzie model (1978) was developed on the assumption that rifting occurred almost instantaneously over a geologically short time span. However, Cochran (1983) suggested that this is rarely the case and that rifting may continue for ten to fifty million years. Lateral heat flow resulting from stretching over such long time intervals was considered to affect significantly the extent of syn-rift and post-rift subsidence. In such circumstances, assessment of crustal thinning therefore cannot be made accurately from calculations of post-rift sediment thickness.

Uniform simple-shear stretching model: Wernicke (1985) has suggested that major detachment faults play a key role in mantle-lithosphere extension. These faults behave as through-crust shear zones, separating the crust into upper and lower plates. The displacement across the shear zone causes asymmetrical uplift and subsidence

patterns in the resulting sedimentary basins. It is suggested that subsidence occurs above areas of significant crustal thinning but limited mantle thinning, whereas at greater depths on the shear zone, the crust remains unthinned while the mantle-lithosphere is attenuated. This causes upwelling of hot asthenosphere and uplift of the overlying crust. Beach (1986) postulated that such a mechanism may have been of importance in accounting for the discrepancy in structural styles between the Norwegian and British sectors of the northern Viking Graben. However, Badley et al. (in press) suggested that this could not be verified and any one of a number of mechanisms might cause the variations observed.

5.3.2 Mechanisms for the development of structural highs

The mechanisms, timing and extent of uplift associated with basin-development are of particular interest in the present study. The axes-of-uplift model described by Arkell (1933a) recorded the presence of relative positive areas within a basin, but a mechanism for their uplift was not developed. The basin-and-swell model of Hallam (1958), Sellwood & Jenkyns (1975) and Hallam & Sellwood (1976) recognised the importance of faulting as a control on sedimentation, but mechanisms for relative uplift were again not developed. Halokinetic movements were tentatively suggested to be of importance in the formation of swells (Sellwood & Jenkyns, 1975; Townson, 1975). The crustal thinning and heating models of McKenzie (1978) and later works attempt to account for the controls on uplift.

In general, structural highs of two magnitudes are recognised in and adjacent to extensional sedimentary basins:

1. large platform or massif areas, typically bounded by major basin-controlling faults (Fig. 5.2a,b,c). These structures occur principally at the margins of basins, or between basins (e.g. Anglo-Brabant, Cornubian, Welsh and Amorican Massifs).
2. smaller ridges or spurs within basins or at basin margins (Fig. 5.2d). These structures are generally bounded by faults and may comprise one or more rotated fault blocks (e.g. South Dorset High, Hog's Back High, Mere High).

Uplift of massif areas: four principal mechanisms for the uplift of

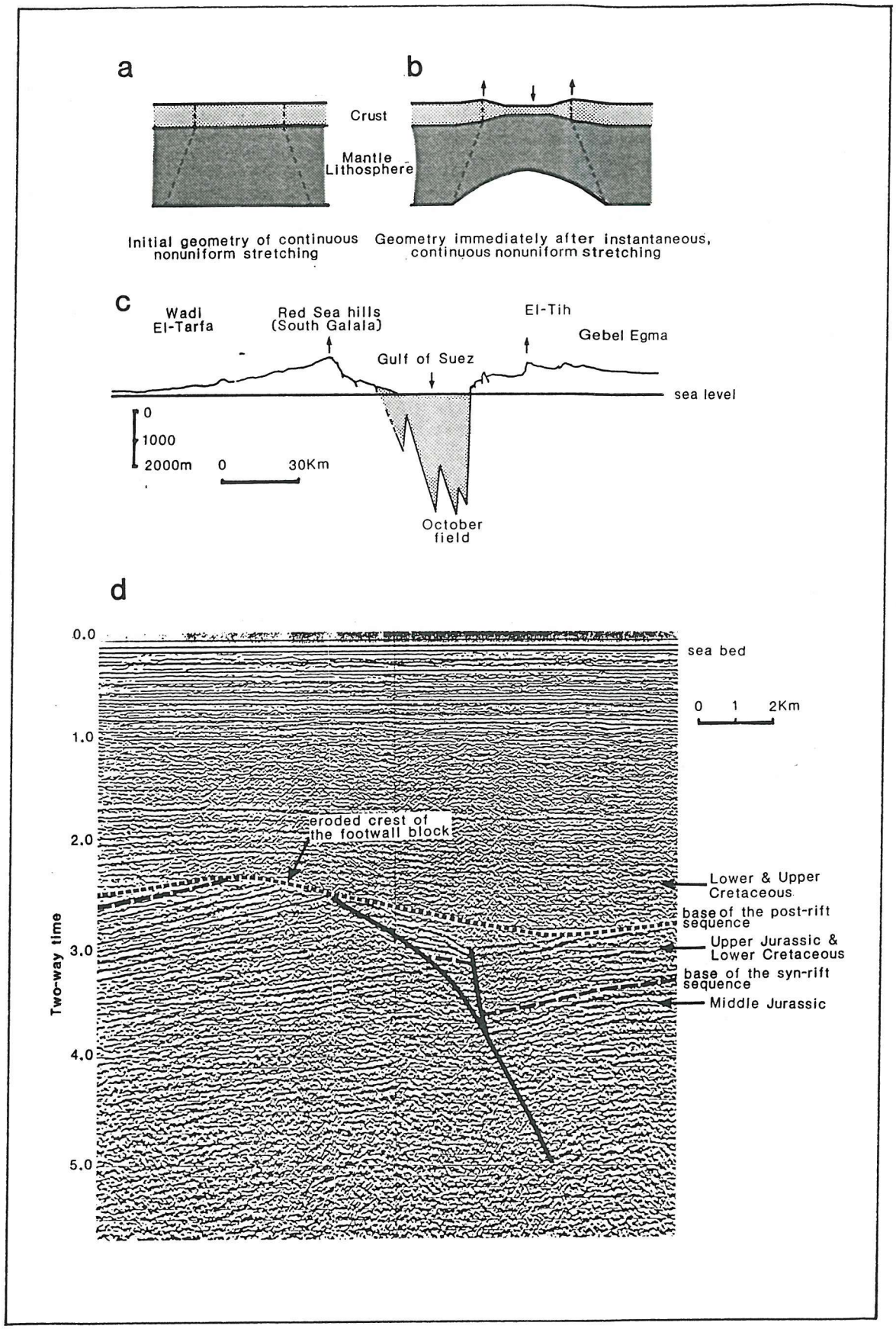


Figure 5.2 Mechanisms for the uplift of massif areas (a,b; modified from Rowley & Sahagian, 1986) and examples of rift-margin uplift (c; after Steckler, 1985) and footwall uplift (d).

massif areas are considered here.

1. Inhomogeneous stretching of the crust and mantle-lithosphere, causing rift-margin uplift was proposed by Royden & Keen (1980) and Rowley & Sahagian (1986). Proportionally greater thinning of the mantle-lithosphere relative to the crust, at the margins of the rift basin is suggested to cause uplift. By this mechanism, uplift at either side of the rift basin may be expected. Uplift would also occur principally during the rifting phase.
2. Simple shearing of the crust and mantle-lithosphere by major faults, causing basin-margin uplift has been suggested by Wernicke (1985). Displacement along the detachment zone results in asymmetrical thinning of the crust and mantle-lithosphere. During the rifting phase, the areas in which thinning of the mantle-lithosphere is greater than thinning of the overlying crust will be uplifted. This mechanism is expected to result in asymmetrical uplift of the basin margins similar to that seen adjacent to the Red Sea (Wernicke & Burchfiel, 1982).
3. Lateral heat flow through the crust, resulting from basin rifting and crustal thinning, has been suggested as a cause of uplift at the margins of rift basins (Cochran, 1983). The transfer of heat results from the thermal gradient produced between the thin, rifted crust warmed by upwelling of the underlying asthenosphere, and the cool adjacent unrifted crust. This mechanism in particular is likely to be effective while the mantle beneath the rifted crust cools subsequent to rifting.
4. Flexure of the crust adjacent to basins undergoing thermal subsidence has been suggested as a mechanism for uplifting the marginal areas adjacent to rift basins (Watts, 1982). Such flexure is likely to be controlled by basement faults, although not all faults active during rifting are likely to have been active during the flexural uplift (Badley et al., in press).

Uplift of intrabasinal areas: the large-scale processes suggested as mechanisms accounting for uplift of massif areas (Royden & Keen, 1980; Rowley & Sahagian, 1986; Wernicke, 1985) are unlikely to account for the uplift of small areas within basins. The most likely process for producing intrabasinal highs is considered to be uplift of footwall areas during faulting (Fig. 5.2d; Jackson & McKenzie, 1983; Barr et al., 1985; Barr, 1987 ; Stein & Barrientos, 1985).

Uplift may result from a number of processes. Jackson & McKenzie (1983) suggested that flexural uplift of localised footwall areas occurs by two processes:

1. elastic rebound associated with normal faulting, and
2. isostasy resulting from unloading of the footwall.

As an alternative model, Barr (1987) expected uplift of entire footwall blocks assuming that isostatic equilibrium was maintained within the basin.

5.3.3 The structural development of Mesozoic basins in southern Britain and adjacent areas

The basins of southern Britain have structural histories similar to the basins elsewhere on the northwest European shelf (Chadwick, 1985a), hence basin-development probably occurred as a series of rifting and thermal subsidence events. Chadwick (1985a) considered that three main rifting phases and a number of more local phases occurred in southern Britain:

1. the Early Permian phase;
2. the Late Triassic to Early Jurassic phase;
3. the Late Jurassic to Early Cretaceous phase.

In each case, it is considered that the basins achieved isostatic equilibrium prior to the next rifting event (Chadwick, 1985a). In southern Britain, major rifting ceased in many areas following mid-Cretaceous movements and as a result, Late Cretaceous times were considered to be an episode of post-rift sedimentation by Watts (1982) and Chadwick (1985a). A change in the tectonic regime during Late Cretaceous or Early Tertiary times, associated with Alpine collision to the south, resulted in the onset of compressional deformation in southern Britain and the southern North Sea and uplift of Mesozoic sedimentary basins.

The subsidence histories of some of the main Mesozoic basins have been described briefly by Chadwick (1985a) and his regional study has shown that although the basin-histories are similar, local variations are of importance. The Worcester and Central Channel Basins formed during Early Permian times, but the East Midlands Shelf did not form a significant sediment trap until Late Permian times. The Weald Basin apparently did not begin to subside until Late Triassic times (Audley-Charles, 1970; Holloway, 1985). The Late

Scythian (Early Triassic) event recognised in the southern North Sea was also of importance onshore in the East Midlands Shelf, the Worcester Basin and the Central Channel Basin. This Late Triassic to Early Jurassic rifting phase corresponds to the Early Cimmerian event of Ziegler (1978). The Late Jurassic to Early Cretaceous phases are probably the equivalents of the 'subsequent' mid-Cimmerian and Late Cimmerian events as defined by Ziegler (1978). The 'main' mid-Cimmerian event (Ziegler, 1978) corresponds to the Middle Jurassic phase recognised in the Weald Basin by Chadwick (1985a, 1986). The intra-Cretaceous (Austrian) phase of tectonic disturbance reported by Kent (1976) and Ziegler (1978) is a result of thermal subsidence.

Extensional tectonic movements are typically of limited lateral extent and rifting events are rarely synchronous over large areas. The naming of tectonic events (e.g. Cimmerian and Austrian) has therefore been avoided in this project.

5.3.3.1 The Late Jurassic to Early Cretaceous rifting phase

The Late Jurassic to mid-Cretaceous interval is of particular interest when considering pebble-bed distributions. Oxfordian tectonic events are reported from a number of basins in the North Sea (Ziegler, 1978) and the increased subsidence rate during the Kimmeridgian Stage onshore in Britain was considered by Chadwick (1985a) to reflect a new phase of extension and rifting. The Late Jurassic to Early Cretaceous structural histories of the basins in southern Britain and adjacent areas are distinct, but have a number of similarities.

5.3.3.2 The Late Jurassic and Early Cretaceous structural development of the Wessex Basin

The restriction of Purbeck Formation and Wealden Group strata to the central parts of the Wessex Basin can be interpreted as the result of low sea-level stand. However, the rapid thickness variations of the latter across faults adjacent to the Anglo-Brabant Massif (Smalley & Westbrook, 1982) indicates that faulting was also an important control on basin-geometry at this time. Thickness variations within the Wealden Beds of the Wessex Basin led Chadwick

(1985b) to suggest that deposition had occurred in east-west orientated grabens. P.Allen (1975) considered that vertical movements on the Massifs were of importance in causing inputs of coarse-grained detritus into the Basin.

Aptian and Albian sediments in Britain were interpreted as post-rift accumulations by Chadwick (1985a), but the principal transgressions during this interval succeed minor tectonic phases. Casey (1961) reported that the Weald Clay Group was locally folded beneath the Lower Greensand Group in the Weald Basin, while Ballance (1963) demonstrated that the Lower Greensand Group overlies folded Wealden Beds strata in the Aylesbury area. In the northwest of the Weald Basin, Hythe Beds and the Sandgate Beds Formations are folded beneath the undeformed Bargate Beds and Folkestone Beds Formations respectively (Kirkaldy, 1933b). This was interpreted as resulting from compression adjacent to the Hog's Back structure. Middlemiss (1967) reinvestigated some of the folds and suggested that they were produced by rotational shear, not compressional pure shear. The folds occur adjacent to the Hog's Back Fault, which had up to 1500m pre-mid Cretaceous normal displacement (Smalley & Westbrook, 1982) and might alternatively be interpreted as rollover structures formed during extension.

Evidence of movements immediately prior to mid-Cretaceous times are common in southern Britain, but the distinction between the end Jurassic to Early Cretaceous movements and mid-Cretaceous movements is less clear. The isopachyte maps of Wilson (1968), Penn et al. (1980), Sellwood et al. (1985), Whittaker (1985) and Sellwood et al. (1986) reveal that many extensional faults were active for much of the Mesozoic Era.

The Mendips High at the western margin of the Wessex Basin was shown by Kent (1949) to be an extension of the Welsh Massif. Reverse faults which cut the Palaeozoic rocks in the Mendips were considered to be southerly dipping Variscan thrust surfaces by Brooks et al. (1977) and Williams & Chapman (1986). Deep seismic traverses across southern England (Kenolty et al., 1981; Chadwick et al., 1983) have detected a series of southerly dipping reflections which have been interpreted as Variscan thrusts (Kenolty et al., 1981; Chadwick et al., 1983; Williams & Brooks, 1985). These thrusts are overlain by

northward-facing hangingwall anticlines. Bouroz (1960) recognised similar structures in the Pas de Calais where the hangingwall anticlines increase in amplitude and become more open southward, away from the Anglo-Brabant Massif.

In southern England, extension during the Mesozoic Era is considered to have occurred as displacement on low-angle fault planes, coupled with preferential thinning of the crust between the Variscan hangingwall anticlines. These low-angle faults cut the Mesozoic cover as well as the Palaeozoic basement (Chadwick et al., 1983; Fig. 5.3).

Isostatic instability in the crust, as a result of relaxation along thrusts, will cause uplift of the relatively thicker crust beneath associated hangingwall anticlines and subsidence of the footwall areas (cf. Jackson & McKenzie, 1983). Chadwick et al. (1983) recognised two principal basement anticlines to the south of the Devizes-Hog's Back line in southern England. The more southerly occurs to the south of the Vale of Wardour (Quantock-South Hants High) and the more northerly occurs between the Vale of Wardour and the Vale of Pewsey (Mere High-Portsdown High). A series of smaller tight folds occur to the north of the Vale of Pewsey (Fig. 5.3).

When subjected to Late Cretaceous and Tertiary compression, the basement and basin-faults were apparently inverted (Arkell, 1947a; Phillips, 1964; Chadwick, 1985a; Bevan, 1985a) causing reverse faulting and folding along pre-existing lines of weakness. The asymmetrical or monoclinal folds in the Mesozoic and Tertiary sequences of southern England are recognised as having formed adjacent to faults which had undergone significant normal displacement during the Mesozoic Era. From the sub-crop and isopachyte maps of Whittaker (1985), it is apparent that the areas of greatest Tertiary uplift occurred over the areas of greatest Mesozoic subsidence.

5.3.3.3 The Late Jurassic and Early Cretaceous structural development of the margins of the Anglo-Brabant Massif

The absence of information concerning structures on the margin of the Anglo-Brabant Massif in recent literature (Ziegler, 1981;

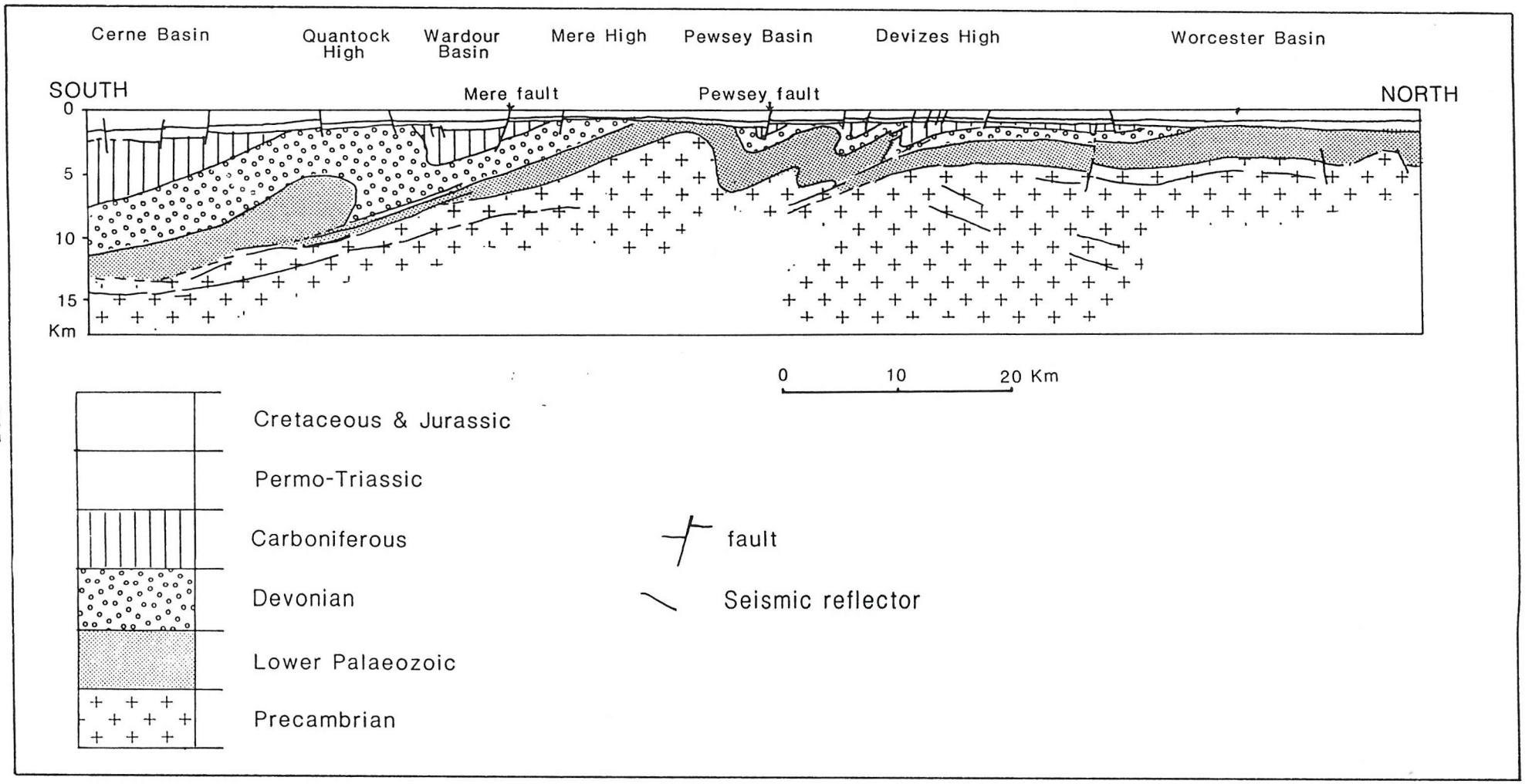


Figure 5.3 The deep structure of the Wessex Basin (after Chadwick et al., 1983).

Whittaker, 1985) probably reflects the minimal tectonic activity which occurred in the area during the Mesozoic Era. Rastall (1925) recognised two northwest-southeast orientated axes passing through the southeast Midlands; the Charnwood and Nuneaton structures, which were reported to have influenced sedimentation during the Jurassic and Cretaceous Systems. However, Hallam (1958) stated that there was insufficient sedimentological evidence to support their existence. The geophysical investigations of Chroston & Sola (1975), Allsop & Jones (1981) and Allsop (1985) did, however, detect northwest-southeast trending gravity anomalies in this area. The major thickness variations in the Lower Cretaceous deposits on the margins of the Anglo-Brabant Massif (Casey, 1961; Owen, 1972) are probably, therefore, attributable to the effects of subsidence and uplift adjacent to northwest-southeast orientated faults.

The influence of northeast-southwest trending structures on the margins of the Anglo-Brabant Massif is questionable. Arkell (1933a) noted a series of post-Oxfordian age northeast-southwest trending Jurassic inliers at Islip. Allsop & Jones (1981) and Allsop (1984) detected Carboniferous inliers with this orientation in Cambridgeshire and north Norfolk. However, similar trends are not recognised from the other geophysical studies carried out in the area. The importance of northeast-southwest trending structures as controls on sedimentation is therefore uncertain.

5.3.3.4 The Late Jurassic and Early Cretaceous structural development of the East Midlands Shelf

On the East Midlands Shelf, sedimentation rates during the Mesozoic Era were less than in the Wessex Basin (Chadwick, 1985a). Few tectonic structures have been recognised in the Cretaceous sequence and subsidence appears to have occurred uniformly over the area. To the south, the Shelf passes onto the Anglo-Brabant Massif without an obvious boundary between the two. At its northern margin, the Shelf passes into the Market Weighton High. The southern boundary of the Market Weighton High is poorly defined. Strahan (1886) and Swinnerton (1935) noted that thinning of the Cretaceous sequence near Nettleton in northern Lincolnshire was probably fault controlled and this is likely to mark the approximate position of the southern boundary of the structure. The Market Weighton High was

considered by Arkell (1933a) to be a typical axis of uplift, but was shown in the later work of Kent (1955, 1980) and Bott et al. (1978) to be a stable block bounded by the Howardian–Flamborough fault-zone to the north. East of the High this fault-zone probably passes into the Central Axis-Dowsing fault complex. The area to the north of the fault-zone subsided rapidly during the Jurassic System, whereas the areas to the south and west remained relatively stable and subsided more slowly.

Kent (1955) tentatively postulated that uplift of the Market Weighton High resulted from diapiric movements of Permian salt, but the absence of significant thicknesses of salt in boreholes on the crest of the structure (Kent, 1980) indicated that this model was improbable. Bott et al. (1978) interpreted the negative gravity anomaly below the High as a buried granitic intrusion. Recent seismic reflection investigations of the structure have led to the suggestion that the gravity anomaly may be caused by a graben filled with Carboniferous sediments (Arveschoug, 1986). However, this has yet to be verified with borehole results.

5.4 ENVIRONMENTAL CHANGES IN SOUTHERN BRITAIN DURING LATE JURASSIC AND EARLY CRETACEOUS TIMES: EVIDENCE FROM COARSE-GRAINED DETRITAL SUITES

There is evidence of both regional and local tectonic movements plus possible eustatic events, in southern Britian and adjacent areas during Late Jurassic and Early Cretaceous times. The basin-rifting events and an associated regional marine regression resulted in erosion of both local topographic highs and the massifs surrounding the basins. In offshore areas, these events are clearly recognised from seismic investigation and a number of examples have been published. Typical of such is the description by Montadert et al. (1977) and Barr (1987) of uplifted and rotated fault-blocks on the margins of the Bay of Biscay. Evidence of similar small-scale features onshore is limited. The oilfields at Wytch Farm, Dorset (Colter & Havard, 1981) and Humbley Grove, Hampshire (Sellwood et al., 1985) are both rotated fault-blocks, but little detailed information is available documenting their geological histories. Examination of the provenance of coarse-grained detritus can provide an indication of the timing and extent of uplift on a regional scale

(P.Allen, 1967a), but may also provide evidence of local tectonics (Arkell, 1939b; West & Hooper, 1969; Plint, 1982).

Both geographical and stratigraphical variations in composition have been recognised in pebble-suites from the Upper Jurassic and Lower Cretaceous rocks of Britain. Regional variations are in general a function of the geological composition of the source areas, but are also influenced by the mode and direction of transportation, the distance from source and the length of time that phenoclasts remained in the sedimentary environment. Stratigraphical variations in the pebble-suites occur both locally and regionally and resulted from environmental controls such as the relief of the source areas and their distance from the site of deposition. Tectonic and eustatic events, therefore, would have significantly affected the distribution of coarse-grained detritus.

5.4.1 Regional stratigraphical variations in the extrabasinal detrital-suites

In southern Britain, a change in the composition of the coarse-grained detrital suites occurred during Early Cretaceous times. Such changes are recognised in at least three areas, but probably did not occur simultaneously. The differences in the pebble-suites indicate that during Early Cretaceous times a new detrital suite, significantly different from the Late Jurassic suites, was introduced into the basins. The timing of the influxes reflects the different histories of the basins and provides an indication of progressive change in regional sediment-provenance.

On the East Midlands Shelf, the change in the pebble-suites occurred during the Aptian and Albian Stages. To the south, there was a change in the composition of the detrital-suites between the Portlandian and Berriasian Stages.

5.4.1.1 The northern part of the East Midlands Shelf

Pebble-suites from the Lower Cretaceous rocks of the East Midlands Shelf were collected from the Mid-Spilsby Nodule Bed, the basal Claxby Ironstone Formation and the Carstone Member (Table 1.2). The suites of the Mid-Spilsby Nodule Bed and Claxby Ironstone

Formation are sufficiently similar to suggest that the pebble-suite of the latter was derived almost entirely from the Spilsby Sandstone Formation, with little further introduction of detritus (Fig. 5.4; Sect. 4.2.6.1). In contrast, the Carstone Member contains a significantly greater proportion of quartz pebbles than the older Cretaceous pebble beds and also contains sparse limestone and chert clasts of probable Jurassic origin. It is evident therefore that a fresh influx of coarse-grained detritus was introduced onto the northern part of the East Midlands Shelf during Late Aptian or Early Albian times.

The Carstone Member overlies the older Cretaceous deposits unconformably (Strahan, 1886) and it is improbable that the changes in detrital input resulted purely from sedimentological controls. Two causes of the influx are possible:

1. a rise in the sea-level increased the area of marine influence and resulted in the erosion of the massifs and highs surrounding the basin;
2. the marine transgression and erosion followed an episode of uplift.

The increased quartz content of the Carstone Member pebble-suite towards the Market Weighton High (Sect. 4.2.6.3; Fig. 4.20a) probably resulted from the erosion of Middle Jurassic pebble beds on the High during the mammillatum Zone transgression. The absence of similar detritus in the older Lower Cretaceous pebble beds implies a change in provenance and an influx of detritus from the north. Such a change is more consistent with a phase of post-Valanginian uplift on the Market Weighton High than eustatic onlap onto an unaffected structure (Fig. 5.4b). Uplift probably occurred with the onset of thermal subsidence on the East Midlands Shelf and the Cleveland Basin. Lateral heat flow or crustal flexure possibly elevated the high between the two basinal areas.

5.4.1.2 The southern part of the East Midlands Shelf

Pebble beds in the Sandringham Sands Formation which were deposited in the southern part of the East Midlands Shelf, were not sampled for this study. Casey (1967) stated that the coarse-grained detrital-suite was similar to those of the Lydite Beds and the basal Spilsby Sandstone Formation pebble bed. This suggests that they are

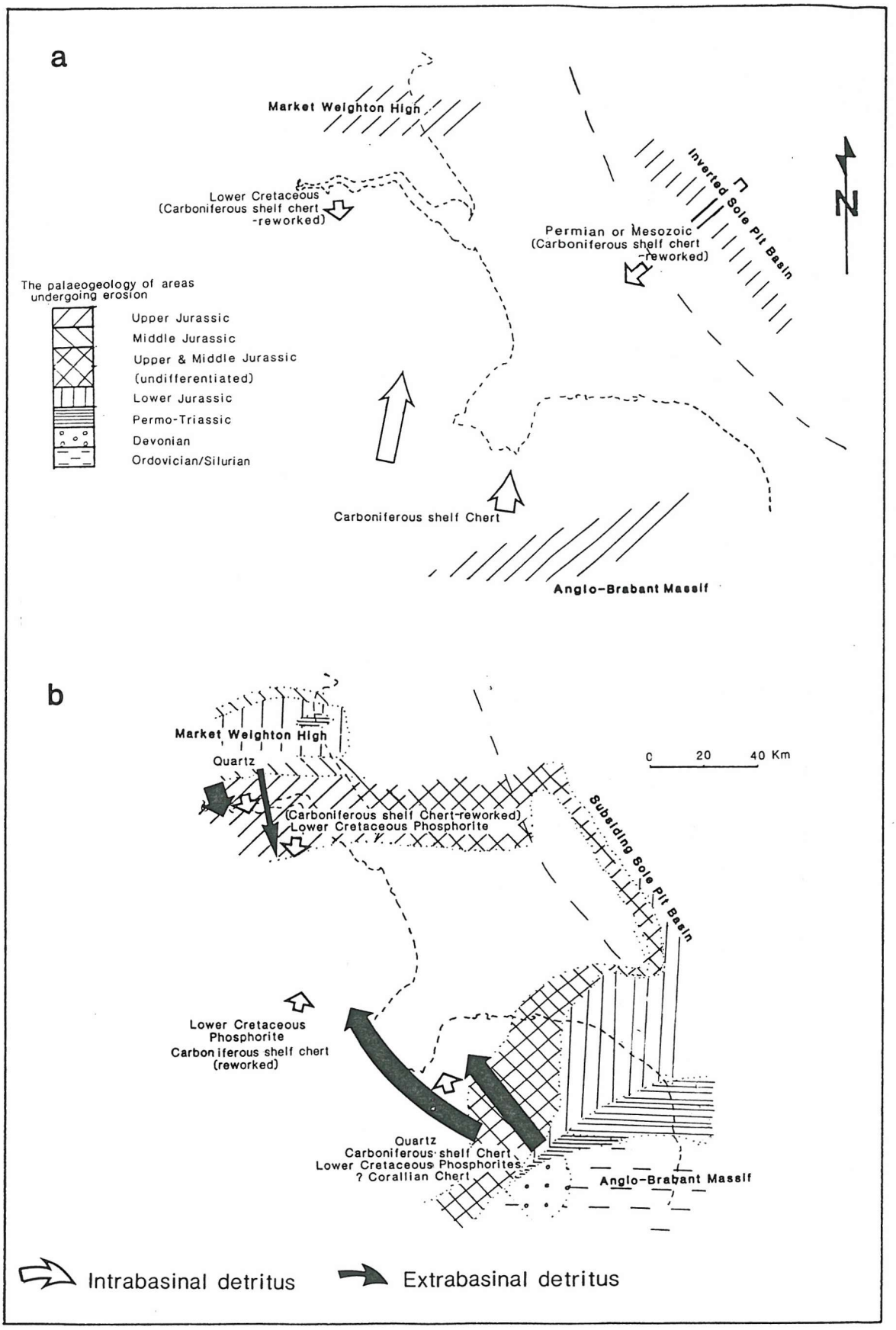


Figure 5.4 Provenance maps for the coarse-grained detritus in the Spilsby Sandstone and Claxby Ironstone Formations (a) and the Carstone Member (b) on the East Midlands Shelf.

chert-rich and therefore similar to the older Lower Cretaceous pebble beds on the northern part of the East Midlands Shelf. In contrast, the Carstone Member pebble-suite on the southern part of the Shelf is quartz-rich and the chert suite apparently differs compositionally from those of the older pebble-suites to the north since it contains a higher proportion of bioclastic Carboniferous shelf cherts (Sect. 4.2.6.3; App. I). Rare limestone and chert pebbles of probable Jurassic origin are also present in the Carstone Member and Versey & Carter (1926) noted pebbles of Ordovician slate. The Carstone Member, therefore appears to be an accumulation of relatively immature detritus introduced onto the East Midlands Shelf during mid-Cretaceous times. The quartz-rich source area for the Carstone Member pebble-suite was probably on the northern margin of the Anglo-Brabant Massif. The influx is likely to have resulted from uplift of the Shelf margins in association with the thermal subsidence of the Shelf and the Sole Pit Basin to the northeast.

5.4.1.3 The Oxford-Cambridge Shelf

Pebble-suites from Upper Jurassic and Lower Cretaceous rocks have been collected from the Oxford-Cambridge Shelf (Fig. 1.2). As on the East Midlands Shelf, the older pebble-suites are dominated by chert but younger pebble-suites contain appreciable quantities of quartz. The Lydite Beds were assumed to be of northern derivation by Neaverson (1925), but the composition of the detrital suite does not support this and the Anglo-Brabant Massif is an equally possible source area. In contrast, palaeocurrent indicators in the Lower Greensand Group imply transportation of detritus from the north in Bedfordshire (Schwarzacher, 1953), and from the northwest in Oxfordshire (Arkell, 1947b; Krantz, 1972).

The precise timing of the compositional change is unclear because the oldest Lower Cretaceous pebble-suites, those of Berriasian to Aptian age, have not been sampled. Casey & Bristow (1964) noted pebbles of quartz, jasper and quartzite, and P.Allen (1967a) reported tourmaline-bearing pebbles in the Whitchurch Sands of the south Midlands. This implies that the change in detrital provenance probably occurred close to the Jurassic-Cretaceous boundary. P.Allen (1981) suggested that the Whitchurch Sands pebble-suite was derived from the Anglo-Brabant Massif to the east

and Keeping (1880) considered that quartz-rich detritus in the Lower Greensand Group of Potton and Upware (Cambridgeshire) was also derived from the Anglo-Brabant Massif.

The source for the Lower Cretaceous detritus in the southern part of the Oxford-Cambridge Shelf remains uncertain. From the information gathered for this study it has been possible to demonstrate that, following the deposition of an Upper Jurassic chert-rich pebble-suite, rejuvenation of the source massifs caused the introduction of quartz-rich detritus into the area. The quartz was probably obtained by reworking of Triassic or Devonian pebble beds or Lower Palaeozoic basement sources (Sect. 4.2). The presence of tourmalinite pebbles in the Lower Greensand Group (Sect. 4.2.4.3) possibly implies some derivation from Triassic pebble beds.

The presence of quartz-rich pebble-suites in the Lower Cretaceous fluvial deposits (Casey & Bristow, 1964; P.Allen, 1967a) suggests that the change in detrital source can not be attributed to marine transgressions, but was due either to a progressive denudation of the source massifs (P.Allen, 1967a) or tectonic reactivation of the massifs. Since the massifs may be assumed to have been progressively eroded during the Jurassic System, their relief was probably subdued. Fortuitous destruction of the Carboniferous limestone cover (source of the chert) and erosion of older quartz-rich strata at this time is improbable, and therefore tectonic uplift of the source massifs is considered likely.

Ballance (1963) demonstrated that, in the Aylesbury area, the Wealden Beds, which overlie Upper Jurassic strata unconformably, were folded and faulted prior to the deposition of the Lower Greensand Group. At least two tectonic events (pre-Wealden Beds; pre-Lower Greensand Group) therefore occurred during Early Cretaceous times in this area. Such a history is significant since it is consistent with Early Cretaceous rifting and deformation succeeded by basin-margin uplift during the mid-Cretaceous phase of thermal subsidence.

5.4.1.4 The Weald Basin

The pebble beds of the Weald Basin have been studied by several workers in the past (Wells & Gossling, 1947; P.Allen, 1960, 1961,

1967a), but only the Bargate Beds, Folkestone Beds and Gault Clay Formations have been examined during this project. However, from published information and data obtained during this study a number of points salient to the Early Cretaceous history of the area have been deduced.

Jurassic pebble beds are not exposed in the Weald Basin, but a pebble bed was reported at the base of the Portland Sand Formation in the Warlingham borehole (Worssam & Ivimey-Cook, 1971). The composition of the pebble-suite was not described in detail.

The description of the pebble-suites from the Hastings Beds Formation (P.Allen, 1960, 1961, 1967a) indicates that the detritus entering the Weald Basin during the Hauterivian Stage differed from that of the Lydite Beds in the south Midlands. P.Allen (1975, 1981) concluded that Early Cretaceous uplift of the Anglo-Brabant Massif (Londinia) was the cause of the pebbly sand influxes into the Weald Basin. This is consistent with the isostatic uplift model of basin margins during rifting (Royden & Keen, 1980; Wernicke, 1985). The effective elevation of the massif would have been enhanced by the regionally low sea-level at this time (Vail & Todd, 1981).

A significant change in the composition of the detrital-suites between those of the top Lower Tunbridge Wells Sandstone Formation and the top Ashdown Beds Formation pebble beds in mid-Sussex was recognised by P.Allen (1954, 1960, 1961, 1967a). He observed a greater proportion of Kimmeridgian and Devonian detritus and less Portlandian and Lower Carboniferous detritus in the younger Lower Tunbridge Wells Sandstone Formation suite than in the Ashdown Beds Formation (Figs. 5.5a,b). P.Allen (1967a) interpreted this as a function of progressive denudation of the Anglo-Brabant Massif. The Portland Group cover was removed from the Kimmeridge Clay Formation and the Carboniferous limestone cover was eroded off Devonian strata. However, this model does not account for a similar change recorded in the Lower Greensand Group of the north Weald Basin by Wells & Gossling (1947; Fig. 5.6). The Lower Greensand Group sample locality is a short distance to the south of the suggested entry point of the Hastings Beds Group river system (P.Allen, 1954, 1967a) and the pebble-suites of both the Hastings Beds Group and the Lower Greensand Group appear to have been derived from the north (Fig. 5.5).

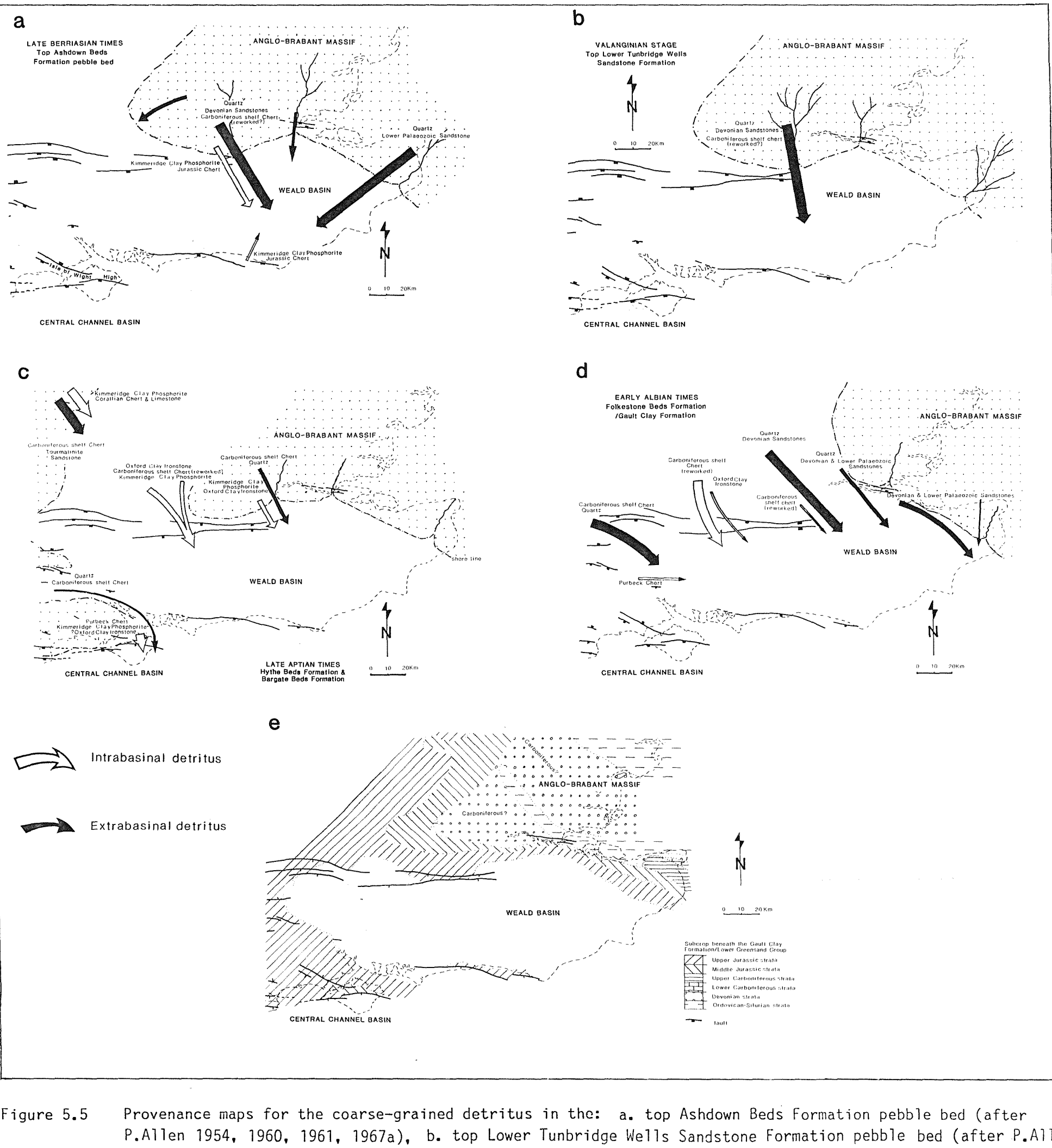


Figure 5.5 Provenance maps for the coarse-grained detritus in the: a. top Ashdown Beds Formation pebble bed (after P.Allen 1954, 1960, 1961, 1967a), b. top Lower Tunbridge Wells Sandstone Formation pebble bed (after P.Allen 1954, 1960,1961, 1967a), c. Hythe Beds Formation and Bargate Beds Formation pebble suites (in part after Wells & Gossling, 1947), d. Folkestone Beds Formation pebble suites (in part after Wells & Gossling, 1947), and e. a map of the subcrop beneath the Lower Greensand Group and Gault Clay Formation in southeast England (after Whittaker, 1985).

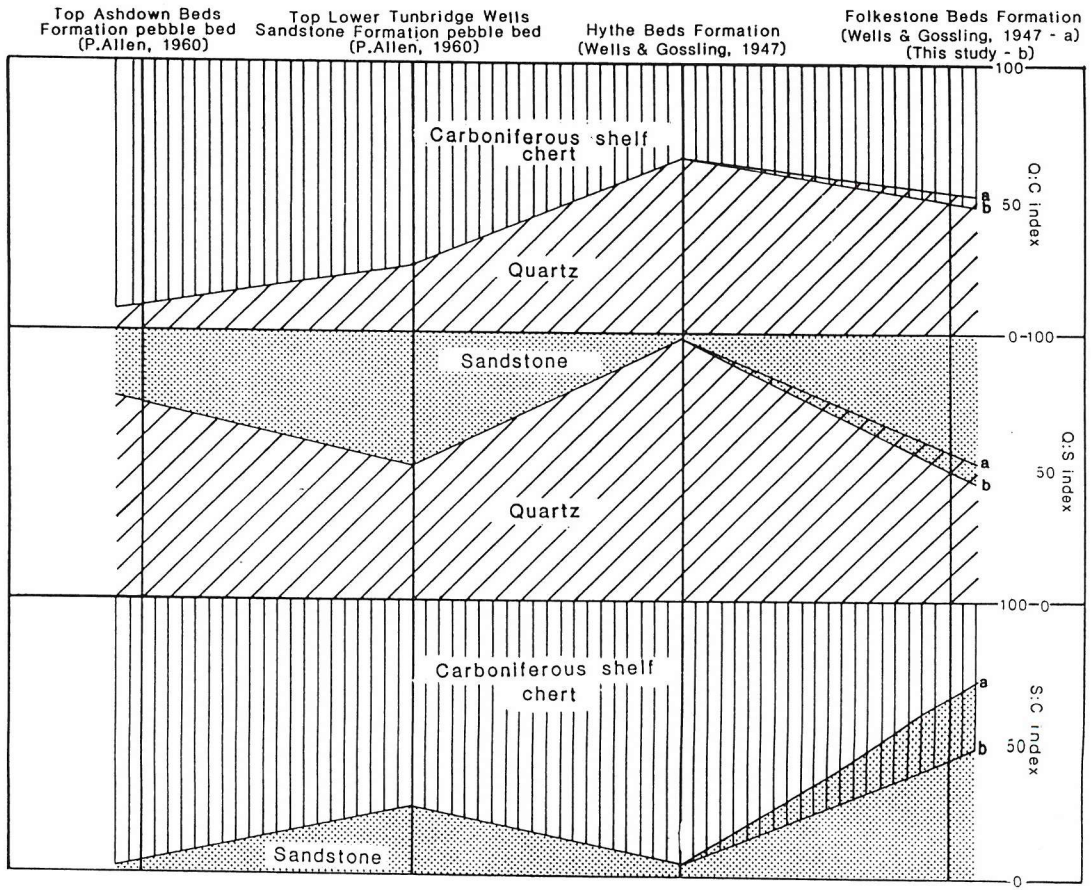


Figure 5.6 Compositional variations in the Lower Cretaceous coarse-grained detrital suites in the northern central Weald (in part after Wells & Gossling, 1947; P.Allen, 1960).

If the change in the Hastings Beds Group pebble-suites results from progressive uplift, then the variation in the Lower Cretaceous pebble-suites has two explanations. It is the result of either:

1. the denudation of different areas of the Anglo-Brabant Massif at different dates, or
2. the derivation of the pebble-suites from different source areas.

The palaeocurrent data of Narayan (1963, 1971) demonstrates that the principal transport direction in both the Hythe Beds and Folkestone Beds Formations was to the southeast and therefore the source area for the Lower Greensand Group detritus in the central northern Weald Basin is apparently in the vicinity of the Hastings Beds Group source area. In consequence, progressive uplift does not satisfactorily account for the variations recognised in all the Lower Cretaceous pebble-suites.

An alternative mechanism for the repetitive change in the detrital-suites must therefore be considered. The main evidence used by P.Allen to suggest progressive removal of the Jurassic and Palaeozoic covers was the reduction in the proportion of Jurassic and Carboniferous detritus in the younger beds. A similar trend for the Lower Greensand Group was interpreted by Wells & Gossling (1947) as an indication that the Hythe Beds Formation pebble-suite was in part derived from Jurassic rocks, but that the younger Folkestone Beds Formation pebble-suite was derived from the the Palaeozoic basement of the Massif to the north. This assumes that Jurassic sediments include pebble beds with Carboniferous shelf chert pebbles, as in the case of the Lydite Beds of the south Midlands. This assumption is supported by the presence of a pebble bed in the Portland Group of the Warlingham borehole, in the northwestern Weald Basin (Worssam & Ivimey-Cook, 1971).

The alternating provenance pattern in the Hastings Beds Group and Lower Greensand Group is accounted for by a combination of changing basin size and effective area of erosion plus progressive uplift and denudation of the Anglo-Brabant Massif. A simplified four stage provenance history for Lower Cretaceous sediments in the central Weald Basin is therefore proposed:

1. the top Ashdown Beds Formation pebble-suite was partially derived

from Upper Jurassic rocks with small quantities of detritus derived directly from the Palaeozoic sources on the Anglo-Brabant Massif. The influxes resulted from uplift at the basin margins during Late Jurassic and Early Cretaceous rifting.

2. extension of the river system to the north or the down-cutting through the Jurassic cover following uplift resulted in the erosion and incorporation of Devonian sandstone and quartz pebbles into the Lower Tunbridge Wells Sandstone Formation suite.
3. the Early Aptian sea did not extend beyond the former Wealden Beds basins (Middlemiss, 1975) and at this time the shore-line probably lay on the southern margins of the Anglo-Brabant Massif. There is no evidence of significant Aptian fluvial input into the basin and clasts were probably derived from coastal exposures and submarine outcrops. The high phosphorite content reported in the Hythe Beds Formation (Wells & Gossling, 1947) suggests that outcropping Jurassic sediments were an important source of detritus, but the greater quartz content in the pebble-suite relative to the top Ashdown Beds Formation and top Lower Tunbridge Wells Sandstones Formation pebble-suites (Fig. 5.5) was possibly the result of a greater basement (probably Devonian rocks) influence.
4. a further increase in the proportion of sandstone and quartz pebbles in the Folkestone Beds Formation is interpreted as resulting from the Early Albian transgression and consequent erosion and transportation of Devonian and Lower Palaeozoic detritus to the south.

This alternative model does not necessitate the existence of chert-bearing Carboniferous limestones on the Anglo-Brabant Massif during Early Cretaceous times, since the Lydite Beds could be the source of the chert pebbles. However, the greater proportion of bioclastic cherts in the Folkestone Beds Formation relative to the Hythe Beds Formation, noted by Wells & Gossling (1947), implies that more than one source of chert pebbles probably existed. A similar feature is recognised on the East Midland and Oxford-Cambridge Shelves where bioclastic cherts are apparently more common in the mid-Cretaceous pebble beds than in the Upper Jurassic or basal Cretaceous beds (Sects. 4.2.4.7, 4.2.6.4). On the East Midlands Shelf, the change is associated with the influx of detritus into the basin during mid-Cretaceous times. It is tentatively suggested that bioclastic chert-rich pebble-suites are less mature than the

bioclastic chert-poor pebble-suites. A point of note is the scarcity of bioclastic cherts in the Lydite Beds at Swindon (App.I, Table i.cxv). The change in the Lower Greensand Group pebble-suites therefore strengthens the theory of the reworking of Jurassic detritus during the Aptian Stage. It also suggests derivation of chert clasts during the Albian Stage from primary sources on the Anglo-Brabant Massif.

The change in composition between the Hythe Beds and the Folkestone Beds Formations reported by Wells & Gossling (1947) is significant. Whether or not the change may be ascribed to tectonic rejuvenation of the Anglo-Brabant Massif is uncertain. The detritus of the Hythe and Folkestone Beds Formations was probably capable of being transported in the strong tidal currents known to have been active in the area during the Aptian and Albian Stages (J.R.L.Allen & Narayan, 1964; Narayan, 1971). The change may simply reflect the onlap onto the Palaeozoic basement of the mid-Cretaceous sea due to sea-level rise. Alternatively, the Aptian and Early Albian influences of coarse-grained detritus may have resulted from uplift at the margins of the Weald Basin in association with the thermal subsidence of the basin. Evidence for similar uplifts at the margins of the East Midlands Shelf (Sects. 5.4.1.1, 5.4.1.2) suggests that tectonic uplift is probable.

5.4.1.5 The western Central Channel Basin

Stratigraphical variations in the pebble beds of Dorset have been studied in detail. As in other areas in southern Britain, changes in the provenance of the Dorset detritus was found to occur during earliest Cretaceous times.

The Oxfordian and Early Berriasian pebble-suites: the pebble-suite of the Preston Grit Member, Corallian Group has a composition similar to those of the Upper Jurassic pebble beds on the Oxford-Cambridge Shelf. Older pebble beds with similar composition are not present in Dorset, hence, a northern source is probable for the Corallian Group detritus (Fig. 5.7a).

Pebbles similar to those in the Corallian Group are found in the middle Purbeck Formation. For reasons discussed in Section 5.4.2.5 it

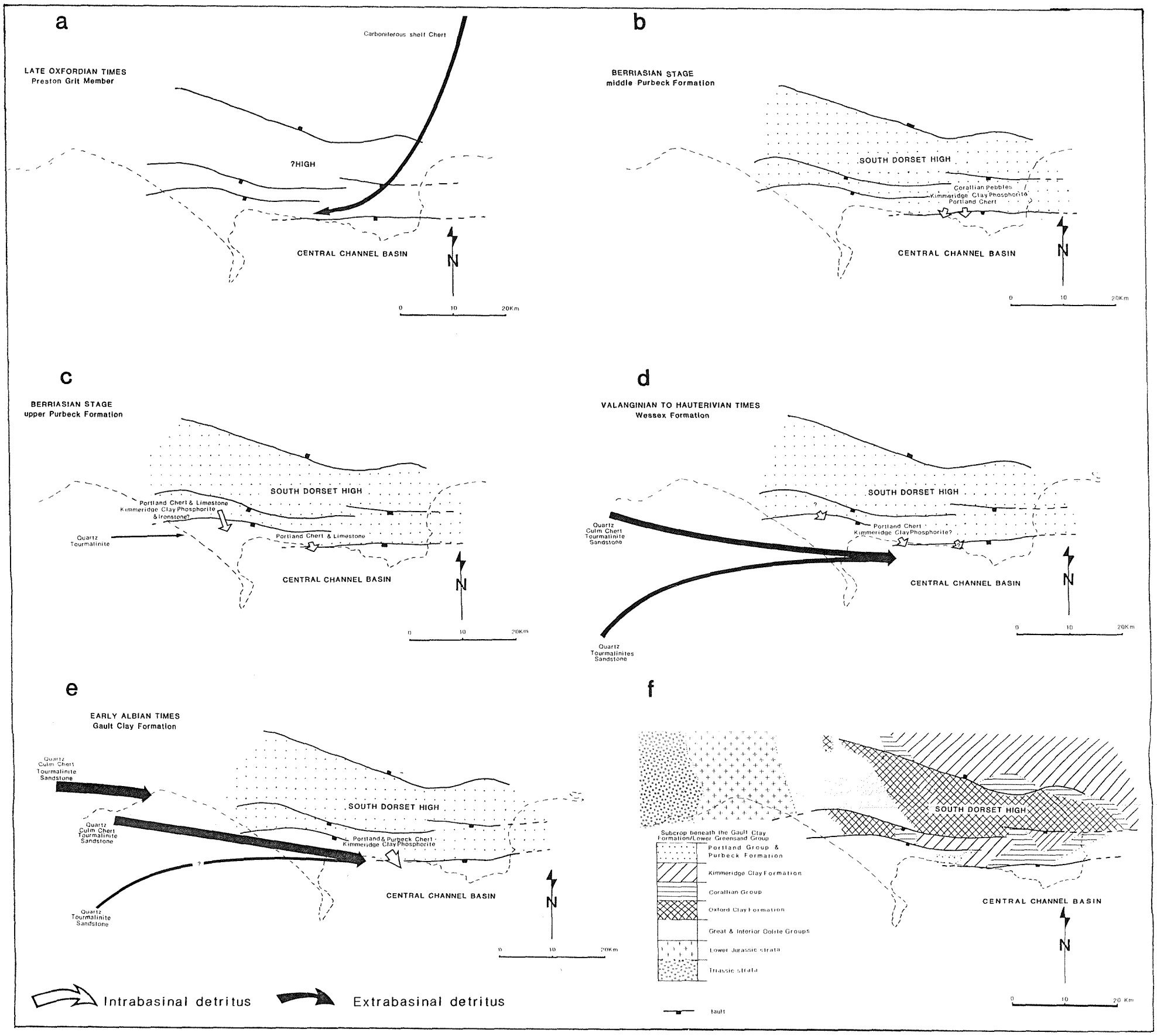


Figure 5.7 Provenance maps for the Preston Grit Member (a), the middle Purbeck Formation (b), the upper Purbeck Formation (c), the Wessex Formation (d) and the Gault Clay Formation (e) and a map of the subcrop beneath the Lower Greensand Group and the Gault Clay Formation (f; after Whittaker, 1985) in the western Central Channel Basin.

is possible that the middle Purbeck Formation pebble-suite was derived largely from the Corallian Group (Fig. 5.7b).

The Late Berriasian to Middle Albian pebble-suites: the first indication of a change in detrital provenance is found with the influxes of tourmaline and feldspar-rich sands in the "Unio" Member, Purbeck Formation (Fig. 5.7c). The sands are associated with small pebbles of quartz and quartz with acicular tourmaline. Both clast-types are more common in the Wessex Formation (Sect.4.2.1.4).

In accordance with the conclusions of Kirkaldy (1947a) and P.Allen (1972), the Wessex Formation detritus is interpreted as having been derived principally from Cornubia, but with some detritus from Armorica or similar metamorphic basement sources to the southwest of Britain (Fig. 5.7d). The Wessex Formation of Dorset is dominated by fluvial channel sands and overbank sediments (Stewart, 1978). The sand influxes were probably the result of climatic variations in the source areas to the west (P.Allen, 1981; Sladen, 1983). The distinctive conglomeratic unit in the Wessex Formation, the Coarse Quartz Grit, however, is significantly coarser-grained than the majority of the other beds and was probably not formed simply by a climatic event. The possibility of tectonic uplift on the western massifs causing an influx of coarse-grained detritus was suggested by P.Allen (1972) and Hughes & Croxton (1973). Such marginal uplift probably occurred in conjunction with rifting in the Celtic Sea, Southwestern Approaches and Biscay Basins.

In east Dorset, the basal Gault Clay Formation pebble-suite differs compositionally and morphologically from the Wessex Formation pebble-suite. In contrast, the basal Gault Clay Formation pebble-suite of west Dorset cannot be satisfactorily distinguished from the Wessex Formation pebble-suite of east Dorset (Sect. 4.2.1.6). The greater rounding of the basal Gault Clay Formation pebbles indicates that if they were reworked from the Wessex Formation then they were subjected to abrasive processes for an interval sufficient to cause a change in clast-morphology. The compositional and morphological differences between the Wessex Formation and Gault Clay Formation pebble-suites of east Dorset indicate that the latter were not reworked from local sources and that extrabasinal clasts in the Gault Clay Formation were probably

transported into the area from the west (Fig. 5.7e).

The change in the source of pebble-suites in Dorset from the north to the west, between Oxfordian and Late Berriasian times, implies a significant change in the palaeogeography. The pebble-suites provide evidence of uplift on the massifs of Cornubia and Armorica, both of which are at present situated on the margins of the northwest European shelf. Reconstructions of the palaeogeographic setting for Late Jurassic and Early Cretaceous times by P.Allen (1969), Williams (1973, 1975) and Wilson (1975) place these massifs on the margins on the North Atlantic rift. Uplift of the massifs was possibly associated with the Early Cretaceous rifting (P.Allen, 1969; Ziegler, 1978; Naylor & Shannon, 1982). The massifs were probably areas of isostatic basin-margin uplift (cf. Royden & Keen, 1980; Wernicke, 1985).

5.4.2 Variations in the intrabasinal detrital-suites: evidence for intrabasinal tectonic movements

Variations in the provenance of extrabasinal detritus provides an indication of regional changes in the palaeogeography, but gives only an approximate indication as to the extent of erosion and location of the source areas. Such features are recognised more readily from the examination of detritus derived from intrabasinal and basin-marginal sources. Clasts of young intrabasinal rocks are typically less resistant than extrabasinal clasts and therefore polyphase recycling is less probable.

Intrabasinal pebbles are found in many of the Upper Jurassic and Lower Cretaceous pebbly horizons, especially reworked phosphorites and ironstones and to a lesser extent limestones and cherts. Reworking of intrabasinal clasts may occur either during transgressive phases or as a result of rejuvenation of source areas through tectonic uplift.

5.4.2.1 The East Midlands Shelf

The intrabasinal clast suites in the Lower Cretaceous pebble beds are separable into those of the Mid-Spilsby Nodule Bed and the Claxby Ironstone Formation and those of the Carstone Member.

The Mid-Spilsby Nodule Bed and Claxby Ironstone Formation: intrabasinal clasts are sparse in both the Mid-Spilsby Nodule Bed and the basal Claxby Ironstone Formation pebble bed. Phosphorite is present in both horizons, but its source could not be identified. An Upper Jurassic source is probable, since repeatedly reworked phosphorite clasts are present at the base of the Spilsby Sandstone Formation (Kelly, 1980). At Nettleton, Lincolnshire, the basal Claxby Ironstone Formation pebble bed includes calcite-cemented sandstone pebbles derived from the underlying Spilsby Sandstone Formation.

The Carstone Member: the abundant phosphorite clasts in the Carstone Member include sparse fossil casts. Belemnite phragmacone casts, superficially resembling Lower Cretaceous belemnitellids, are present in the suite. Oakley (1942) noted that phosphate nodules were uncommon in the Kimmeridge Clay Formation of Lincolnshire and Yorkshire, but were present in the Spilsby Sandstone Member. Swinnerton (1935) also recorded phosphate nodules in the Lower Tealby Clay Member. Clasts similar to those in the Carstone Member have not been found in the Lower Cretaceous pebble beds of southern England where much of the phosphatic detritus is derived from the Kimmeridge Clay Formation. Reworking of the Spilsby Sandstone Formation and the Tealby Formation nodule beds on the East Midlands Shelf is therefore probable.

Ironstone pebbles in the Carstone Member are less rounded than the phosphates and are probably locally derived (Versey & Carter, 1926). The reworking of ironstones from the Sandringham Sands Formation (Versey & Carter, 1926) or from the Roach and Tealby Formations (Strahan, 1886) is probable. The greater rounding of the phosphorites relative to the ironstones in the Carstone Member and the increasing I:P index upward through the Carstone Member at South Ferriby (Sect. 4.2.6.3), implies that ironstone clasts were also derived from intraformational sources.

Scarce weathered cherts and calcite-cemented sandstone clasts in the Carstone Member are tentatively ascribed to an Upper Jurassic or Lower Cretaceous sources. Rhaxella cherts similar to those described by Sorby (1851) and Wilson (1939) suggest derivation from the Corallian Group (Fig. 5.4). Volgian or Middle Jurassic cherts are

unknown in this area but are possibly alternative sources.

The pebble beds of the East Midlands Shelf contain little evidence for a significant, localized input of detritus. They do however, contain a variety of intrabasinal clasts probably reworked from the basin-margins. The concentration of intrabasinal clasts in the Carstone Member probably resulted from erosion at the basin margins during the mammillatum Zone transgression (Fig. 5.4b).

5.4.2.2 The Oxford-Cambridge Shelf

In the south Midlands, intrabasinal clasts are abundant in two of the horizons studied; the Upper Lydite Bed and the Faringdon Sponge Gravel.

The Upper Lydite Bed: at Swindon, phosphorites are common and their state of preservation implies that little reworking or transportation occurred prior to deposition. The clasts were probably derived from the underlying Swindon Clay.

Lower Greensand Group: intrabasinal clasts are common in the Faringdon Sponge Gravel where the Lower Cretaceous strata overstep the Kimmeridge Clay Formation onto the Corallian Group. The beds contain limestone and chert clasts from the Corallian Group and phosphorite and possible limestone pebbles from the Kimmeridge Clay Formation.

The Lower Greensand Group outliers in Oxfordshire and Wiltshire occur in predominantly northwest-southeast-trending synclines and a structural control on their orientation is probable. The troughs are likely to have formed by flexural subsidence across faults during the phase of general thermal subsidence (Chadwick, 1986) in the Wessex Basin. The Jurassic pebbles in the Faringdon Sponge Gravel were reworked during the nutfieldiensis Zone transgression from the submarine highs which were probably undergoing footwall uplift adjacent to an offshore tidal trough.

The other pebble beds in the south Midlands contain little intrabasinal detritus. The phosphorite clasts in the Seend Ironsand and the Gault Clay Formation of Wiltshire resemble the phosphorites

from the Kimmeridge Clay Formation, but their source has not been identified.

5.4.2.3 The Weald Basin

Detritus from Jurassic sources is not common in the samples collected from the Weald Basin. Clasts of Kimmeridge Clay Formation phosphorite and possible Jurassic chert were reported in the Hastings Beds Group (P.Allen, 1960) and Jurassic pebbles, including Oxfordian ironstone clasts, were noted in the Hythe Beds Formation (Wells & Gossling, 1947) and the Bargate Beds Formation (Arkell, 1939b). The Folkestone Beds Formation contains little identifiable Jurassic detritus (Sect. 4.2.3.2).

The contemporaneous introduction of Jurassic detritus into the Weald and Central Channel Basins during Late Aptian times is associated with the nutfieldiensis Zone transgression. The transgression was considered by Cooper (1977) and Rawson & Riley (1982) to be of eustatic origin; however, evidence of folding prior to the onlap (Kirkaldy, 1933b; Casey, 1961) suggests that a tectonic influence was of importance. Movements on the margins of the Anglo-Brabant Massif and intrabasinal highs were probably influential in causing the detrital influx. The lateral distribution of the Bargate Beds Formation adjacent to the Hog's Back Fault, and the abundance of Jurassic clasts in these beds, are consistent with uplift of the area immediately to the north of the fault, resulting in an input of immature detritus (Fig. 5.5c).

5.4.2.4 The eastern Central Channel Basin

The Lower Greensand Group pebble beds of the Isle of Wight may be separated into three phenoclast assemblages:

1. the pebble beds of the Ferruginous Sands Formation are composed predominantly of phosphorite and chert pebbles from Jurassic sources and ironstone clasts of contemporaneous or Jurassic origin. Extrabasinal clasts are sparse;
2. the Sandrock Formation assemblage is dominated by extrabasinal clasts and contains few intrabasinal pebbles;
3. the Carstone Member pebble assemblage is also dominated by

extrabasinal clasts, but contains rare Jurassic chert and phosphorite pebbles.

Ferruginous Sands Formation: the pebble-suite of the Ferruginous Sands Formation includes Kimmeridge Clay Formation phosphorites and Purbeck Formation chert. Portland Limestone Formation chert is rare. Dike (1972b) reported an Oxfordian ammonite, but Oxfordian clasts have not been detected during the present study. Poor rounding of the chert and phosphorite clasts indicates that they were of local derivation, but the absence of limestone clasts suggests that transportation or weathering was sufficient to destroy less resistant clasts before deposition. A southern source for the Ferruginous Sands Formation detritus was suggested by Dike (1972b), but the identification of a major Cretaceous high to the north of the Island (Whittaker, 1985; Fig. 5.8c) suggests that derivation from the north was more probable (Fig. 5.8a). The Ferruginous Sands Formation pebble beds are predominantly of nutfieldiensis Zone age and were deposited during a transgressive phase following minor regional disturbances (martinioides entrenchment; Casey, 1961). The scarcity of pebbles other than ironstones below the nutfieldiensis Zone pebble beds indicates that the martinioides event probably uplifted the local high, causing an influx of immature coarse-grained detritus into the basin.

Sandrock Formation: the high-energy, near-shore depositional environment of the Sandrock Formation was apparently unsuitable for the preservation of phosphate and ironstone clasts. Possible Jurassic cherts are present in very low abundance.

Carstone Member: these pebble beds are composed principally of extrabasinal clasts (Sect. 4.2.2.3), but contain a small proportion of Portland Limestone Formation chert and Kimmeridge Clay Formation phosphorite.

Comparison of the Ferruginous Sands Formation and Carstone Member phenoclast-suites: The distinct difference between the pebble-suites of Jurassic clasts in the Ferruginous Sands Formation and those in the Carstone Member indicates that at least two source-areas existed during the Aptian and Albian Stages in the Isle of Wight area (Fig. 5.8). The Ferruginous Sands Formation contains detritus from a

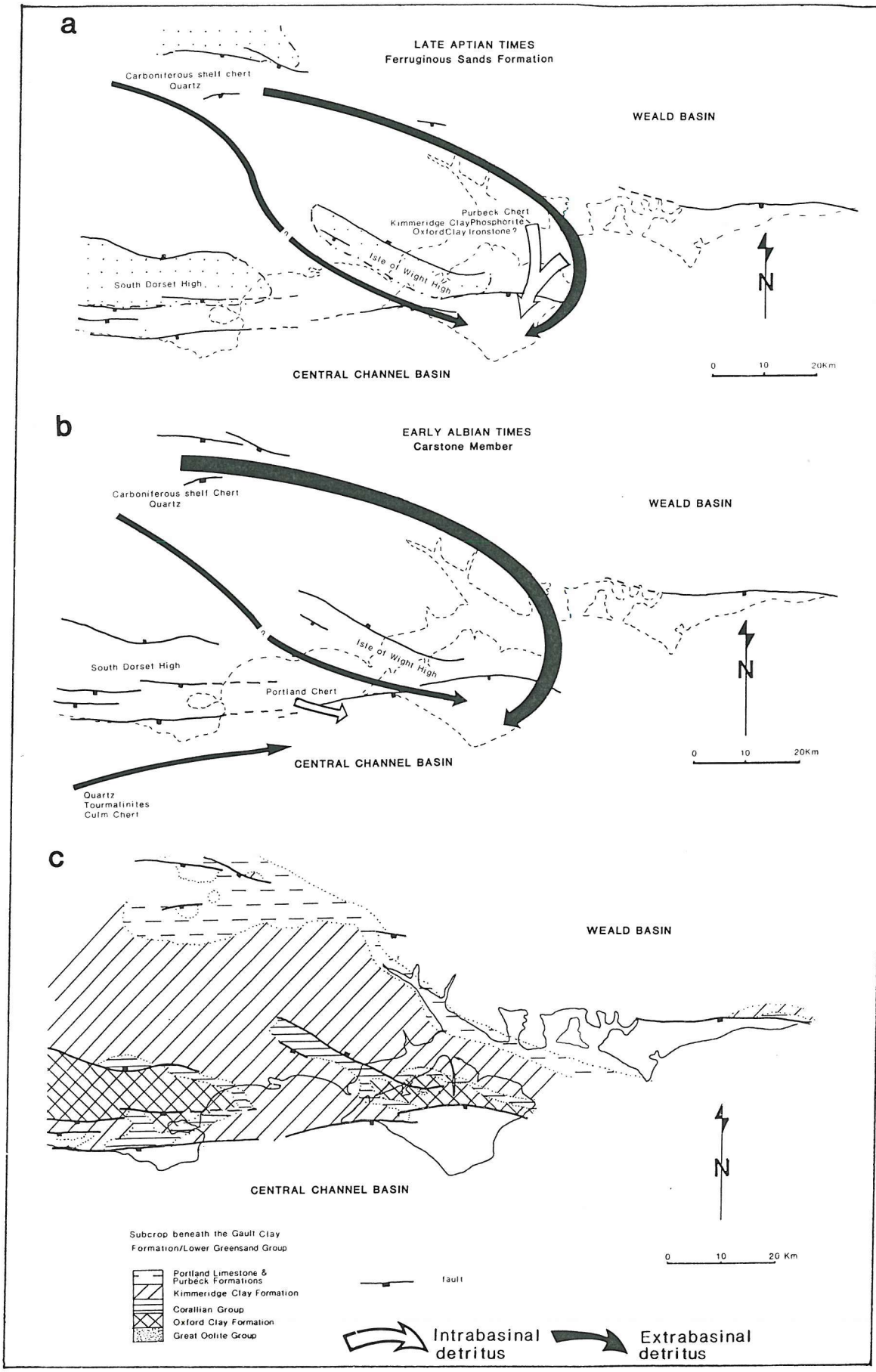


Figure 5.8 Provenance maps for the coarse-grained detrital suites in the Ferruginous Sands Formation (a) and the Carstone Member (b), and a map of subcrop beneath the Lower Greensand Group and Gault Clay Formation (c; after Whittaker, 1985) in the Isle of Wight and adjacent areas.

source-area of Kimmeridge Clay and Purbeck Formations. The Carstone Member contains pebbles from a source-area with Portland Limestone Formation.

An indication of the probable source of the Carstone Member detrital clasts is gained by examination of the chert types in the surrounding area. In Dorset, Portland Limestone Formation chert is more abundant than Purbeck Formation chert; Kimmeridge Clay Formation phosphorites are moderately abundant. To the north, in the Vale of Wardour, both Portland Limestone Formation and Purbeck Formation cherts are sparse. In the area immediately to the north of the Isle of Wight, the Portland Limestone Formation is absent but chert is present in the basal and middle Purbeck Formation (Taitt & Kent, 1958). The Ferruginous Sands Formation detritus could have been derived from the north or northeast of the Isle of Wight, but the Carstone Member pebble-suite could not. The composition of Jurassic pebbles in the Carstone Member is consistent with those expected from a Dorset-type source area (Fig. 5.8b). The change in the source of the intrabasinal detritus during mid-Cretaceous times possibly indicates uplift in the west causing the introduction of a small quantity of Portland Limestone Formation chert. It has not been possible to identify the precise source area of the Jurassic detritus. The absence of Purbeck Formation chert and significant quantities of Kimmeridge Clay Formation phosphorite in the Carstone Member indicates that the area to the north of the Isle of Wight probably did not supply a significant quantity of detritus during the tardefurcata and mammillatum Zones. This was perhaps due to negligible movement on the faults bounding the Isle of Wight High at this time.

5.4.2.5 The western Central Channel Basin

In the investigation of local tectonic events in southern Britain, the coarse-grained detrital-suites of Dorset provide much information concerning the extent and timing of uplift of local structures. Five pebble-bearing horizons were examined and these may be separated into three assemblages by their intrabasinal phenoclast suites:

1. the Corallian Group phenoclast-assemblage, which contains little

intrabasinal detritus;

2. the Purbeck Formation and Wessex Formation phenoclast-assemblages which contain intrabasinal detritus largely from the Kimmeridge Clay Formation and Portland Limestone Formation sources;
3. The Gault Clay Formation phenoclast-assemblage, which contains detritus from Kimmeridge Clay Formation, Portland Limestone Formation and Purbeck Formation sources.

Corallian Group: intraformational sandstone pebbles and phosphorite pebbles are present in the Corallian Group but are never abundant.

The middle Purbeck Formation: clasts of Portland Limestone Formation chert in the upper Intermarine Member and phosphatic clasts from the Kimmeridge Clay Formation in the Chief Beef Member indicate that erosion had penetrated down into the upper Kimmeridge Clay Formation by Early Berriasian times. However, the precise extent of erosion during the episode of middle Purbeck Formation deposition is uncertain. On many of the rotated fault-blocks to the north of the Abbotsbury Fault and Purbeck Monocline, the Oxford Clay Formation subcrops beneath the Gault Clay Formation (Whittaker, 1985; Fig. 5.7b). The problem therefore is to assess the extent of Early Cretaceous uplift on these structures.

Intrabasinal clasts indicate erosion of the upper Kimmeridge Clay Formation, but whether or not erosion of the Oxford Clay Formation was occurring at this time is uncertain. The extrabasinal clasts in the Purbeck Formation possibly provide some further indication as to the extent of uplift since they have three possible sources:

1. a primary source to the north. A northern source is assumed since the majority of the clasts are of silicified Carboniferous limestone (Sect. 4.2.1.1);
2. older pebble beds to the north. The Lydite Beds and the Corallian Group pebble beds of the south Midlands have pebble suites that are compositionally similar to the Purbeck Formation pebble-suite (Sects. 4.2.4.1, 4.2.4.2);
3. local pebble beds in southern Dorset. The Corallian Group pebbles are morphologically similar and there is a compositional similarity (Sect. 4.2.1.6).

Extrabasinal clasts have been found only in the area between Worbarrow and Acton and are restricted stratigraphically to beds of the Intermarine Member, the Scallop Member and the Chief Beef Member. If transportation of the clasts was from outside the immediate area, then a greater lateral distribution of such clasts would be expected. The phenoclasts are assumed therefore to have been reworked locally from older pebble beds. Neaverson (1925) stated that the Lydite Beds do not extend south of the Vale of Wardour. However, the Corallian Group of Dorset contains sparse pebbles and is therefore a potential source of reworked clasts. Extraformational pebbles have not been reported from other Jurassic horizons in southern Dorset.

The composition of the Purbeck Formation and Corallian Group pebble-suites is similar, but the scarcity of pebbles in the beds has prevented statistical comparison of the two suites. The most striking similarity between the two pebble-suites is the shape and size of the clasts (Sects. 4.2.1.1, 4.2.1.2). Both suites are composed of granule and fine-pebble grade clasts of subrounded to rounded Carboniferous shelf chert and quartz.

If the extrabasinal pebbles in the middle Purbeck Formation were derived from the Corallian Group, then the most probable source area would have been directly to the north of the site of deposition (Fig. 5.7b). This is significant since it implies that much of the uplift on the footwall block occurred during Early Cretaceous times.

The upper Purbeck Formation: the "Unio" Member, Purbeck Formation was found by West & Hooper (1969) to contain Portland Limestone Formation and Kimmeridge Clay Formation detritus at Friar Waddon, Dorset. They concluded that the probable source of the detritus was the partially developed Weymouth anticline to the south of Friar Waddon. Subsequently, P.Allen (1981) suggested that a more probable source for the detritus was the area of uplifted fault-blocks to the north of the Abbotsbury Fault.

Re-examination, during the present study, of samples collected by Dr. West has shown that the majority of the clasts were from the Portland Limestone Formation and neither chert nor limestone clasts from the Purbeck Formation were detected. Phosphorite and scarce goethite ooids of possible Kimmeridgian age were found. The absence

of Purbeck Formation clasts implies that the source of the Friar Waddon detritus was an area in which the Purbeck Formation was either thin or absent. The area to the south of Friar Waddon typically contains Purbeck Formation limestones, even on the swell areas (West, 1975; El-Shahat, 1977) and was therefore an improbable source for the detritus of the "Unio" Member pebble-suite. The goethite grains, although not conclusive evidence, may indicate erosion of a Jurassic ironstone in the vicinity of Friar Waddon. Local reworking of the Kimmeridgian Abbotsbury Ironstone is possible. The absence of Carboniferous shelf chert pebbles suggests that the Corallian Group was not undergoing erosion. However, the scarcity of such clasts in the middle Purbeck Formation to the east suggests that dilution of the coarse-grained detrital-suite by both westerly-derived quartz and tourmaline-rich and locally-derived Portland Limestone Formation detritus would probably have precluded their recognition.

The pebbles from the "Unio" Member in the Lulworth area differ from those at Friar Waddon. Clasts are very sparse and the only detritus found was from the Portland Limestone Formation. The limestone and chert fabrics in the pebbles resemble those of the Portland Limestone Formation in local outcrops. The source of the detritus was probably in the area to the north of West Lulworth (Fig. 5.7c), where the Gault Clay Formation overlies unconformably the Kimmeridge Clay Formation (House, 1969). Kimmeridge Clay Formation detritus is not present. This absence is not, however, evidence that the Kimmeridge Clay Formation was not eroded during Late Berriasian times, all pebble types being extremely scarce. Similarly, the absence of Purbeck Formation limestone and chert pebbles does not indicate that this unit was not being eroded. However, because such clasts are also absent at Friar Waddon, it is likely to imply the early removal or non-deposition of the lower and middle Purbeck Formation on the uplifted areas.

The Wessex Formation: the Wessex Formation of Dorset was reported by P.Allen (1981) to be devoid of Jurassic clasts. However, this detailed study has revealed that intrabasinal pebbles of Portland Limestone Formation chert are present in this horizon. Limestone and phosphorite clasts were not found and Purbeck Formation detritus is very scarce. The Portland Limestone Formation cherts are weathered, subrounded to rounded and contain few carbonate inclusions. The

lithotypes recognised indicate clast-derivation from local sources of the Portland Limestone Formation of swell-facies (Fig. 5.7d).

The Gault Clay Formation: the basal Gault Clay Formation pebble beds were deposited during the *mammillatum* to *dentatus* Zone transgression, following intra-Cretaceous faulting and folding and planation of the uplifted fault-blocks (Ringstead phase as defined by Dewey, 1982). The pebble-suite of the basal Gault Clay Formation is important since it includes Portland Limestone Formation chert and Kimmeridge Clay Formation phosphorite pebbles (derived from rocks deposited prior to the phase of Early Cretaceous uplift and erosion) plus Purbeck Formation chert pebbles (silicified deposits formed contemporaneously with the phase of uplift; Fig. 5.7e). It can therefore be interpreted as a late syn-rift or post-rift pebble bed. Field descriptions of the Gault Clay Formation in southern England (Owen, 1971a), are consistent with a post-rift sequence onlapping onto peripheral highs at the basin-margin. Uplift of the highs probably resulted from flexural compensation of thermal subsidence (Watts, 1982) or lateral heat flow in association with cooling and subsidence of the thinned crust in the adjacent basin (Cochran, 1983).

Development of the South Dorset High: The pebble beds of Dorset appear to have many of the characteristics expected of sediments deposited in an extensional basin adjacent to a basin-margin high. A four phase history of the South Dorset High is distinguished:

1. the Corallian Group contains extrabasinal clasts and sparse intrabasinal detritus, hence the South Dorset High appears to have been neither a sediment source nor a barrier to the southerly transportation of coarse-grained detritus during the Oxfordian Stage. The pebble-suite is therefore interpreted as a pre-uplift assemblage;
2. the middle and upper Purbeck Formation pebble-suites are composed principally of clasts reworked from local areas. Normal faulting in southern Dorset, associated with rifting, probably resulted in the formation of a high, capable of acting as a detrital source and a barrier to further input of northern detritus into the area;
3. the Wessex Formation contains westerly derived extrabasinal detritus and minor amounts of locally derived intrabasinal detritus. The intrabasinal clasts are principally of pre-rift

lithotypes. The relative scarcity of intrabasinal clasts and the absence of less resistant locally derived lithotypes in the Wessex Formation indicates that the source high was undergoing only episodic uplift and was, in general, of subdued relief. The high was probably a controlling influence on the distribution of Wessex Formation sediments in the area (P.Allen, 1981; Stewart, 1981b; Chadwick, 1985b);

4. the Gault Clay Formation onlaps onto the former high and its basal pebble bed contains both pre- and syn-rift intrabasinal detritus in addition to westerly derived extrabasinal detritus. This is consistent with the characteristics expected for a pebble-suite derived from a peripheral high elevated during thermal subsidence in a basin.

The effect of eustatic controls on the pebble-suites appears to have been minimal. It has been suggested that the mammillatum to dentatus Zone transgression had an eustatic origin (Vail & Todd, 1977), but even if this is the case, it clearly follows a major rifting event in southern Dorset. The change in composition of the pebble-suites cannot be ascribed purely to a fall in sea-level. The contrast in the composition of the Corallian Group and Gault Clay Formation extrabasinal pebble-suites probably resulted from the changes in regional palaeogeography associated with the Cretaceous development of the Wessex Basin.

CHAPTER VI
DISCUSSION AND CONCLUSIONS

6.1 GENERAL

The examination of Upper Jurassic and Lower Cretaceous phenoclast suites in southern Britain has revealed local and regional stratigraphical variations and regional geographical variations. The regional stratigraphical and geographical differences are attributed to the structural development of the sedimentary basins during the major phase of Late Jurassic and Early Cretaceous rifting and associated changes in sea-level. Local variations are related to the tectonic development of specific structures. These acted episodically as sediment sources and barriers to sediment transportation.

The study of local stratigraphical variations in the composition of Dorset phenoclast suites provides evidence for the rate and extent of uplift of the South Dorset High during Early Cretaceous times. The conclusions derived from this study have implications for the development of other structural highs in southern Britain and their potential as trapping structures for hydrocarbons.

Regional differences in the composition of the phenoclast suites studied enables an interpretation to be made of the effect of tectonics and eustacy on the provenance of Upper Jurassic and Lower Cretaceous sediments in southern Britain.

6.2 THE LATE JURASSIC AND EARLY CRETACEOUS DEVELOPMENT OF THE SOUTH DORSET HIGH

The presence of locally derived older detritus in a sedimentary sequence provides evidence for erosion of topographic highs adjacent to the basin of deposition. Erosion of highs results from a lowering of the erosional base-level by tectonic uplift, sea-level fall or a combination of both. Eustatic or isostatic controls are commonly considered to be the controlling factors governing sea-level changes (Vail et al., 1977; Donovan & Jones, 1979). It is probable, however, that the influence of tectonic controls on sea-level has been underestimated in the past. For example, onlap and offlap relationships can equally well be generated by basin subsidence and local uplift of fault-associated highs (Watts, 1982), as by eustatic processes.

The identification of the source of detritus in a sedimentary sequence can be used as an indicator of the extent of erosion in an area at a point in time. Variations in the detrital suites can therefore be of importance in determining rates, timing and extents of uplift. However, a number of problems exist with such a technique. Resistant detritus is likely to be reworked through one or more sedimentary cycles (e.g. P.Allen, 1967a) and may also be transported long distances from its source (e.g. Sneed & Folk, 1958). Identification of a precise source of mature coarse-grained detrital suites is therefore difficult and estimation of the timing of erosion is generally not possible. A further problem, in part related to reworking, is the progressive physical and chemical destruction of weaker clasts. The detritus present in pebble beds provides only an indication of the most resistant lithotypes eroded from the source area and may not be from the oldest strata to have undergone erosion. Normally, phenoclast suites will provide only a conservative estimate of the extent of erosion in the source area. However, first-cycle clasts in immature phenoclast suites are not typically transported far from their source and provide a suitable means for the analysis of erosion and transportation.

Late Jurassic and Early Cretaceous tectonic movements are well documented in the offshore areas around Britain where interpretation of seismic data has provided a better understanding of basin structures (publications in Bally, 1983; Illing & Hobson, 1981; Woodland, 1975). In contrast, only limited seismic information has been published from onshore areas in Britain.

Compositional variations in the Lower Cretaceous coarse-grained detrital assemblages in Britain provide a means of investigating basin-development, especially in areas where detritus is derived from local sources. In the course of this study, it was found that the Lower Cretaceous pebble suites of Dorset indicate the approximate timing and extent of uplift of an intrabasinal structure; the South Dorset High.

6.2.1 The South Dorset High

Dorset is an area in which significant Early Cretaceous tectonic

activity occurred. It is situated at the northwestern margin of the Central Channel Basin, in an area where the Upper Cretaceous cover has been locally removed, exposing an apparently complete Jurassic sequence and a partial Lower Cretaceous sequence. Evidence of Jurassic and Early Cretaceous tectonics in Dorset is clearly demonstrated from local field studies (Jenkyns & Senior, 1977), and also in the maps and memoirs of the Geological Survey which depict the Gault Clay Formation overstepping faulted and folded Jurassic and Triassic strata (Strahan, 1898; Arkell, 1947a, Wilson et al., 1958). The South Dorset High is defined as the area of pre-Gault Clay Formation uplift north of the Abbotsbury-Ridgeway fault complex and the Purbeck Monocline, extending approximately 25km north to the margins of the Cerne Basin (Fig. 1.2). It is not a single structure but a series of rotated fault blocks, inclined principally to the north (Stoneley, 1982).

Strahan (1898) considered that intra-Cretaceous folding had occurred following deposition of both the Wealden and Lower Greensand Groups. Little further information has become available concerning the precise timing of the movements. West & Hooper (1969), however, demonstrated that Early Cretaceous uplift occurred locally in Dorset, by recognising Kimmeridge Clay Formation and Portland Limestone Formation detritus in the upper Purbeck Formation to the north of Weymouth.

The principal Cretaceous structures in the area are east-west trending faults and associated rotated fault blocks (Ridd, 1973; Colter & Havard, 1981). During the Cretaceous Period, the majority of these faults underwent normal displacement with down-faulting of the southern (hangingwall) blocks (Mottram, 1949; Mottram & House, 1956; House, 1961). Basin inversion during Late Cretaceous times resulted in the reactivation of the normal faults as high-angle reverse faults, producing a series of northward-facing, asymmetrical folds (Arkell, 1947a; Phillips, 1964; Bevan, 1985a). Monoclinal folds in the Isle of Wight (Bevan, 1985b), the Vale of Wardour (Mottram, 1961), the Vale of Pewsey and on the northern margin of the Weald (Hog's Back; Lake & Shephard-Thorn, 1985) are assumed to have formed in a similar manner (Chadwick et al., 1983; Chadwick, 1985a, 1986).

Colter & Havard (1981) noted that in Dorset, the Jurassic succession was thicker on the southern (down-thrown) side of the fault complexes, and implied that the major faults had a prolonged Mesozoic history. Pre-Albian Stage normal faulting has been well documented in the literature but evidence of significantly earlier faulting is more sparse. Movements during the Hauterivian and Valanginian Stages were suggested by West (1975) and Stewart (1978) to have produced the conglomerate of oil-impregnated intraformational sandstone clasts in the Wessex Formation at Mupe Bay. Ensom (1984b) identified syn-sedimentary slumps in the Purbeck Formation and suggested that they were associated with contemporaneous tectonics.

Facies-variations in the Portland Limestone Formation (Townson, 1975) and thickness variations in the basal Purbeck Formation (West, 1975) have enabled the identification of local swells in Dorset. These structures have been interpreted as being tectonic in origin and possibly a product of halokinesis (Townson, 1975). Whittaker (1980), however, stated that anomalous thicknesses of salt had not been detected in the area, therefore, halokinesis is an improbable driving mechanism. The association of the swell facies in the Lulworth area (Drummond, 1970; Townson, 1975; West, 1975) with major faults, is probably not fortuitous. Footwall-uplift as a result of isostatic unloading during faulting has been described by Jackson & McKenzie (1983) and provides a possible mechanism for the development of intrabasinal highs in the South Dorset area.

6.2.2 The Late Jurassic to Early Cretaceous history of the South Dorset High as indicated by phenoclast suites

The pebble suites of Dorset are separable into two types:

1. extrabasinal detritus derived from the north (Corallian Group) and west (Wessex and Gault Clay Formations);
2. intrabasinal clasts derived from local sources
   a. those with clasts from the Portland Limestone and Kimmeridge Clay Formations (Purbeck Formation and Wessex Formation pebble beds), and
   b. those with clasts from the Purbeck, Portland Limestone and Kimmeridge Clay Formations (basal Gault Clay Formation pebble beds).

The compositional variations in the intrabasinal suites resulted from the progressive development of the South Dorset High during Late Jurassic and Early Cretaceous times. Early Cretaceous uplift of the South Dorset High is likely to have occurred in association with basin-rifting (Stoneley, 1982). The pebble suites may therefore be considered in relation to the tectonic history of the area and three assemblages are recognised.

6.2.2.1 Pebble beds deposited prior to uplift and erosion of the South Dorset High

The Corallian Group pebble suite does not include intrabasinal clasts. Derivation of detritus from the north indicates that the South Dorset High did not act as a barrier to sediment-transportation. This suite is therefore considered to be a pre-Late Jurassic to Early Cretaceous uplift ('pre-rift') assemblage.

6.2.2.2 Pebble beds deposited during uplift of the South Dorset High

The restriction of the Purbeck Formation and Wealden Group deposits in southern Britain to areas away from highs (Arkell, 1933a; Chadwick, 1985b) is consistent with them being syn-rift sedimentary sequences. The composition of intrabasinal pebble suites is in accordance with such an origin (i.e. they contain Portland Limestone Formation detritus but very little Purbeck Formation detritus). Although Portland Limestone Formation of swell facies was probably deposited on the highs or at their margins, Late Jurassic uplift was probably sufficient to restrict the Purbeck Formation to the basinal areas.

Purbeck Formation phenoclast suites

The coarse-grained detritus in the Purbeck Formation provides an indication of the timing and extent of uplift on local structures in Dorset not previously realised from field investigations. Pebble suites from three areas in Dorset have been examined.

Friar Waddon: the "Unio" Member contains limestone, chert and phosphorite clasts of Jurassic origin at Friar Waddon (West & Hooper, 1969; Ensom, 1984a). The Abbotsbury Fault, a short distance to the north of Friar Waddon, was active during mid-Cretaceous times (Arkell, 1947a; House, 1961) and the footwall area was the probable source of the "Unio" Member detritus (P.Allen, 1981; Sect. 5.4.2.5). Alternatively, hangingwall sources may have existed. Jackson & McKenzie (1983), however, suggested that the overall subsidence of the hangingwall block would be greater than uplift on antithetic faults. Hangingwall sources, therefore, would have been only of small areal extent and are unlikely to have sourced the significant quantity of coarse-grained detritus at Friar Waddon.

Lower and middle Purbeck Formation detritus has not been recognised in the "Unio" Member pebble suite, but Portland Limestone Formation limestone and partially silicified limestone clasts are abundant. The absence of Purbeck Formation detritus is significant and implies that the Purbeck Formation was either thin or absent in the source area.

North of the Abbotsbury Fault, the Gault Clay Formation rests on Middle and Upper Jurassic deposits. If thin but complete Kimmeridge Clay Formation and Portland Limestone Formation sequences, similar to those of the swell between Ringstead and Lulworth, were deposited on the high then cumulative pre-Albian erosion of up to 450m has occurred (maximum probable thicknesses calculated from Arkell, 1947a; Wilson et al., 1958; Colter & Havard, 1981, have not been corrected for compaction). The pebbles in the "Unio" Member indicate that at least 70m of erosion occurred by Early Berriasian times. However, since the Kimmeridge Clay Formation contains few resistant lithotypes, it is probable that erosion was more extensive. Goethite ooids in the upper Purbeck Formation possibly indicate erosion of the Abbotsbury Ironstone (Sect. 5.4.2.5), which would imply that up to 300m of erosion had occurred by Early Cretaceous times in this area. The mid-Cretaceous phase of faulting (Ringstead event of Dewey, 1982), commonly considered to be the most significant in Dorset, was therefore of less importance than initially considered (Fig. 6.1).

Lulworth: pebbles of limestone and chert from the Portland Limestone Formation in the "Unio" Member at Lulworth Cove and Stair Hole appear

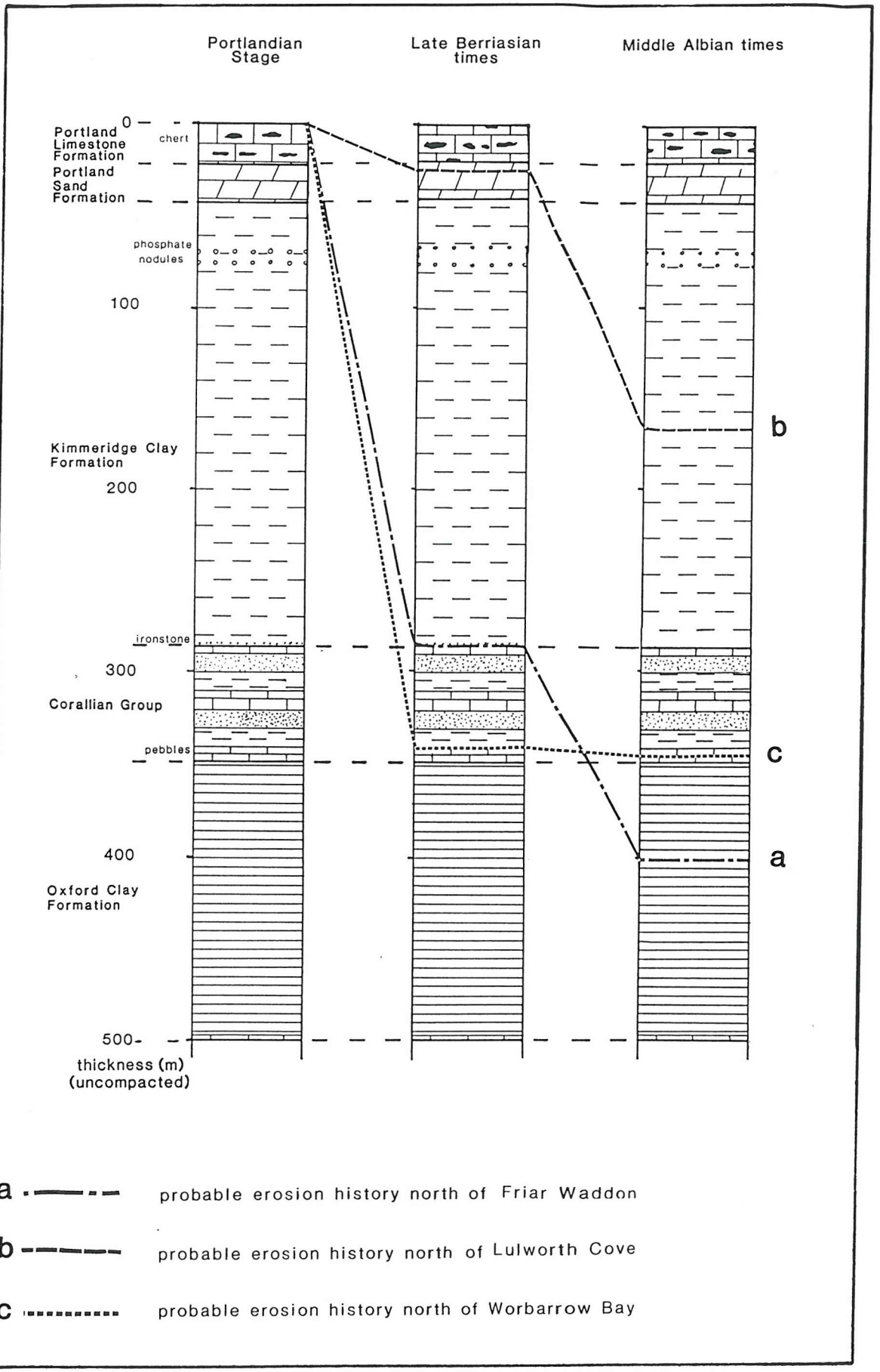


Figure 6.1 Erosion-history diagram for the upfaulted areas north of a. Friar Waddon, b. Lulworth Cove and c. Worbarrow Bay, Dorset. Thicknesses are not corrected for compaction.

to have been derived from a local high, probably on the uplifted block to the north of Lulworth Cove (Sect. 5.4.2.5). The scarcity of pebbles in the upper Purbeck Formation at Lulworth suggests that relief on the high was not great and only small quantities of detritus survived erosion.

The total extent of pre-Albian Stage erosion to the north of Lulworth was of the order of 150m (Fig. 6.1; estimate of maximum compacted thickness), with possible additional erosion of an unknown thickness of Wealden Group sediment. At least 20m of erosion occurred by Early Berriasian times. However, the scarcity of pebbles and the lack of resistant lithotypes in the Kimmeridge Clay Formation leaves the possibility that erosion was more extensive.

Worbarrow Tout: in the area from Worbarrow Tout to Acton, intrabasinal and extrabasinal clasts are present in the middle Purbeck Formation phenoclast suite. Pebbles of intrabasinal origin are scarce, but the samples collected include phosphatic casts from the Kimmeridge Clay Formation and a solitary clast of Jurassic bioclastic chert. The chert clast was derived from a local source, probably in the Portland Limestone Formation (Sect. 4.2.1.2).

The presence of a distinctive extrabasinal suite in the same beds as those containing intrabasinal detritus is of importance. The middle Purbeck Formation extrabasinal pebbles have a restricted stratigraphical and geographical distribution in Dorset, which indicates that they are of probable local origin (Sect. 4.2.1.5). Older pebble beds in the Dorset area are scarce, but the Corallian Group contains limestones with granules and pebbles. The similarity in appearance of the Corallian Group and the Purbeck Formation phenoclast suites and their general compositional affinity, suggests that reworking of Corallian Group pebbles into the Purbeck Formation may have occurred.

If the extrabasinal detritus in the Purbeck Formation was reworked from Jurassic pebble beds then the pebble suite proves that erosion down to at least the Corallian Group had occurred by Early Berriasian times (Fig. 6.1). It is assumed that the Upper Jurassic rocks in the source area were of swell facies (Arkell, 1938; Townson, 1975; West, 1975), therefore, the extent of Early Cretaceous erosion

is estimated at 400m (maximum compacted thickness) and mid-Cretaceous movements would have been minimal (Fig. 6.1).

Whether early Cretaceous uplift at Friar Waddon and Lulworth was of similar magnitude is uncertain, since evidence, in the form of reworked clasts, is not preserved. The scarcity of suitable resistant Kimmeridge Clay Formation lithotypes suggests that uplift may indeed have been similar at Lulworth. However, the absence of identifiable Corallian Group clasts at Friar Waddon indicates that Early Cretaceous uplift was limited and that significant mid-Cretaceous uplift also occurred.

Wessex Formation phenoclast suites

The locally derived detrital suite in the Wessex Formation comprises principally Portland Limestone Formation chert of swell facies, similar to that exposed at Lulworth and Portland. The proximity of the former to the sample sites indicates that it was the more probable source (Sect. 2.2.1.4). The suite contains negligible quantities of Purbeck Formation detritus and Kimmeridge Clay Formation clasts have not been detected. The absence of the latter possibly resulted from the scarcity of suitable resistant lithotypes in the Kimmeridge Clay Formation. In contrast, the scarcity of Purbeck Formation chert (only silicified wood has been found in the Wessex Formation; Sect. 4.2.1.4) cannot be accounted for by the previous explanations and has two possible causes:

1. Purbeck Formation detritus is scarce in the Gault Clay Formation, but the proportion of Portland Limestone Formation to Purbeck Formation cherts probably reflects their relative proportions in the exposed source rocks. In the Wessex Formation pebble beds, where Portland Limestone Formation detritus is scarce, Purbeck Formation clasts should be present in very low abundance and might not be detected by standard sampling procedures;
2. Purbeck Formation cherts were not present in the source areas.

It is improbable that Purbeck cherts had not formed by the Valanginian Stage. Pseudomorphs after gypsum (Pls. 14-2, 14-4) and replaced aragonitic bioclasts (Pl. 15-3) indicate that silicification occurred during early burial diagenesis. The possibility of not detecting locally derived clasts was reduced by selected sampling.

Jurassic chert pebbles are identified in both the Wessex and Gault Clay Formations by their white cortices. Examination of such samples from the former revealed that only Portland Limestone Formation detritus was present. It is therefore probable that Purbeck Formation limestones were either not deposited in the source area or were thin and lacked chert.

It can be concluded that the South Dorset High had undergone sufficient uplift during Early Cretaceous times to cause erosion of the Portland Limestone Formation. However, the scarcity of Jurassic clasts in the Wessex Formation suggests that the topography of the high during the Valanginian and Hauterivian Stages, was not sufficient to result in the formation of large scree slopes.

6.2.2.3 Pebble beds deposited during transgressions resulting from regional thermal subsidence

The overstep of the Gault Clay Formation across faulted and folded older strata indicates that it was deposited following the principal phase of deformation. The incorporation of Purbeck Formation clasts, in addition to older Jurassic clasts in the suite is therefore consistent with a post-rift origin.

In Dorset, the mid-Albian transgression followed a phase of post-earliest Cretaceous normal faulting and caused the onlap of the Gault Clay Formation onto the former high. The transgression resulted in shoreline retreat across peneplaned fault blocks with low relief and the deposition of a thin, laterally extensive pebble bed. Petrographical matching of the basal Gault Clay Formation intrabasinal detritus and the probable source-lithotypes indicate that transportation away from the source localities was limited.

6.2.2.4 A schematic model for the development of the South Dorset High

It is possible, using the evidence outlined previously, to construct a simple model (Fig. 6.2) for the development of the Dorset area, which follows the basin formation model of McKenzie (1978). The model is potentially applicable to the other structural highs in southern England and northern France.

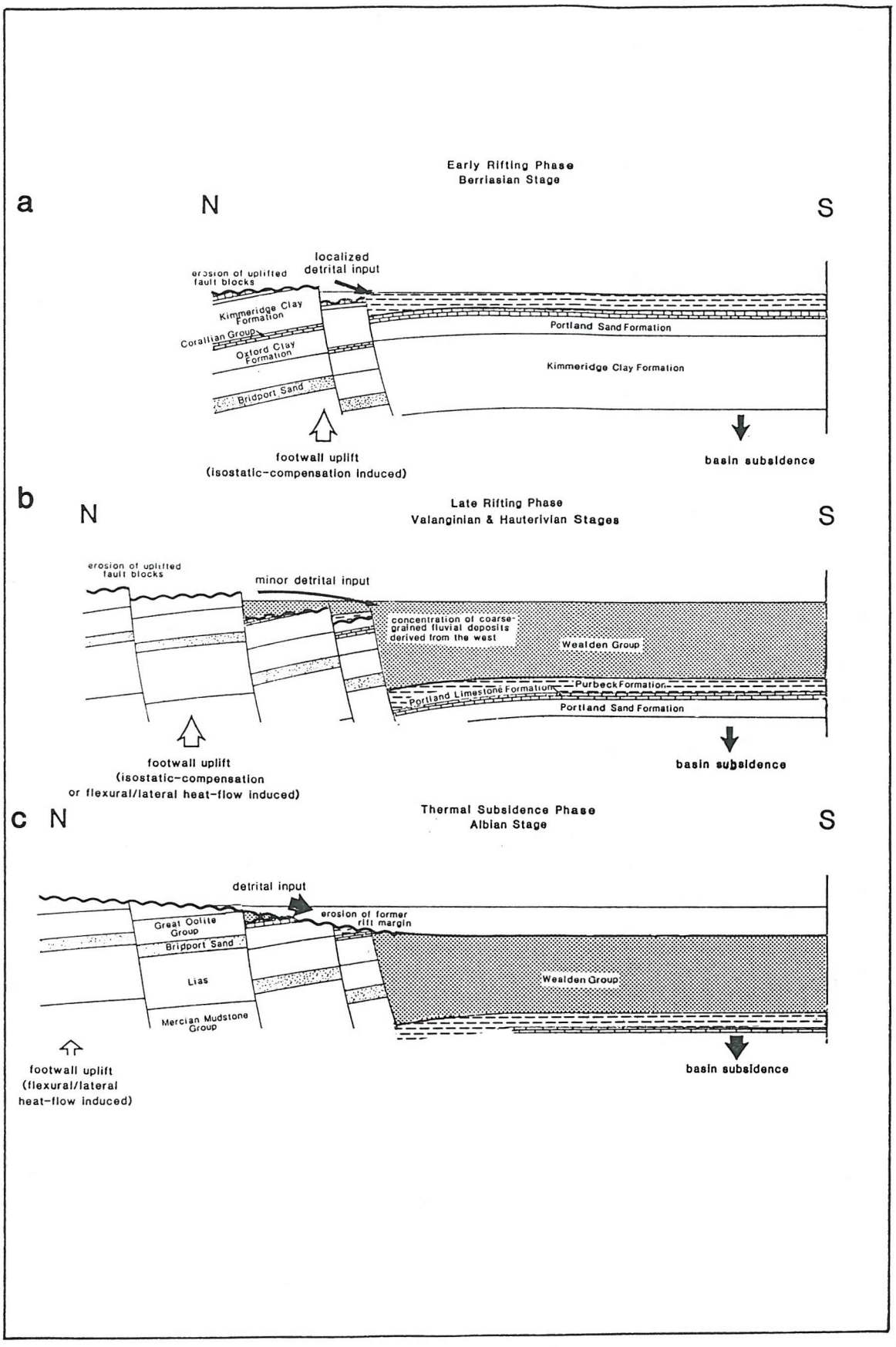


Figure 6.2 A schematic illustration of the structural evolution of the South Dorset High.

The Lower Cretaceous pebble beds in the Purbeck Formation were deposited during a phase of crustal extensional rifting (Fig. 6.2a) which caused the uplift and erosion of the footwall blocks. The detritus incorporated in the basinal areas immediately adjacent to uplifted areas is composed principally of clasts derived from the 'pre-rift' source rocks on the fault-blocks (e.g. Portland Limestone and Kimmeridge Clay Formations, and possibly the Corallian Group).

The pebble suite of the Wessex Formation was probably composed of 'syn-rift' deposits. The intrabasinal pebble suite is dominated by 'pre-rift' lithotypes (Portland Limestone Formation chert). The rate of rifting, however, had apparently diminished, such that the South Dorset High became a low-relief structure from which little detritus was shed (Fig. 6.2b). The elevation of the high was sufficient to control the distribution of detritus entering the area from the uplifted massifs to the west and to prevent detrital influxes from the north.

The initiation of thermal subsidence following the rifting phase was marked by reduction in coarse-grained clastic input into the area from the west and the transition to more argillaceous depositional conditions during the Barremian Stage (cf. Vectis Formation). As subsidence continued during the Aptian and Albian Stages, the mid-Cretaceous sea onlapped onto the former high and resulted in the erosion of both the 'pre-rift' (Portland Limestone Formation and Kimmeridge Clay Formation) and 'syn-rift' deposits (Purbeck Formation) along the margins of the high (Fig. 6.2c).

Rotated fault-blocks, which in Dorset are of the type described by Colter & Havard (1981), have been recognised in many other extensional basins, principally from seismic surveys. The timing and extent of movement and associated onlap and offlap across deeper structures can be demonstrated from high quality seismic data. However, such information is interpretative and the stratigraphic control results principally from correlation with borehole data; interpretation may be inhibited in tectonically complex areas (e.g. major fault zones). Provenance analysis of immature detritus provides a method of structural interpretation complementary to geophysical techniques. Such techniques have a potential for greater

stratigraphical resolution than seismic studies and may therefore prove informative in basinal areas of structural complexity.

6.2.3 The burial history of the South Dorset High and its significance for hydrocarbon migration and entrapment

The Early Cretaceous structural high in southern Dorset includes the oilfields at Wytch Farm, Arne and Wareham. An understanding of the development of the structure is therefore of importance for the assessment of both its potential as a hydrocarbon trap and the time from which hydrocarbons could have accumulated.

Burial-history diagrams have been constructed for the South Dorset High (Fig. 6.3) and the Central Channel Basin (Fig. 6.4) from published literature and borehole information (Colter & Havard, 1981; Terris & Bullerwell, 1965) and from data gathered during this study. Studies reveal that the basinal area subsided at a moderately rapid rate during Jurassic and Early Cretaceous times and did not undergo significant uplift until Late Cretaceous times (Fig. 6.4). In contrast, the high was probably an area of slow deposition or non-deposition during the Jurassic System and underwent uplift during earliest Cretaceous times (Fig. 6.3). As noted previously, the timing and extent of the uplift is not fully resolved, but it is probable that the Early Cretaceous event was of equal if not greater extent than the mid-Cretaceous updoming in the area.

The significance of the structural-development history for hydrocarbon entrapment is that the trapping structures were probably formed during earliest Cretaceous times. Hydrocarbon migration subsequent to the uplift could therefore have resulted in accumulations within the high. Evidence for the timing of oil migration in Dorset is limited. Colter & Havard (1981) suggested that migration occurred from earliest Cretaceous to mid-Tertiary times. The early migration date is possibly confirmed by the presence of oil-impregnated clasts in Wessex Formation sands (Taitt & Kent, 1939). Oil sands are present in the Lulworth area adjacent to the Purbeck Disturbance (Terris & Bullerwell, 1965) and this possibly implies leakage of hydrocarbons along the controlling faults of this structure during Early Cretaceous times. If, therefore, a significant phase of hydrocarbon migration occurred during Early

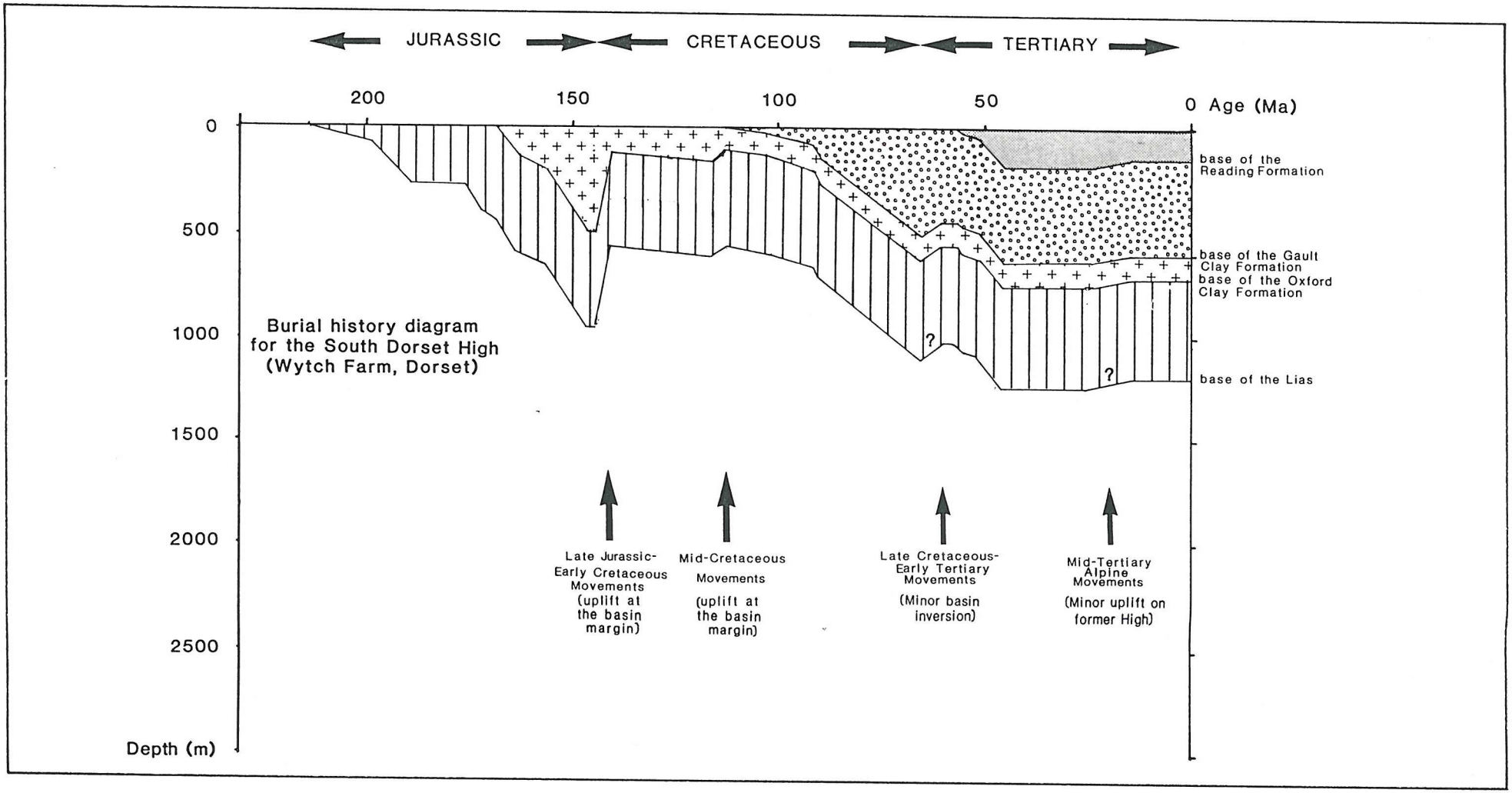


Figure 6.3 Burial-history diagram for the South Dorset High, Wytch Farm oilfield.

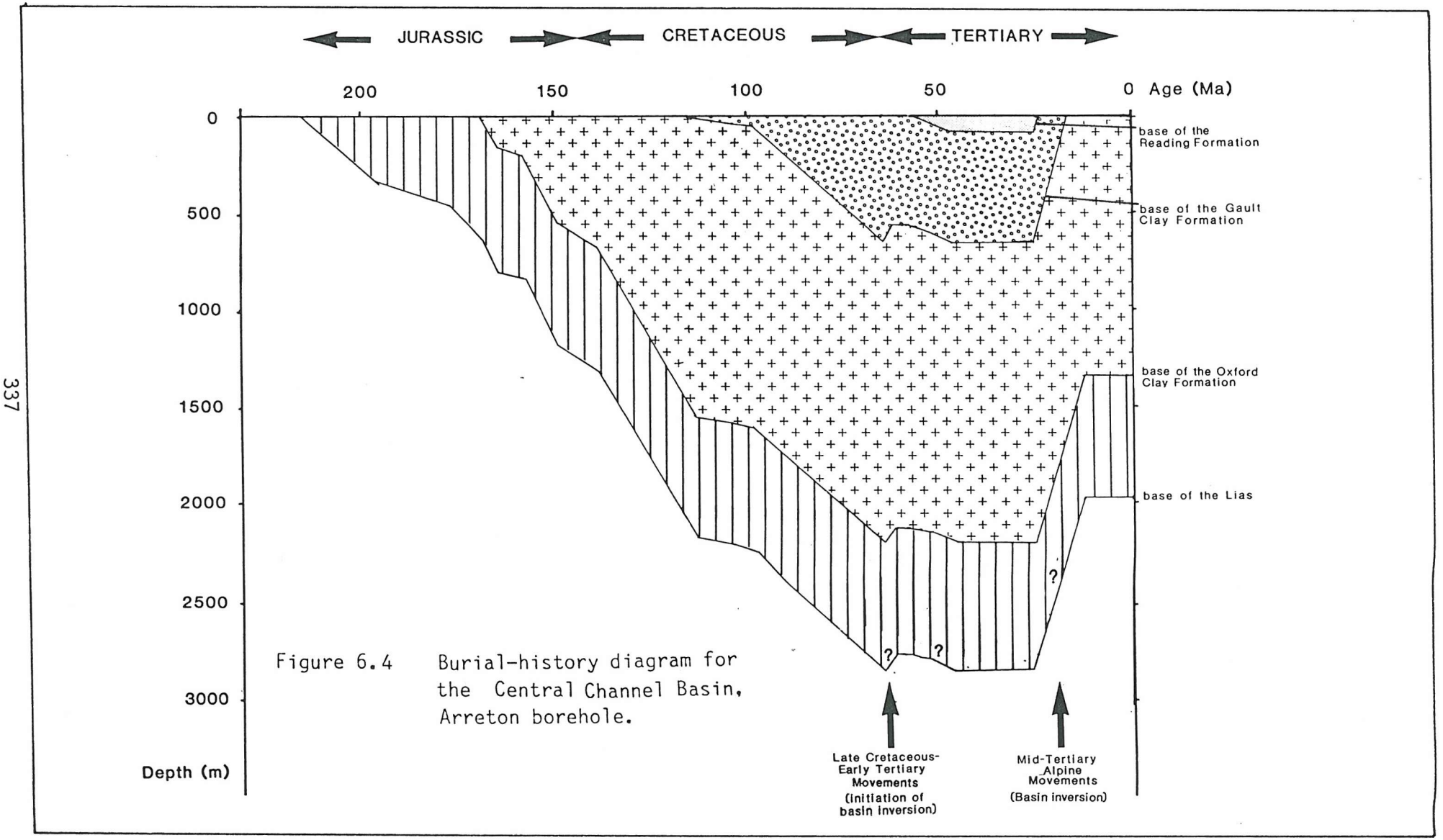


Figure 6.4 Burial-history diagram for the Central Channel Basin, Arreton borehole.

Cretaceous times then potential trapping structures were probably in existence in the uplifted and rotated fault blocks to the north of the Purbeck Disturbance.

6.2.4 The implications of Early Cretaceous movements in the Wessex Basin

The Purbeck Monocline is one of a number of similar structures present in the south of England and in northern France (e.g. Isle of Wight, Bevan, 1985b; the Vale of Wardour, Mottram, 1961; the Vale of Pewsey and along the North Downs including the Hog's Back, Smalley & Westbrook, 1982, Lake & Shephard-Thorn, 1985; the monoclinal folds in the central Channel, Smith & Curry, 1975 and the Pays de Bray Anticline). The east-west orientation of the structures in southern England and the northwest-southeast orientation in northern France and southeast England probably reflects the basement structures of the areas (Chadwick et al., 1983).

Evidence from field mapping, borehole and seismic information indicates that a number of the major asymmetrical Tertiary folds occur adjacent to Mesozoic highs (Fyfe et al., 1981; Whittaker, 1985). The covering of these structures by Aptian and Albian deposits indicates that mid-Cretaceous movements were in fact also of importance in their formation. By analogy with Dorset, it is probable also that several of the structures were affected by Late Jurassic and Early Cretaceous uplift.

6.3 STRATIGRAPHICAL AND GEOGRAPHICAL VARIATIONS IN THE UPPER JURASSIC AND LOWER CRETACEOUS PHENOCLAST SUITES OF SOUTHERN BRITAIN AND NORMANDY

Variations in the Upper Jurassic and Lower Cretaceous coarse-grained petrographic suites of southern Britain occur both geographically and stratigraphically. The distribution and provenance of phenoclasts in a basin are functions of basin-geometry, sedimentary environment and source-area geology. The basin-shape and the mode of sediment transportation are parameters controlled by tectonics and eustasy. Climatic controls may affect the type and

abundance of the coarse-grained detritus entering a basin.

The extent to which the fall in Late Jurassic to Early Cretaceous sea-level was related to global eustatic events is at present in question (Sect. 5.2). Vail & Todd (1981) and Hallam (1978) suggested an eustatic control of the sea-level fall, but noted that the interpretation of eustatic sea-level changes during this interval in northwest Europe is confused by the effects of contemporaneous tectonic movements. Beach (1984), in a recent study of Cretaceous rifting in the Witch Ground Graben, failed to recognise any effects of eustatic sea-level changes, thus providing a further example of the conflict between the eustatic and tectonic schools of thought.

The tectonic activity which inhibits the interpretation of eustatic changes during Late Jurassic and Early Cretaceous times probably caused a number of local unconformities and regional disconformities in the basins around Britain and in adjacent areas. Evidence for the existence of Late Jurassic and Early Cretaceous fault-controlled basins in the North Sea and other offshore areas around Britain has come to light with the publication of hydrocarbon exploration data. Similar geological information onshore is sparse; intra-Cretaceous faulting and folding have, however, been recorded for a long time (Fisher, 1856; Strahan, 1898). Evidence of Late Jurassic movements have also been reported (Arkell, 1933b; Townson, 1975; West, 1975; Hallam & Sellwood, 1976; Wright, 1981). The structural history of the Mesozoic basins in southern England has most recently been summarised by Chadwick (1985a, 1986).

The Late Jurassic to the mid-Cretaceous interval was principally a time of crustal extension in northwest Europe (Ziegler, 1981). Significant Early Cretaceous uplift of Mesozoic basins is rare in this area. It has been suggested that strike-slip movements were important during Early Cretaceous times in the southern North Sea (Glennie & Boegner, 1981) and also during mid-Cretaceous times in southern England (Drummond, 1970). These movements resulted in local uplift of individual fault blocks. Rifting appears to have ceased in most areas in southern Britain by mid-Cretaceous times (Chadwick, 1985a, 1986), but local movements continued during Late Cretaceous times (Drummond, 1970; Gale, 1978; Robaszynski, 1981; Jarvis & Woodroof, 1984).

Evidence of climatic variations during Early Cretaceous times in northwest Europe has been documented by Sladen (1983). The decrease in aridity from Late Jurassic to Early Cretaceous times was considered by P.Allen (1981) and Sladen (1983) to have been caused by the combined effects of massif-uplift and the increasing influence of the humid oceanic winds from the opening North Atlantic Ocean. The increased precipitation and run-off from the uplifted massifs resulted in the influx of arenaceous and pebbly detritus into the basins of southern England during Early Cretaceous times. Weathering of the highlands and the more quiescent episode which followed Late Jurassic - Early Cretaceous rifting caused the progressive denudation of the intrabasinal highs and reduced the input of arenaceous material into the basins (P.Allen, 1981). Fresh influxes of sand entered the sedimentary basins of southern England in association with Aptian and Early Albian marine transgressions. These sediment-inputs were either the result of post-rifting rejuvenation of source areas or were caused by a progressive sea-level rise.

The compositional differences in the Upper Jurassic and Lower Cretaceous pebble beds are considered to reflect environmental changes and hence provenance. The detritus is separated into three stratigraphical assemblages:

1. the Oxfordian to Early Berriasian assemblage;
2. the Late Berriasian to Barremian assemblage;
3. the Aptian to Middle Albian assemblage.

The youngest of these assemblages has been further divided into the Aptian subassemblage and Early and Middle Albian subassemblage. Three petrographic provinces and five subprovinces are recognised in the latter.

6.3.1 The provenance of the Oxfordian to Early Berriasian phenoclast assemblage

A limited quantity of coarse-grained detritus from this assemblage was studied (Corallian Group, Lydite Beds, Spilsby Sandstone Formation, Purbeck Formation), but an understanding of the group is of importance for the interpretation of the provenance of the younger pebble suites.

6.3.1.1 The provenance of the Corallian Group and Lydite Beds phenoclast suites

Influxes of coarse-grained detritus into the South Midlands during Late Jurassic times probably resulted from a drop in relative sea-level caused by a combination of eustatic sea-level fall and tectonic uplift of marginal highs. The important feature of these phenoclast suites is their apparent compositional uniformity across the region (Neaverson, 1925; Talbot 1972). They contain a high proportion (greater than 70%) of Carboniferous shelf chert, lesser quantities of quartz and little sandstone (Sect. 4.3.1). Intrabasinal detritus was principally derived from the formations underlying the pebble beds. However, the Purbeck Formation includes clasts reworked from significantly older Upper Jurassic source rocks.

The small siliceous clasts in these suites are of Palaeozoic or Precambrian origin. The bulk of the phenoclast population is of chert derived from Carboniferous limestones but rounding of the clasts suggests that reworking from older pebble beds is probable. Quartz and quartzite pebbles are also well rounded. The absence of quartzite and tourmalinite pebbles indicates that Triassic pebble beds (e.g. Kidderminster Conglomerate), in which such clasts are moderately common (Wills, 1956), are unlikely to have provided significant quantities of detritus. The scarcity of tourmalinites also indicates that the crystalline massifs of Cornubia and Armorica were of little importance as source areas.

The predominance of silicified mudstones, wackestones and packstones in the pebble suites contrasts with the types of Carboniferous cherts found in situ which commonly include grainstones and coarse-grained packstones. It is probable that the coarser-grained cherts were less resistant to weathering and attrition and that the detrital suite is highly mature. The red colouration of some chert pebbles may have resulted from staining in older pebble beds, possibly of Permian or Triassic age. However, Carboniferous limestones are locally reddened in situ and the colouration is not a definite provenance indicator.

The increase in abundance and grain-size of pebbles to the north in both the Corallian Group pebble beds (Talbot, 1972) and the Lydite Beds (Neaverson, 1925) was used to attribute a northern source to the detritus by these authors. The chert-bearing limestones of Yorkshire or Derbyshire were suggested as potential sources. The probability

of a northern source area for the pebbles was apparently supported by the composition of the heavy mineral suites. The high kyanite and staurolite content of the sand-fractions (Neaverson, 1925; Talbot, 1972) was considered to indicate derivation from the Scottish or Scandinavian Massifs. Alternative sources for the pebble-grade detritus, not considered by Neaverson (1925) or Talbot (1972), are the Anglo-Brabant and Welsh Massifs. At least three possible sources of the Carboniferous shelf-chert detritus may, therefore, be considered: the Pennine High, the Welsh Massif and the Anglo-Brabant Massif.

The Pennine High: the abundance of chert in these phenoclast suites suggests that pebbles were derived from an area composed predominantly of Palaeozoic sediments. The concept of a source area of Carboniferous limestone downs and sea cliffs on the Pennine High was put forward by Casey (1967). This is an attractive model, but it entails three principal problems, each of which is discussed below:

a. was the Pennine area an important Mesozoic High;
b. if the area was a high, then had erosion penetrated to a sufficient depth to expose suitable source rocks for the chert;
c. if it was a source area, then could it supply material of the type present in the pebble beds?

a. Whether or not the Pennine-Derbyshire area was a high during Late Jurassic times is uncertain. Several areas with possible granitic basement at shallow depth (e.g. the Market Weighton High, Bott et al., 1978; the Mid-North Sea High, Donato et al., 1983, Leeder, 1983) were uplifted during the Mesozoic Era. The Pennine-Derbyshire area, which is probably also above basal granites (Bott, 1967), may therefore also have undergone uplift and erosion at this time.

b. The present level of erosion in the Pennine-Derbyshire area is limited and the Dinantian limestones have been removed only in small areas. The areal extent of Upper Carboniferous and Permo-Triassic rocks during the Cretaceous System was probably greater than at present. Walsh et al. (1980) suggested that the southern Pennines were covered by Namurian sediments even as recently as the Pliocene Stage. There is, therefore, some question as to the extent of Jurassic and Cretaceous erosion in this area.

c. Detritus in the Upper Jurassic pebble beds was derived from an

area with few quartz or quartzite sources. This implies that metamorphic basement is unlikely to have been the source area for this detritus. Similarly, strata with quartz-rich pebble beds were probably also scarce. In the Pennine area, Lower Palaeozoic basement is exposed locally but is not of significant areal extent. Lower Palaeozoic rocks, however, were probably exposed in the adjacent Lake District area. Pebbly Devonian strata are absent in the Pennines, but pebble beds are present in the Millstone Grit. Gilligan (1919) examined the pebble suite of the Millstone Grit in Yorkshire and reported that although cherts were present, the suite was dominated by quartz. Derivation of Upper Jurassic phenoclasts from the Dinantian and Namurian limestones of the Pennines and not from the Namurian and Westphalian sandstones is therefore difficult to explain.

The presence of probable Carboniferous oolitic cherts (Sect. 3.2.1.9) in all the pebble suites of this assemblage (Chap. IV) also suggests that a northern source is unlikely. Neaverson (1925) and Wells (1947) suggested derivation of oolitic chert clasts in the Lydite Beds and Lower Greensand Group respectively from the Durness Dolomite Formation or the Torridon Group of northwest Scotland. Detritus derived from a metamorphic terrain would, however, be expected to be rich in quartz and would therefore not form a detrital suite similar to that in the Oxfordian to Early Berriasian assemblage. Oolitic cherts are present in the Dinantian rocks of South Wales (Robinson, 1935) and in the Kent Coalfield (Strahan, 1912), but are less common in the north of England.

The Welsh Massif: the Welsh Massif was a potential source area for the Upper Jurassic detritus. However, the coarsening of the Lydite Beds and the Corallian Group pebble beds away from South Wales (Neaverson, 1925; Talbot, 1972) and the presence of quartz-rich Namurian pebble beds in the area suggest that it was probably not the principal source. North Wales was a possible source area, but the presence of Namurian and Westphalian cover sequences, with quartz-rich pebble beds, imply that detritus from this area is unlikely to have been a suitable source.

The Anglo-Brabant Massif: Carboniferous limestones have only been detected on the margins of the Anglo-Brabant Massif (Wills, 1973; Whittaker, 1985), but this is probably in part the result of the deep level of Mesozoic erosion in the area. It is probable that the

former extent of Upper Palaeozoic limestones was greater and that they were of similar facies to those in South and North Wales. The Anglo-Brabant Massif was a good potential source of the Oxfordian to Early Berriasian phenoclast assemblage for two principal reasons:

a. the extent of pre-mid-Cretaceous erosion (limited erosion beneath the Permian strata) implies that the Carboniferous cover was probably removed during Late Jurassic or Early Cretaceous times, and
b. there were probably few potential quartz sources in the area younger than the Dinantian chert-source rocks. Whittaker (1985) noted that Namurian strata are not present in the Oxfordshire, Berkshire or Kent coalfields and they probably never existed on the Massif. Devonian sedimentary rocks probably contain quartz pebble-bearing sandstones (see P.Allen, 1967a), but may have been largely covered by Carboniferous strata in Late Jurassic times. Hence, prior to the removal of the Carboniferous cover from the Anglo-Brabant Massif, the area could have provided a relatively quartz-free source (Fig. 6.5).

6.3.1.2 The provenance of the Mid-Spilsby Nodule Bed phenoclast suite

The detritus of the Mid-Spilsby Nodule Bed appears to be a concentration of clasts from the Lower Spilsby Sandstone Member. The pebble suite contains a predominance of Carboniferous shelf chert and lesser amounts of quartz and quartzite. A primary source area of Carboniferous sediment, with little exposure of quartz-bearing or quartz pebble-bearing rocks, is therefore probable. Ingham (1929) interpreted the high abundance of kyanite and staurolite in the Spilsby Sandstone Formation as an indication of a northern source of the sediment, but commented on the dissimilarity of the Spilsby Sandstone Formation and Millstone Grit heavy mineral suites. In contrast, Glennie & Boegner (1981) and Badley & Price (in press) suggest derivation from the Sole Pit area, where Cretaceous rocks overstep from Jurassic to Permian rocks, but do not rest on the Palaeozoic basement (Fyfe et al., 1981; Glennie & Boegner, 1981). Hence, if this is the source then the pebbles would be reworked from older pebble beds. Carboniferous shelf chert is present in the Rotliegendes Group sandstones in the southern North Sea, but these beds also contain a variety of volcanic and low-grade metasediment clasts. The pebble suites of the Permian sandstones are therefore likely to be similar but less mature than those of the Spilsby Sandstone Formation.

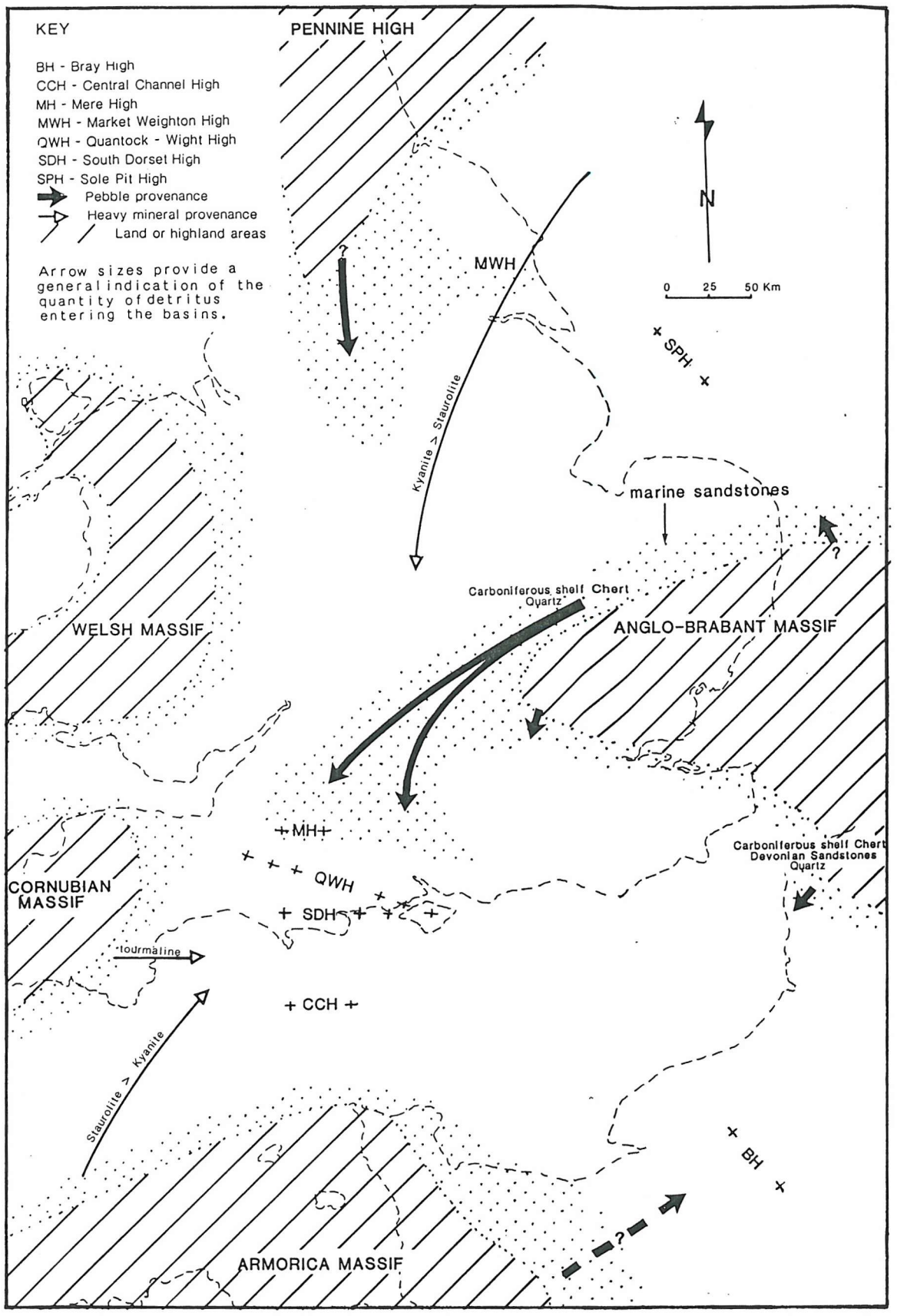


Figure 6.5 A palaeogeographical map showing pebble and sand provenance from Late Kimmeridgian to Portlandian times, based on the present study, with supplementary palaeogeographical data from Ziegler (1981) and provenance data from Neaverson (1925) and Latter (1926).

The similarity of the Spilsby Sandstone Formation pebble suite to that of the Lydite Beds implies that a similar source and derivation from the Anglo-Brabant Massif is probable. The absence of limestone pebbles, carbonate inclusions in the cherts and a scarcity of silicified grainstones imply that the pebble suite is mature and reworking of older Mesozoic pebble beds on the margins of the Massif is possible (Fig. 6.6). The presence of pebble beds of Volgian age in the southern part of the East Midlands Shelf possibly implies that the chert detritus was transported into the area during Late Jurassic times and subsequently reworked from the basin-margins during earliest Cretaceous times. Reworking of Upper Jurassic rocks in this area was noted by Kelly (1980).

6.3.1.3 The provenance of the middle Purbeck Formation phenoclast suite

The phenoclast suite of the middle Purbeck Formation of Dorset contains locally derived detritus from Upper Jurassic sources in addition to extrabasinal detritus. The extrabasinal clasts are similar compositionally and morphologically to those of the Corallian Group in the area and it is probable that the Purbeck Formation clasts were reworked from local Corallian Group pebble beds (Sect. 4.2.1.6). Evidence for the erosion of the Corallian Group during Early Cretaceous times is sparse, but clasts of upper Kimmeridge Clay Formation and Portland Limestone Formation origin are present in the middle Purbeck Formation (Fig. 6.6).

6.3.2 The provenance of the Late Berriasian to Barremian phenoclast assemblage

Influx of sand and gravel into the sedimentary basins of southern Britain during Early Cretaceous times occurred in response to the low sea-level and the uplift and rejuvenation of the basement massifs (P. Allen, 1981). Samples from "Neocomian" pebble beds in Dorset and the East Midlands were examined, together with specimens, lent by Prof. P.Allen, from the Hastings Beds and Weald Clay Groups of southeast England. The phenoclasts of this assemblage and those of the Oxfordian to Early Berriasian phenoclast assemblage are distinctly different in Dorset, but in the East Midlands, the pebble suites are similar.

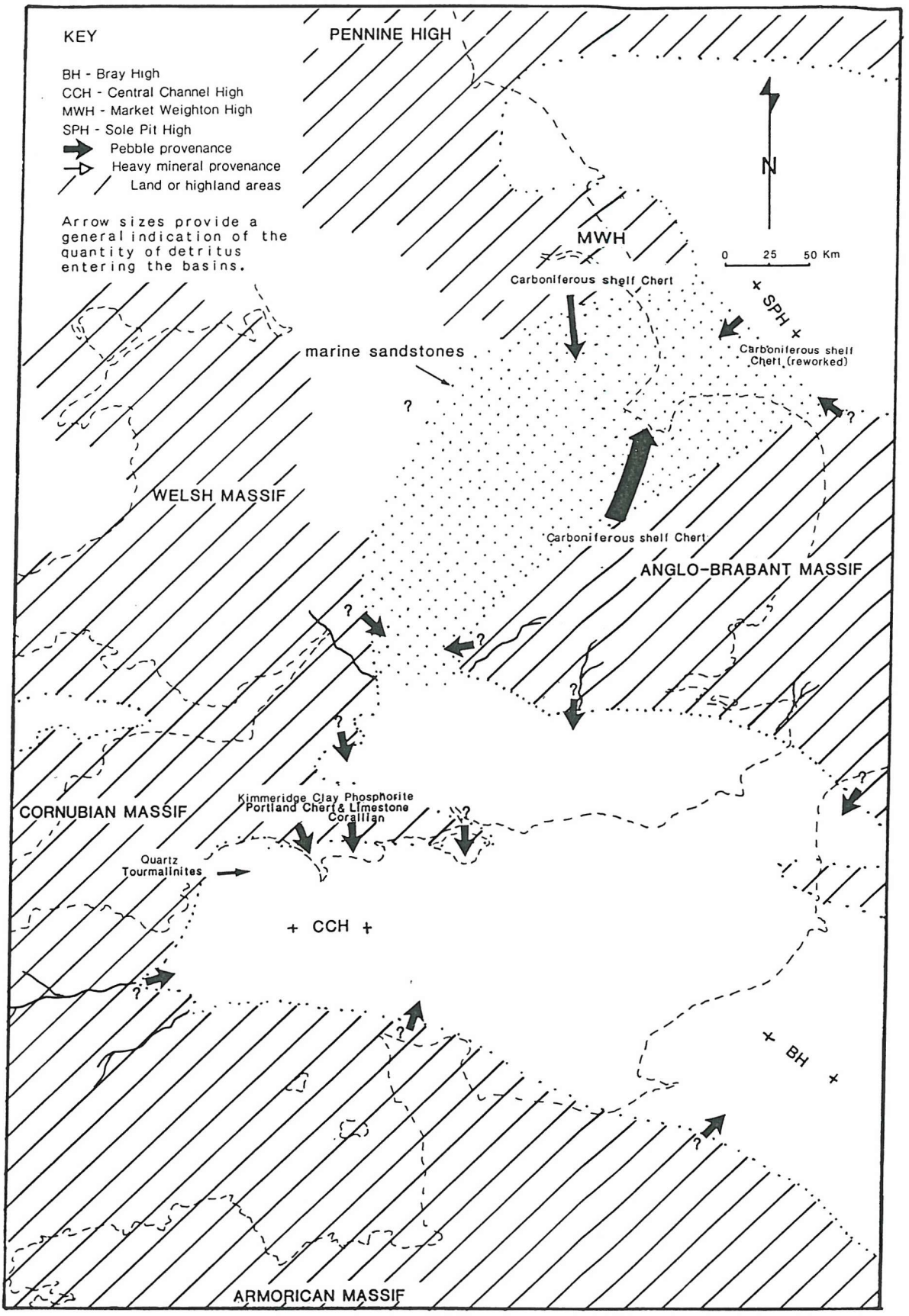


Figure 6.6 A palaeogeographical map showing pebble and sand provenance during Early Berriasian times, based on the present study, with supplementary palaeogeographical data from Anderson (1985), Glennie & Boegner (1981), Kelly (1983) and Howitt (1964).

6.3.2.1 The provenance of the "Unio" Member phenoclast suite

In Dorset, extrabasinal coarse-grained detritus in the "Unio" Member of the Purbeck Formation is sparse. The sands and granules present appear to have been derived from western sources (Sect. 4.2.1.3). Pebbles of Carboniferous shelf chert were not found. The "Unio" Member extrabasinal suite is similar to that in the Wessex Formation in this area, but exotic clasts are less abundant. Limestone and chert clasts from the Portland Limestone Formation and phosphorite clasts from the Kimmeridge Clay Formation are locally abundant and indicate that uplift occurred in the Dorset area during earliest Cretaceous times.

6.3.2.2 The provenance of the Wessex Formation phenoclast suite

The Wessex Formation phenoclast suite in Dorset was considered by Kirkaldy (1947a) to have been derived from the Cornubian Massif. It was demonstrated by P.Allen (1972), however, that clasts from deformed Precambrian and Lower Palaeozoic basement sources (Armorica/Galicia) were also present in the detritus. The detrital suite recognised in this study was similar to that described by previous workers. Quartz with acicular tourmaline, quartz-tourmaline vein-rocks, tourmalinized pneumatolytic breccia and radiolarian chert are all lithotypes present on the Cornubian Massif (Fig. 6.7), but the foliated-tourmalinites have no known counterparts in southwest England. Such clasts were probably derived from the massifs to the southwest of Dorset or from Triassic pebble beds of east Devon (Fig. 6.7). The angularity of the clasts in the finer grade pebble-fraction indicates that much of the detritus was derived directly from its source, as stated by P.Allen (1972), and reworking was improbable. However, rounded and reddened, medium to large pebbles present in low abundance have possibly been reworked from the Triassic pebble beds.

In contrast to earlier studies, chert pebbles of local origin have been found in the Wessex Formation in Dorset. Their scarcity is possibly the result of a dilution effect, caused by the large influx of extrabasinal detritus. The absence of limestone and phosphorite clasts indicates that local source areas were probably of low relief. Weathering possibly resulted in the breakdown of the less resistant rock types on the highs.

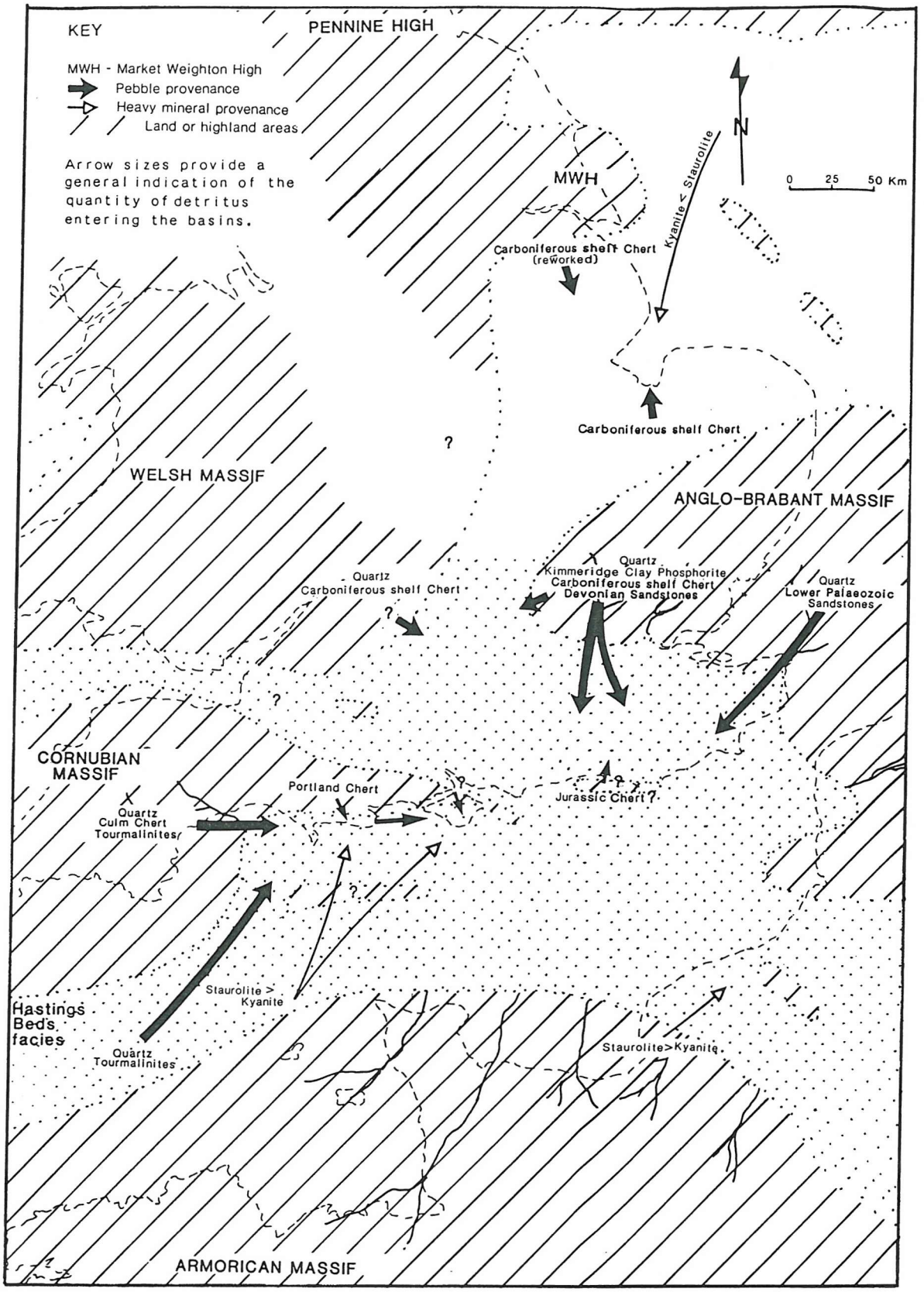


Figure 6.7 A palaeogeographical map showing pebble and sand provenance from Valanginian to Hauterivian times. Provenance data for the western Central Channel Basin and the East Midlands Shelf is based on the present study, with additional provenance data for the Weald Basin from P.Allen (1954, 1960, 1961, 1967a). Further palaeogeographical data is from P.Allen (1967a, 1981), Kamerling (1979), Rawson & Riley (1982) and Pomerol (1963).

6.3.2.3 The provenance of the Claxby Ironstone Formation phenoclast suite

The sedimentation pattern in the East Midlands area differed from that of Dorset during Early Cretaceous times, since there is little evidence for fresh influxes of coarse-grained detritus into the area. The pebbles in the Claxby Ironstone Formation are similar to those of the Spilsby Sandstone Formation, both in composition and size. This is consistent with the coarse-grained detritus in the Early Valanginian pebble bed having been derived from the older Cretaceous pebble beds (Fig. 6.7).

6.3.2.4 The provenance of the Hastings Beds Group phenoclast suite

The studies of Hastings Beds Group pebble beds made by P.Allen (1949, 1954, 1960, 1961, 1967a) revealed that detritus entering the Weald Basin during Early Cretaceous times was derived from the adjacent Anglo-Brabant Massif. Little reworking of intrabasinal pebble beds was considered to have occurred. P.Allen (1954) demonstrated that two principal detrital assemblages existed in the Hastings Beds Group. A western river entering the Weald Basin to the south of London drained a hinterland of Devonian pebbly sandstones of Old Red Sandstone lithofacies and Carboniferous limestone with chert (Fig. 6.7), both partially covered by Jurassic rocks at the basin-margins. An eastern river entered the basin in east Kent with its headwaters in Lower Palaeozoic and Upper Carboniferous rocks (Fig. 6.7). P.Allen (1954, 1967a) also recognised a change in the composition of the western pebble-suite through time. A greater abundance of Devonian sandstone and quartz clasts in the younger pebble beds was interpreted as the result of progressive erosion on the Anglo-Brabant Massif and removal of the Carboniferous and Jurassic covers.

It is probable, however, that the removal of a Jurassic cover with Carboniferous chert-rich pebble beds from above the Devonian rocks would have had a similar effect. Examination of the Lower Cretaceous pebble-suites suggests that this is more probable than direct reworking from a Carboniferous limestone source (Sect. 5.4).

6.3.2.5 The provenance of the Weald Clay Group phenoclast suite

Coarse-grained detritus continued to enter the Weald Basin from the north during the Barremian Stage and the influxes of sediment were suggested to result from the episodic uplift and rejuvenation of

the Anglo-Brabant Massif (P.Allen, 1975). The Weald Clay Group phenoclast suites in the western Weald are similar to those of the Hastings Beds Group in mid-Sussex.

6.3.3 The provenance of the Aptian and Albian phenoclast assemblage

The third phenoclast assemblage includes the pebble beds of the Lower Greensand Group and the basal Gault Clay Formation. The marine inundation of the Wessex Basin during Early Aptian times altered the mode of detrital transportation, reducing the importance of fluvial processes and enhancing the effects of marine-shelf mechanisms. The phenoclast suites of the Lower Greensand Group and Gault Clay Formation have been separated on compositional differences into an Aptian subassemblage and an Albian subassemblage.

6.3.3.1 The provenance of the Aptian phenoclast subassemblage

Pebble beds of rolled Kimmeridgian phosphorites and extrabasinal pebbles are present at the base of the Lower Greensand Group in the Isle of Wight, Dorset and parts of the Weald (Casey, 1961). However, significant influxes of coarse-grained detritus did not enter the basins until Late Aptian times.

The Late Aptian pebble beds were examined in three areas; the southern Midlands, the Weald and the Isle of Wight. The extrabasinal detrital suites for each area are distinct, but all the pebble suites are characterized by an abundance of intrabasinal detritus.

6.3.3.1a The provenance of the Faringdon Sponge Gravel and the Seend Ironsand phenoclast suites

The Faringdon Sponge Gravel and the slightly younger Seend Ironsand in the South Midlands are sedimentologically distinct, but the extrabasinal pebble suites of the two horizons are similar. The Faringdon Sponge Gravel contains pebbles and cobbles of Jurassic detritus and a suite of coarse to fine pebble-grade extrabasinal detritus. In contrast, the Seend Ironsand contains small pebbles, principally of extrabasinal origin. Both extrabasinal assemblages contain approximately equal proportions of quartz and Carboniferous shelf chert. Sandstone clasts are scarce, but rounded quartzite and

quartz-tourmaline pebbles are found in the Faringdon deposits.

The contrast in composition of these Lower Greensand Group extrabasinal suites from those of the Lydite Beds indicates that both the Faringdon and Seend deposits must contain detritus transported into the basin subsequent to the Portlandian Stage. Palaeocurrent indicators imply that sediment sources existed to the north or northwest of Faringdon and west or northwest of Seend (Krantz, 1972; Bridges, 1982). The presence of Kimmeridge Clay Formation phosphorites and Corallian Group limestones and cherts in the Faringdon Sponge Gravel and probable Jurassic phosphorites in the Seend Ironsand indicate that reworking of the Upper Jurassic pebble beds must have occurred. It is concluded, therefore, that the detritus was brought into the Wessex Basin during Aptian times, from quartz-rich and chert-poor sources.

Several sources of the quartz probably existed to the northwest of the south Midlands. Derivation from the Lower Palaeozoic rocks of the Welsh Massif was possible, but alternative sources were the Devonian, Carboniferous and Triassic pebble beds in the same area. The presence of small but significant quantities of tourmalinized quartzites in the Faringdon Sponge Gravel may provide the key to the provenance of some of the detritus. Tourmalinized sediments, igneous rocks and vein rocks are present in the Triassic pebble beds of Devon, Somerset, the Midlands and southern Cheshire (Campbell-Smith, 1963). Similar pebbles are not found in the Devonian rocks on the Welsh Massif (J.R.L.Allen, 1974; 1975). Tourmalinites are present in the Torridon Group of northwest Scotland (Williams, 1969; P.Allen et al., 1974), but the relatively large size of the clasts in the Lower Greensand Group (Sects. 4.2.4.3, 4.2.4.4) suggests that this is an improbable source. Palaeocurrent indicators (Krantz, 1972) imply that it is unlikely that the Devon or Somerset Triassic pebble suites could have directly sourced the detritus in the Faringdon Sponge Gravel. Triassic pebble beds exposed on the margins of the Palaeozoic inliers of the Midlands and the Welsh Massif were therefore the most probable detrital source rocks (Fig. 6.8). In addition to the tourmalinites, Triassic pebble beds would also have provided quartz and quartzite clasts. Derivation of quartz detritus from the Devonian and possibly the Carboniferous rocks of the eastern part of the Welsh Massif may also have occurred.

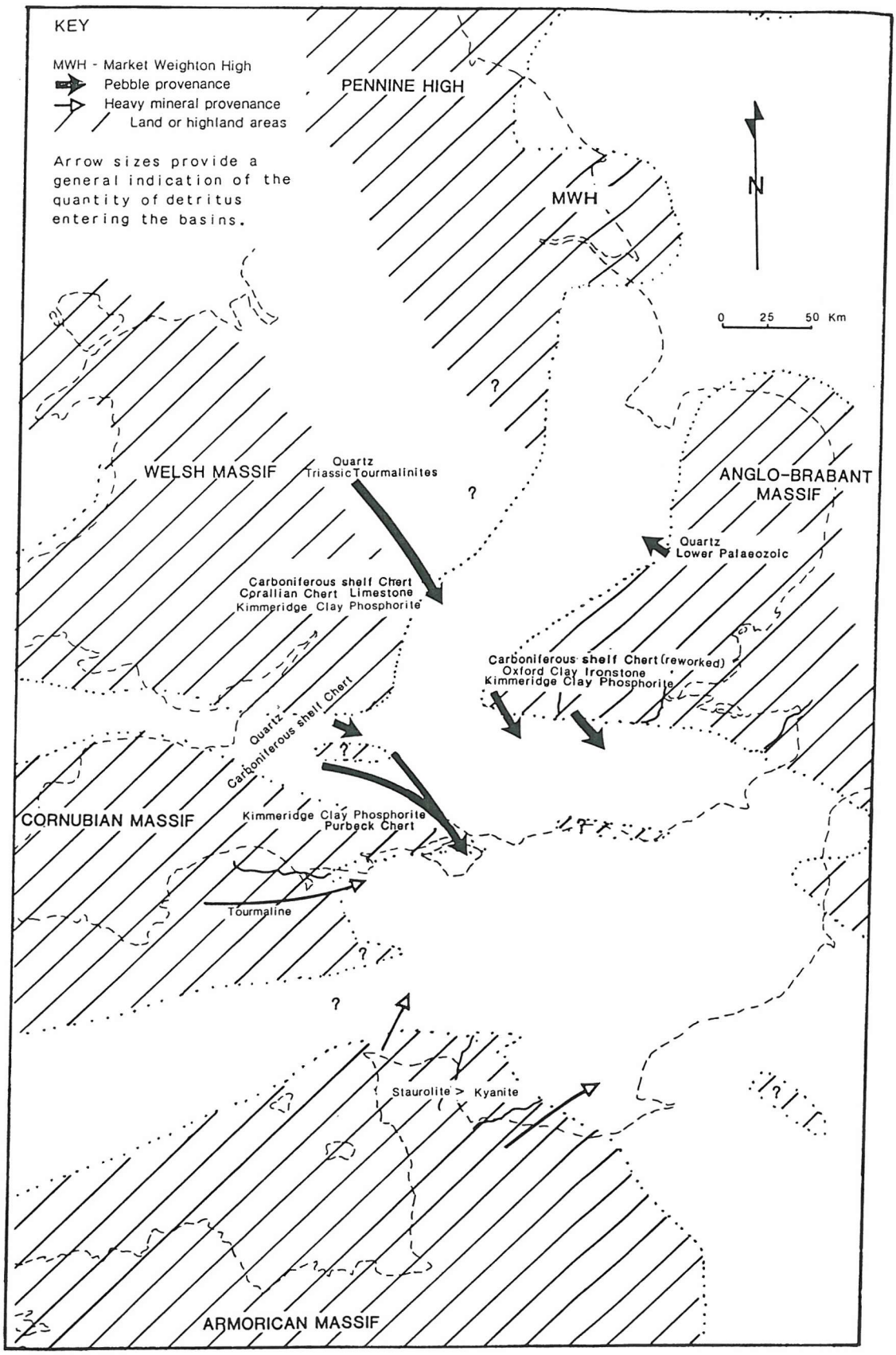


Figure 6.8 A palaeogeographical map showing pebble and sand provenance during Late Aptian times, based on the present study, with supplementary palaeogeographical data from Rawson & Riley (1982), Middlemiss (1975) and Robaszynski (1981) and provenance data from Juignet et al. (1973).

The mode of transportation of the clasts to the site of deposition at Faringdon is uncertain. The tourmalinite, quartzite and some quartz pebbles are rounded and up to 60mm in length. They are, therefore, unlikely to have been transported by marine-shelf processes. The lack of evidence for significantly higher sea-level in southern Britain during the earliest Aptian Stage makes shore-line transportation improbable. Clasts, therefore, may have been transported by fluvial processes from the margins of the Welsh Massif during Early Cretaceous times and reworked during the Aptian transgressions.

The finer grained phenoclast suite in the Seend Ironsand contains fewer clasts of Jurassic origin than the Faringdon Sponge Gravel. However, the relatively high Carboniferous shelf chert content of the Seend Ironsand pebble suite indicates that the Lydite Beds are probable sources for some of this detritus. Eastern or southeastern palaeocurrent indicators in the Seend Ironsand imply a quartz source in the Bristol or South Wales area (Fig. 6.8). Suitable lithotypes are present in the Devonian rocks in the Mendips, the Welsh Borders and South Wales (J.R.L.Allen, 1974, 1975) and pebble beds also exist in the Millstone Grit of the Welsh Coalfield (Robinson, 1935). Pebbles of quartz were reported from the Rhaetic bone bed in the Bristol district (Short, 1904; Richardson, 1911). Reworking from any one of these pebble beds is possible and the precise source cannot be distinguished.

6.3.3.1b The provenance of the Bargate Beds Formation phenoclast suite

The phenoclast suite of the Bargate Beds Formation is distinctly different from those of equivalent age to the northwest. Silicified limestones from Carboniferous sources are the dominant extrabasinal phenoclast lithotype, but the bulk of the clasts are ironstones and phosphorites derived from the Kimmeridge Clay or Oxford Clay Formations. Clasts of Jurassic chert are not present in the detrital suite. The high Carboniferous shelf chert content of the phenoclast suite is reminiscent of the Lydite Beds (Fig. 4.13) and the presence of reworked Jurassic clasts supports the assumption that the Carboniferous shelf chert and quartz clasts were reworked from

Jurassic pebble beds. Current indicators in the sands imply a northwestern origin of the detritus (Narayan, 1963; Sobey, 1975). Borehole data and the subcrop maps of George (1962), Fyfe et al. (1981) and Whittaker (1985) reveal that the Palaeozoic basement to the north and northwest of the Bargate Beds Formation outcrop is covered by a thin veneer of Jurassic sediment. Direct derivation of chert from Carboniferous sources is therefore improbable.

The similarity in the orientation of palaeocurrents implied from sedimentary indicators in the southern Midlands and Surrey suggests that the two areas were part of the same basin (Bridges, 1982). The difference in the phenoclast suites, however, indicates that they were not, and that a barrier existed between the two areas. The barrier was presumably the margin of the Anglo-Brabant Massif. Detritus transported into the Oxford Shelf area was either not transported as far southeast as the western Weald Basin or it entered the Basin in another area. This suggests that the Bargate Beds Formation detritus was derived from the southern margins of the Anglo-Brabant Massif, with little additional detritus from further afield (Fig. 6.8).

Reports of Purbeck Formation and Portland Limestone Formation chert pebbles in the Hastings Beds Group of Sussex were made by Relf (1916), Milner (1923) and P.Allen (1960). P.Allen (1960, 1967a) suggested that Jurassic chert was derived from the margins of the Anglo-Brabant Massif, south of London. Similar detritus was not found in the Bargate Beds Formation, which implies different sources for the detritus of the Hastings Beds Group and the Bargate Beds Formation. The Bargate Beds Formation phenoclast suite appears to have been derived from the Portland Group of southern Midlands type which contains pebble beds but is not cherty.

6.3.3.1c The provenance of the Ferruginous Sands Formation phenoclast suites

The Ferruginous Sands Formation phenoclast suites of the Isle of Wight are very similar to those of the Bargate Beds Formation, being rich in phosphorite and ironstone clasts. In the Isle of Wight, phosphorite is derived from the Kimmeridge Clay Formation, but the ironstone clasts are probably reworked from either Upper Jurassic or

Lower Cretaceous deposits. Oxfordian clasts have not been found during the present study, but have been reported from an earlier investigation (Dike, 1972b). The pebble suite also contains Purbeck Formation chert in moderate abundance, but Portland Limestone Formation chert is rare. The remainder of the pebble suite is composed of quartz and Carboniferous shelf chert in approximately equal amounts.

The abundance of Jurassic clasts indicates local erosion of an intrabasinal high (Fig. 6.8). The most probable source of the detritus is the area of uplift to the north of the Isle of Wight (Sect. 5.4). The presence of Kimmeridgian ammonites in the Perna Bed at the base of the Lower Greensand Group indicates that erosion of the high occurred during much of the Aptian Stage.

The uplift to the north of the Isle of Wight disturbance (Whittaker, 1985) is reported to have resulted in erosion down to the Great Oolite Group. Oxford Clay Formation and Corallian Group detritus might therefore be expected in the Lower Greensand Group pebble beds of the Isle of Wight. However, the absence of such clasts cannot be considered as an indication that erosion had not extended down to this level since characteristic resistant clasts were probably not present at either horizon.

The provenance of the extrabasinal suite in the Ferruginous Sands Formation is problematical. Lydite beds are present in the Portland Group in the Portsdown boring (Taitt & Kent, 1958) and reworking of such detritus is probable. However, the Isle of Wight pebble beds are distinct from those of the Lydite Beds in the south Midlands because they contain a greater proportion of quartz pebbles. In the absence of information concerning the composition of the Portsdown pebble beds, reworking of these Upper Jurassic pebble beds cannot be proved. The existence of evidence for influxes of quartz-rich detritus during Early Cretaceous times in other areas of southern England suggests that the Ferruginous Sands Formation phenoclast suites are similarly not derived entirely from Upper Jurassic pebble-sources. The absence of a significant fluvial input into the area from the north during deposition of the Wealden Group (P.Allen, 1959; Stewart, 1981b) suggests that older Cretaceous pebble beds were unlikely to be the source of the detritus derived from the

north. The range of clast-sizes is greater than commonly found in tidal sand bodies (i.e. the Folkestone Beds Formation in the Weald Basin; Sect. 2.2.3.1) and therefore transportation across a basin is improbable. The compositional distinction between the Isle of Wight pebble beds (Ferruginous Sands Formation) and those of the northwest Weald (Bargate Beds Formation) suggests that derivation from the Anglo-Brabant Massif is improbable. The phenoclast suites of the Ferruginous Sands Formation are similar to those in the southwest Midlands. It is suggested therefore, that the clasts were transported into the area from the northwest, possibly by longshore movement along shallows on the Quantock-South Hants High (Fig. 6.8).

6.3.3.2 The provenance of the Albian phenoclast subassemblage

Although a number of the pebble beds in the Upper Jurassic and Lower Cretaceous strata were studied in the south of England and northwestern France, the restricted distribution of the pebble beds and the lack of exposure hindered detailed regional studies. Individual Albian pebbly horizons can rarely be traced between basins, but the presence of a number of pebble horizons in this interval enables a comparison to be made of the detrital suites in the basins.

The Albian pebbly horizons studied were deposited in a marine environment, under a variety of sedimentological conditions. Sedimentological constraints therefore existed for the transportation and distribution of the detrital suites.

Where Aptian and Albian deposits have been studied in the same areas, the extrabasinal suites are compositionally similar, but the Aptian pebble beds studied all contain significantly greater proportions of intrabasinal detritus. An example of this has been described previously by Wells & Gossling (1947) in their investigation of the Lower Greensand Group of west Kent. This indicates that the extrabasinal suite entering the basins of southern England during the Aptian and Albian Stages were similar, but that Jurassic source areas were of more importance during the Aptian Stage. This probably resulted from the relatively low Aptian

sea-level and the greater exposure of Upper Jurassic strata at the basin margins and on intrabasinal highs.

The examination of the younger pebble beds in the Lower Greensand Group and their lateral equivalents in the Midlands of England and the north coast of France has enabled separation into three petrographic provinces. Two of the provinces (Dorset and Normandy) are small and contain distinctive pebble suites. The third, the southeast and central English province is larger and includes the Albian deposits of the rest of southern Britain. Compositional variations in the coarse-grained detrital suites in the third province enable its separation into five subprovinces. The boundaries between the provinces and subprovinces are transitional, but may have been, at least in part, structurally controlled.

6.3.3.2a The Dorset Province

The pebble beds at the base of the Gault Clay Formation in Dorset contain a detrital suite primarily of western origin, but with abundant Jurassic detritus in the east of the area. The extrabasinal detritus of the Gault Clay Formation is distinct from the Wessex Formation pebble suite in appearance, the Gault Clay Formation pebbles being more rounded. Compositionally, however, the two suites are similar with high quartz, Culm chert and tourmalinite content (Sect. 4.2.1.6). Sandstone pebbles are not abundant but are more common than in the Aptian and Albian pebble beds to the northeast and east (Sects. 4.2.2, 4.2.3, 4.2.4).

The Gault Clay Formation pebble suite is composed predominantly of quartzose pebbles. This indicates that it was either derived from a source area where weathering was sufficient to break down the less resistant lithotypes, or transportation processes caused the destruction of weaker clasts. The presence of fibrous-quartz pebbles in moderate abundance is probably an indicator of the immaturity of the pebble suite.

Two possible mechanisms for the introduction of the Gault Clay Formation clasts into the the western margin of the Central Channel Basin are envisaged:

1. the clasts were transported from the west during the mid-Albian marine transgression;
2. the clasts were transported into the area by Valanginian-Hauterivian rivers and subsequently reworked during the Albian Stage.

The absence of poorly rounded extrabasinal pebbles in east Dorset where the Gault Clay Formation oversteps the Wessex Formation, implies that local reworking was minimal. However, if the Wessex Formation clasts had been reworked beyond the area and transported into east Dorset, then a compositionally mature pebble suite might be expected (Fig. 6.9).

Jurassic detritus in the basal Gault Clay Formation is derived from the Kimmeridge Clay, Portland Limestone and Purbeck Formations (Sect. 4.2.1.5). These clasts are poorly rounded. They were clearly not transported far from their source and were probably derived from the South Dorset High (Fig. 6.9). The absence of limestone clasts in the suite is probably a consequence of attrition in the shore-line environment.

6.3.3.2b The Normandy Province

The Lower Cretaceous sediments of the Caux and the Calvados coasts lie approximately 150km to the southeast of their stratigraphical equivalents in the Isle of Wight. The French phenoclast assemblage is distinct from the Isle of Wight pebble suites, but is superficially similar to the Dorset assemblage.

Quartz forms the main component of the pebble beds and clasts of fibrous and chloritic quartz are moderately common. Deformed and quartz-veined quartzose phenoclasts, derived from a metamorphic terrain, are also present in the suites. Fine-grained siliceous chert clasts are typically unfossiliferous. The extrabasinal detrital suite was derived principally from metamorphic crystalline basement (Sect. 4.2.7). The westward-onlap of the Aptian and Albian rocks suggests that the Armorican Massif was the principal detrital source. Juignet et al. (1973) considered that many of the clasts were derived from the Cotentin High (Figs. 1.2, 6.5).

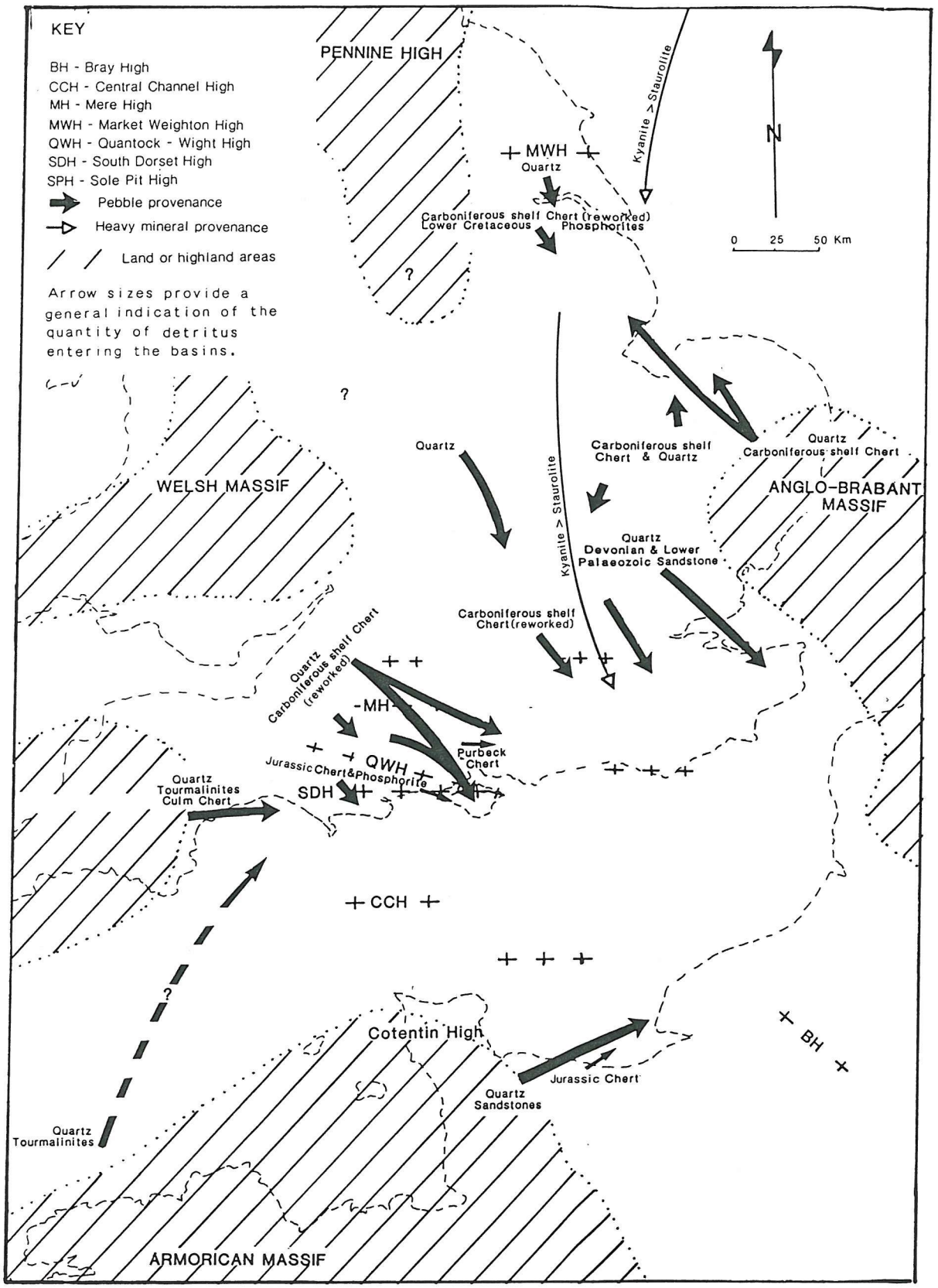


Figure 6.9 A palaeogeographical map showing pebble and sand provenance during Early Albian times, based on the present study, with supplementary palaeogeographical data from Owen (1971a), Middlemiss (1975), Juignet et al. (1973) and Cope (1984).

The inclusion of the Normandy samples in a study of the provenance of Lower Cretaceous sediments in southern Britain, is for comparison with the assemblages of southern Dorset and the Isle of Wight. Whether or not clasts in southern England were derived from an area to the south is difficult to assess in the absence of information concerning the sub-Cretaceous geology of the central English Channel. The Normandy phenoclast-assemblage therefore provides an indication of the type of detritus entering the margins of the Paris Basin and the type of detritus that could potentially have been reworked into southern Britain.

The absence of radiolarian cherts, the low abundance of tourmalinites and the high proportion of foliated and deformed phenoclasts distinguishes the Normandy assemblage from those of southern England. The lack of Culm-type chert and luxullianite-type clasts indicates that there is little Cornubian-type detritus in Normandy and similarly there appears to be little Cotentin-type detritus in the pebble beds of southern England.

The absence of Carboniferous shelf chert clasts in Normandy, but their abundance in the Isle of Wight suggests that the Isle of Wight detritus is unlikely to be derived from Armorica. It does not preclude an unexposed source to the south of the Island, but areas to the north of the Isle of Wight, known to have chert-bearing Carboniferous rocks, were more probable source areas. The apparent distinction between the Albian pebble suites of Normandy and the Lower Cretaceous pebble suites of Dorset puts in some doubt the suitability of Armorica as a source of coarse-grained detritus in southern Dorset (cf. P.Allen, 1972). It is possible that the quantity of Armorican coarse-grained detritus in Dorset is relatively small in comparison to that from the Cornubian Massif.

Intrabasinal clasts are moderately abundant in the Normandy phenoclast assemblage. Chert from Middle Jurassic (Grès du Planet) and possibly Upper Jurassic (Calcaire de Hennequeville) rocks was identified in the pebble bed. Whether the clasts are derived from the Calvados Shelf to the west of the area of deposition (Fig. 1.2) or from intrabasinal highs is uncertain. In southern England, Jurassic chert clasts are concentrated close to their probable source, but examples of far-travelled clasts are found (e.g. Purbeck

chert in the Gault Clay Formation of the southwest Weald and Portland Limestone Formation chert in the Isle of Wight). Juignet et al. (1973) noted that the Bajocian limestone facies of the Grès du Planet have limited distribution to the Bessin area and therefore implied derivation from the west.

6.3.3.2c The Southeast and Central English Province

This area extends from the Central Channel Basin (Isle of Wight) to the East Midlands Shelf and includes the Weald Basin. The pebble suites of the area are distinguished by the abundance of detritus derived from the Anglo-Brabant Massif, Welsh Massif and the Pennine High. Cornubian detritus is present only in the Central Channel Basin and the Wardour Basin. This area is appreciably larger than the two other provinces and is divisible on phenoclast-suite composition into five subprovinces.

i. The Isle of Wight subprovince

The detrital suite of the Carstone Member in the Isle of Wight is composed principally of quartz and Carboniferous shelf chert phenoclasts. Sparse pebbles of radiolarian chert and tourmalinite indicate that some material of western origin is present in the suite. Intrabasinal clasts are less common than in the Aptian pebble beds of this area and are compositionally distinct.

The source of the extrabasinal detritus is probably similar to that of the Aptian pebble beds in the same area (Sect. 6.3.3.1c). The Q:C index of the Carstone Member phenoclast suite (Sect. 4.2.2.3) is greater than that of the Lydite Beds (Sect. 4.2.4.2), but similar to those of the Aptian and Albian phenoclast suites in Oxfordshire and Wiltshire (Sects. 4.2.4.3 to 4.2.4.6). It is probable therefore that the high quartz content in the Isle of Wight is similarly the result of a fresh detrital input and did not result purely from reworking of Upper Jurassic pebble beds.

The greater proportion of Portland Limestone Formation detritus in the Carstone Member, relative to the older pebble beds in the Isle of Wight, is probably the result of detritus having been derived from the west (Fig. 6.9). However, alternative sources of Portland

Limestone Formation detritus possibly existed on the western part of the Quantocks-South Hants High or the Mere High and must be considered. The bioclastic, Rhaxella and oolitic chert pebbles identified in the Isle of Wight could be derived from any of these areas. The scarcity of Purbeck Formation chert in the suite suggests that significant quantities of detritus were not derived from the area immediately to the north of the Isle of Wight (Sects. 4.2.2.4, 6.3.3.1). The scarcity of Kimmeridge Clay Formation phosphorite in the Carstone Member and in the Sandrock Formation was possibly the result of the relative weakness to attrition of such clasts and their consequent destruction through protracted reworking.

In consideration of the greater abundance of pebble beds with extrabasinal clasts in the uppermost beds of the Lower Greensand Group in the Isle of Wight, it is probable that there was a major influx of northern detritus into the Central Channel Basin during the earliest Albian Stage (Fig. 6.9). The mode of transportation of the clasts is unclear. The clast size and suite maturity suggest that transportation by offshore processes was unlikely (e.g. tidal or meteoric currents). Longshore processes may have been active on the margins of the Quantocks - South Hants High resulting in net migration to the southeast. Fluvial processes might have transported detritus to the southeast, but the lack of evidence for a major northern fluvial influence during the Valanginian and Hauterivian Stages (Stewart, 1981b) suggests that an Albian fluvial influx of coarse-grained detritus is less probable.

ii. The Weald subprovince

The Folkestone Beds and Gault Clay Formations in the western Weald Basin have similar detrital suites (Sect. 4.2.3.4). Both pebbly units contain detritus of northern origin, but the lateral study of Folkestone Beds Formation phenoclast suites has demonstrated that east-west variation also occurs. The progressive change in the detrital suites appears to complement the variation observed in the Hastings Beds Group pebble beds by P.Allen (1954, 1967a). The distribution of coarse-grained detritus in the Lower Greensand Group of the Weald indicates that northern and northwestern source areas were the most significant. Transportation and redistribution of fine pebble-grade detritus by tidal currents were of importance

(Narayan, 1963).

The Early Albian transgression resulted in partial flooding of the Anglo-Brabant Massif (Middlemiss, 1975). As the Massif began to become submerged, tidal currents, probably magnified by the restricting basin shape, scoured the Palaeozoic basement and transported sand and gravel into the basin to the south. The fining of the Folkestone Beds Formation to the south and east in the Weald Basin was interpreted by Bridges (1982) as an indication of a diminution of tidal strength in this direction.

The high kyanite and staurolite content of the heavy-mineral fraction of the Folkestone Beds Formation was suggested by Wood (1956) to indicate derivation of arenaceous sediments from Armorica. However, Juignet et al. (1973) and Middlemiss (1975) noted that such a suite might also have been derived from the north and probably had a similar origin to the Lower Cretaceous sands of the East Midlands Shelf (Rastall, 1919, 1930; Versey & Carter, 1926; Ingham, 1929).

The composition of the coarse-grained detrital suite of the Folkestone Beds Formation confirms a northern origin of the sediment. The clasts were derived from Jurassic and Palaeozoic source rocks. The west-to-east variation in the Folkestone Beds Formation detrital suite probably resulted from a combination of the palaeogeology of the Anglo-Brabant Massif and the transport-path of the detritus. The western and southern margins of the Anglo-Brabant Massif were covered by a thin veneer of Jurassic sediments, while the central core was composed of Devonian rocks north of London (Allsop, 1985) and Silurian and Ordovician sediments north of Kent (Wills, 1973; Whittaker, 1985). Further to the east, Dinantian and Westphalian strata are preserved in the Kent Coalfield. The dominance of southeasterly current indicators in the sands of the Folkestone Beds Formation (Kirkaldy, 1947a; Narayan, 1963, 1971) suggests that the detrital suite variation reflects the former outcrop on the Anglo-Brabant Massif to the northwest and not directly to the north of the area of deposition (Fig. 6.9).

In the northwest of the Weald Basin, the detrital suite in the Folkestone Beds Formation is composed of Carboniferous shelf chert and ironstone, with lesser amounts of quartz (Sect. 4.2.3.1). The

suite is similar to that of the Bargate Beds Formation (Sect. 4.2.3.1) except for the scarcity of goethite and phosphorite fossil casts. The compositional similarity of the Lower Greensand Group phenoclast suites suggests that both were derived from a similar source, or that the Folkestone Beds Formation phenoclasts were reworked from older Lower Greensand Group pebble beds. The scarcity of Jurassic clasts in the Folkestone Beds Formation suite possibly reflects a partial burial of Jurassic detrital source rocks by Aptian sediments. Alternatively, the lack of phosphorite clasts may have resulted from their destruction through prolonged reworking.

To the east, the proportion of Carboniferous shelf chert clasts in the Folkestone Beds Formation phenoclast suite decreases and quartzite and sandstone pebbles become a significant component. The sandstones are probably derived directly from Devonian rocks on the Anglo-Brabant Massif to the north. However, the rounding of cherts and quartz pebbles possibly indicates that such clasts are likely to have been reworked. The eastward increase in the abundance of sandstone and quartz pebbles is interpreted as reflecting the composition of the basement rocks on the Massif which was submerged during Early Albian times. The greater sandstone pebble content in the Folkestone Beds Formation relative to the Hythe Beds Formation in the central Weald Basin (Wells & Gossling, 1947) is probably a function of the Early Albian extension of the seas across the Anglo-Brabant Massif and the submergence of the Jurassic rocks which were the source of the Carboniferous shelf chert and phosphorite-rich detritus of the Hythe Beds Formation.

Wells & Gossling (1947) also reported a greater proportion of bioclastic chert pebbles in the Folkestone Beds Formation relative to the Hythe Beds Formation. This is a feature recognised in other areas where fresh influxes of detritus entered a basin (cf. East Midlands Shelf; Sect. 4.2.6.4). Two explanations for the increase in the proportion of bioclastic chert pebbles may be considered:

1. the abundance of bioclastic cherts is an indicator of the maturity of the phenoclast suite (i.e. the bioclastic chert-rich phenoclast suite of the Folkestone Beds Formation was derived from a 'less mature' source on the massif);
2. the abundance of bioclastic chert reflects the source rock

composition (i.e. the pebbles of the Folkestone Beds Formation and Hythe Beds Formation are derived from different source rocks).

Palaeocurrent data (Narayan, 1963) suggest that both the Hythe Beds and Folkestone Beds Formations have similar source areas. It is probable that the Hythe Beds Formation phenoclast suite is derived largely from Jurassic rocks, but that the Folkestone Beds Formation phenoclast suite includes more immature material, possibly derived directly from its source.

In mid-Kent, Carboniferous shelf chert pebbles are scarce and Devonian and Lower Palaeozoic quartz and sandstone pebbles form the bulk of the phenoclast suite. The pebble-grade detritus of the eastern Weald Basin appears to have been derived largely from the Anglo-Brabant Massif (Fig. 6.9). Jurassic detritus was not detected. The angularity of the quartz and sandstone clasts suggests that the clasts were locally derived. The scarcity of chert in the eastern Weald suite indicates that Carboniferous strata are unlikely to have existed to the north and that any older Mesozoic pebble beds contained little chert. The chert clasts were probably introduced into the area from the west or from the margins of the Kent Coalfield.

iii. The Wiltshire and Oxfordshire subprovince

The Albian pebble suites of Hurst Hill, Oxfordshire and Haredene Wood, Wiltshire, are both composed principally of quartz with lesser quantities of Carboniferous shelf chert. Jurassic detritus was not detected in the sands at Hurst Hill. However it is present in low abundance in the basal Gault Clay Formation pebble bed at Haredene Wood. The extrabasinal phenoclasts in the Albian horizons are compositionally similar to those of the Aptian Seend Ironsand and Faringdon Sponge Gravel phenoclast suites.

The pebbles of the basal Gault Clay Formation in the Vale of Wardour are assumed to be of western or northwestern origin. Chert pebbles from Carboniferous limestones are rounded and mature. Reworking of such detritus from the Lydite Bed detritus is probable

(Reid, 1903). Pebbles of quartz are also well rounded. They were possibly derived from Devonian or Triassic pebble beds (Fig. 6.9). The presence of tourmalinite and radiolarian chert clasts implies that there is a small quantity of Cornubian detritus in the suite. However, this detritus has possibly been reworked from Triassic pebble beds in the local area.

iv. The Bedfordshire and Cambridgeshire subprovince

The pebble beds of the Woburn Sands contain similar detrital suites to the overlying basal Gault Clay Formation. It is probable that Woburn Sands detritus was reworked into the basal Gault Clay Formation without a significant influx of coarse-grained detritus into the Bedfordshire and Cambridgeshire area during Early Albian times. The pebble suites of this area are appreciably richer in Carboniferous shelf chert than the pebble suites of the Wiltshire and Oxfordshire subprovince.

Schwarzacher (1953) interpreted palaeocurrent data from the Woburn Sands as indicating dominant currents from the north. The detrital sources of the Woburn Sands, therefore, were probably also to the north. Suitable primary source areas of Carboniferous shelf chert detritus included the Pennine High and the Anglo-Brabant Massif. However, the generally fine grain size of the Early Albian rocks on the East Midlands Shelf indicates that the Pennine area is unlikely to have been a significant detrital source. The compositional maturity of the suite indicates that reworking of Lower Cretaceous or Jurassic pebble beds on the southern margins of the East Midlands Shelf probably occurred (Fig. 6.9).

v. The Lincolnshire and North Norfolk subprovince

The upper part of the Carstone Member in the East Midlands overlies older Lower Cretaceous rocks unconformably and oversteps onto the Jurassic and Triassic rocks at the basin margins (Strahan, 1886; Whittaker, 1985). The phenoclast suite of the Carstone Member differs distinctly from those of the older pebble beds in the area and those of Early Albian age to the south. The Carstone Member contains appreciably greater quantities of quartz than the older pebble beds and the pebble suite also differs morphologically. The

extrabasinal detritus in the Carstone Member is significantly coarser grained than in the Mid-Spilsby Nodule Bed and basal Claxby Ironstone Formation phenoclast suites. These differences indicate that if reworking occurred and the unconformable relationship with the underlying beds suggest that it probably did, then the detrital suite was supplemented by one or more sources.

Although the Q:C index of the Carstone Member increases (higher quartz) to the north, the abundance and size of the extrabasinal clasts decrease. A minor northern source of small quartz pebbles is therefore indicated. The marked increase in the Q:C index between the sample points at Nettleton Bottom and South Ferriby (Fig. 4.20a) provides an indication of the quartz source. Between Nettleton and South Ferriby, the Carstone Member oversteps the older Lower Cretaceous rocks to rest on a thinned Kimmeridge Clay Formation sequence (Strahan, 1886). The Lower Cretaceous pebble beds which probably provided the source of chert and some quartz in the Nettleton suite could not have been a source of pebble beds in the South Ferriby area. There is no evidence for a pebbly Aptian, or Albian facies to the north of the Market Weighton High and coarsening of the Carstone Member to the west or east has not been recognised (Kent, 1980). This suggests that the Market Weighton High was the most probable quartz source. The Lower Sandy Beds (basal Great Oolite Group) in the Worlaby boreholes on south Humberside, were reported to contain "quartz pebbles in the bottom 1.50m" (Richardson, 1979). Middle Jurassic pebble beds on the Market Weighton High were therefore probable sources for some of the Carstone Member detritus on the northern part of the East Midlands Shelf (Fig. 6.9).

On the southern margins of the Lincolnshire and North Norfolk subprovince the extrabasinal pebble suite of the Carstone Member is more chert-rich than to the north. The higher proportion of bioclastic-chert types and carbonate inclusions in the cherts in this suite relative to the older Lower Cretaceous pebble suites indicates that the Carstone Member contains a less mature pebble suite. Versey & Carter (1926) suggested that the Carstone Member pebble detritus was probably derived from a southern source area and this conclusion is supported by the present studies (Fig. 6.9). The Anglo-Brabant Massif is the probable source of both Palaeozoic chert and quartz pebbles. Both phenoclast types were probably present in primary

sources on the Massif. An absence of significant quantities of sandstone and limestone clasts indicates either that the pebble suite was reworked from older pebble beds or that the less resistant clasts were removed through abrasive or corrosive processes. The coarse-grained detrital source rocks on the northern margin of the Anglo-Brabant Massif were probably similar to those on the southern margin of the Massif (Whittaker, 1985), but Lower Palaeozoic rocks were likely to have been of greater importance as a source of quartz than Devonian rocks. Carboniferous limestones have been recognised beneath Permian strata in the East Ruston and Gimmingham boreholes (Allsop, 1984). Other small outliers of Carboniferous rocks probably also subcrop beneath Mesozoic sediments elsewhere on the northern margin of the Anglo-Brabant Massif.

The higher quartz content of the Carstone Member phenoclast suite in the Lincolnshire and North Norfolk subprovince relative to the Woburn Sands and basal Gault Clay Formation pebble suites of the Bedfordshire and Cambridgeshire subprovince suggests that although detritus was shed off the Anglo-Brabant Massif northwards onto the East Midlands Shelf, relatively little material was transported onto the northern part of the Oxford-Cambridge Shelf.

Glennie & Boegner (1981) proposed that uplift and erosion of the Sole Pit area occurred during Early Cretaceous times resulting in influxes of sediment onto the East Midlands Shelf. The coarse-grained detrital suites indicate that although pebble detritus was transported onto the East Midlands Shelf during Late Jurassic times, a more significant input of detritus occurred during mid-Cretaceous times. The later input resulted from basin-margin uplift prior to the mid-Cretaceous transgression. Limited uplift on the Anglo-Brabant Massif and the Market Weighton High during earliest Cretaceous times enabled the reworking only of older pebble beds on the East Midands Shelf and inhibited transportation of clasts from the basement massifs onto the shelf. The mid-Cretaceous uplift of the marginal highs to Southern North Sea Basin margin highs probably occurred as a result of post-rifting thermal subsidence in the basin. Relative elevation of the basin margins through lateral heat-flow (Cochran, 1983) or flexural uplift (Watts, 1982) may have occurred.

6.3.4 Basin development and the provenance of Upper Jurassic and Lower Cretaceous phenoclast suites

The coarse-grained detrital suites in the Weald Basin, the Central Channel Basin and on the Oxford-Cambridge Shelf underwent major compositional changes during earliest Cretaceous times (Berriasian Stage). In these areas, the older phenoclast suites are dominated by Carboniferous shelf chert (Fig. 6.10a), with the younger phenoclast suites generally containing higher proportions of quartz (Figs. 6.10b,c). A similar change occurred on the East Midlands Shelf between the Hauterivian and Albian Stages (Figs. 6.10a,b,c).

The change in the composition of the phenoclast suites in the Weald and Central Channel Basins is interpreted as resulting from Early Cretaceous rift-margin uplift and denudation of the Cornubian, Welsh and southern part of the Anglo-Brabant Massifs. The delayed change in the composition of the Cretaceous phenoclast suites on the East Midlands Shelf was due to the relative stability of this area and the adjacent highs during Early Cretaceous times. The influx of quartz-rich detritus onto the Shelf during the Albian Stage occurred as a result of marine transgressions induced by post-rifting thermal subsidence of the Southern North Sea Basin and the associated uplift of the Market Weighton High and the northern part of the Anglo-Brabant Massif.

6.4 CONCLUSIONS

The phenoclast assemblages of the Upper Jurassic and Lower Cretaceous rocks in southern Britain and Normandy display distinct changes in composition, both geographically and stratigraphically. Such variations in the phenoclast assemblages resulted principally from regional and local tectonic events. They are summarised as follows:

1. Upper Jurassic and Lower Cretaceous phenoclast suites in Dorset indicate the timing and extent of uplift on the South Dorset High and of rifting in the Central Channel Basin. Pre-uplift (pre-rift), syn-rift and post-rift phenoclast suites are preserved in the area.

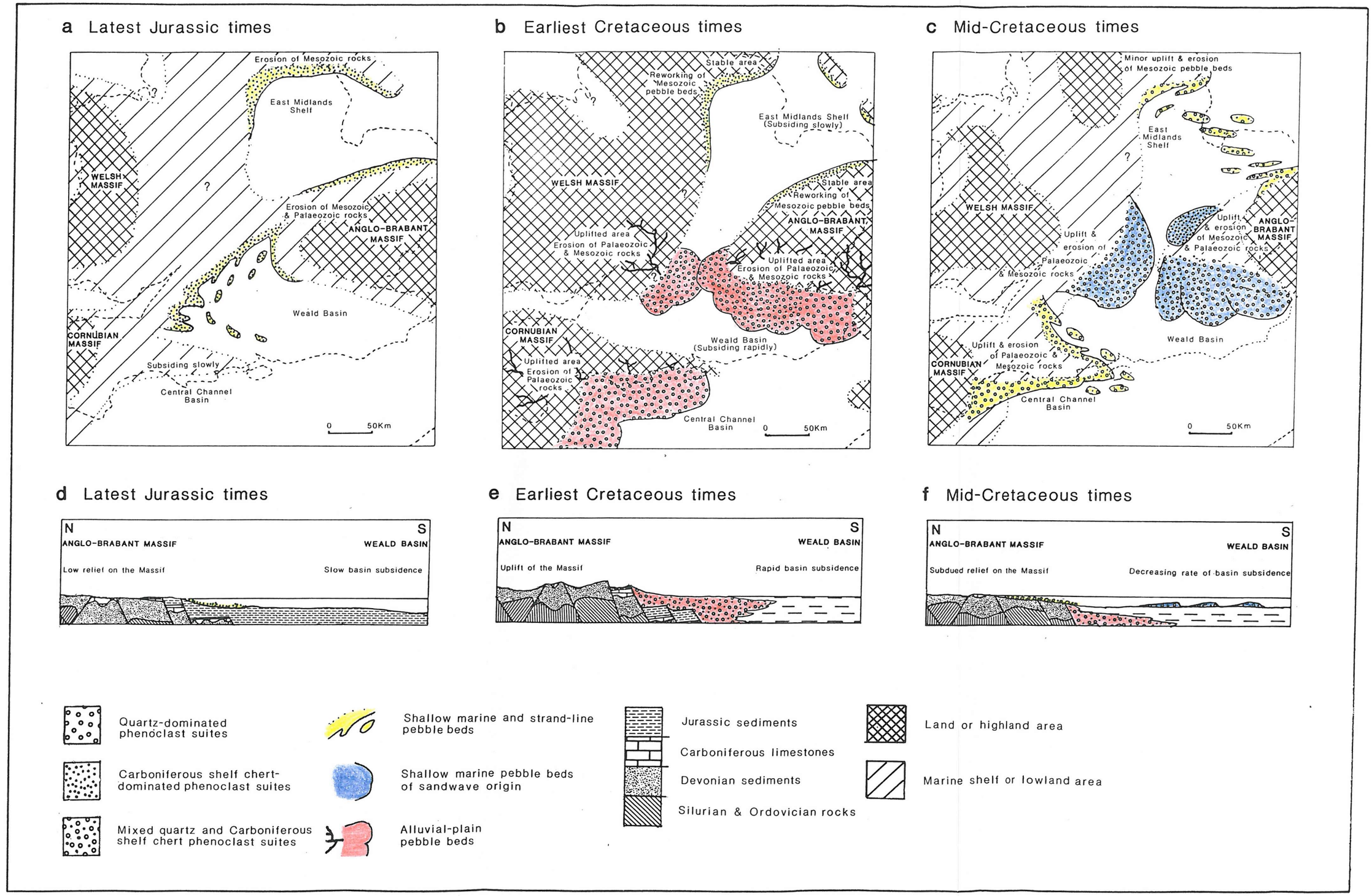


Figure 6.10 Hypothetical palaeogeographical maps (a,b,c) and cross-sections of the southern margin of the Anglo-Brabant Massif (d,e,f), showing the change in phenoclast suite compositions from latest Jurassic to mid-Cretaceous times resulting from basin rifting and associated uplift of the massif areas. Note that the maps and sections are an attempt to depict the general distribution of pebbly facies. Based on this study and previous work referred to in figures 6.5 to 6.9.

a. The pre-Late Jurassic uplift (pre-rift) phenoclast suite of the Corallian Group is composed principally of extrabasinal detritus derived from the north.

b. The syn-rift phenoclast suites of the Purbeck and Wessex Formations contain intrabasinal clasts derived from local pre-uplift sources and an extrabasinal suite derived from the west. The uplifted South Dorset High supplied the intrabasinal clasts and inhibited the transportation of northern extrabasinal detritus into the area.

c. The post-rift phenoclast suite of the basal Gault Clay Formation contains intrabasinal clasts from both pre-uplift and syn-rift sources and extrabasinal detritus from the west. The South Dorset High continued to form a barrier to the southward transportation of coarse-grained detritus.

The intrabasinal clasts in the early, syn-rift suites indicate that at least 100m and possibly 400m of uplift of the South Dorset High occurred during earliest Cretaceous times.

2. Three mid-Cretaceous petrographic provinces are recognised from the composition of the phenoclast suites: Dorset; Normandy; and Central and Southeastern England.

a. The Dorset Province is dominated by detritus from the Cornubian Massif, but contains minor amounts of Armorican detritus.
b. The Normandy Province contains detritus derived from the west, principally from the Cotentin High.
c. The Central and Southeastern English Province includes detritus derived from the Anglo-Brabant and Welsh Massifs, with a possible limited contribution from the Pennine High. This province is divisible into five subprovinces:
   i. the Isle of Wight subprovince is dominated by pebble-grade detritus from the margins of the Welsh Massif and with minor quantities of southwestern detritus.
   ii. the Wiltshire and Oxfordshire subprovince contains detritus predominantly from the margins of the Welsh Massif and includes little southwestern detritus.
   iii. the Weald subprovince contains detritus derived

principally from the Anglo-Brabant Massif, but with minor amounts of detritus derived from the Welsh Massif in the southwest Weald. Lateral variations in petrographic suites result from the direction of sediment-transportation and the palaeogeology of the source massif.

iv. the Cambridgeshire and Bedfordshire subprovince contains coarse-grained detritus derived mainly from older Cretaceous or Upper Jurassic pebble beds on the northern margin of the Anglo-Brabant Massif.

v. the East Midlands subprovince contains detritus derived from the Anglo-Brabant Massif to the south and the Market Weighton High to the north.

3. A change from assemblages dominated by Carboniferous cherts to those dominated by quartz occurs in southern Britain. This change took place during Early Cretaceous times in central-southern England, but did not occur before mid-Cretaceous times in the East Midlands of England. The change in detrital provenance resulted from the relative uplift of the Cornubian, Welsh and Anglo-Brabant Massifs during basin-rifting and a regional marine regression. The Early Cretaceous inversion of the Sole Pit area and reworking of intrabasinal pebble beds delayed the change in the composition of the pebble suites in the East Midlands.

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APPENDICES

THE PROVENANCE OF UPPER JURASSIC AND LOWER CRETACEOUS COARSE-GRAINED DETRITUS IN SOUTHERN ENGLAND AND NORMANDY

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APPENDIX I

PHENOCLAST SUITE COMPOSITIONS

APPENDIX I

PHENOCLAST SUITE COMPOSITIONS

Generalized modal compositions of the pebble suites have been calculated and are tabulated below. The associated sedimentary facies of the pebbly deposits are described in detail in Chapter II and National Grid references for the sample localities are given in Appendix III.

The samples analysed were mechanically sieved and the grain-sizes noted above the tables refer to clasts trapped in each sieve.

The phenoclasts were separated into compositional groups (see Chapter III). The modal composition was then calculated by either counting the number of clasts or by weighing the clasts in each group. Terms used in the tables are listed below;

FREQ = Frequency; the number of clasts in each group.
%FREQ = Percentage frequency; the modal percentage calculated from the frequency.
WEIGHT = Weight of clasts in each phenoclast group.
%WT = Percentage weight; the modal percentage calculated from the weight of each phenoclast group.
P = Present but less than 0.5%.

Percentages are given to the nearest whole figure for samples with 150 grains or less than 150 grains and to the nearest 0.5% for samples with greater than 150 grains. Total percentages may not add up to 100% because of rounding off.

The phenoclast groupings

QUARTZ

Opaque quartz: Polycrystalline quartz, normally white (Sect. 3.2.14.1).

Trans quartz: Polycyrstalline quartz, translucent or semi-translucent (Sect. 3.2.14.1).

Sheared quartz:	Polycrystalline quartz, with a deformed fabric (Sect. 3.2.14.3).
Pink quartz:	Polycrystalline quartz, normally pink or pinkish white (Sect. 3.2.14.1).
Dark quartz:	Polycrystalline quartz, normally dark grey (Sect. 3.2.14.1).
Fibrous quartz:	Polycrystalline quartz with elongate crystallites, normally white (Sect. 3.2.14.2).
Granular quartz:	Finely crystalline quartz (Sect. 3.2.14.1).
Quartz+chlorite:	Quartz with inclusions of chlorite (Sects. 3.2.14.1, 3.2.14.2).
Quartz+pyrite:	Quartz with inclusions of pyrite (Sects. 3.2.14.1, 3.2.14.2).
Veined quartz:	Polycrystalline quartz with thin quartz veins.

JURASSIC CHERTS

Pale undiff chert:	Weathered chert of indistinguishable type, but of probable Jurassic origin.
Pale bio:	Weathered chert with skeletal fragments (Sect. 3.2.1.1).
Pale ool:	Weathered chert with ooids (Sects. 3.2.1.2, 3.2.1.4).
Pale Rhax:	Weathered chert with Rhaxella spicules (Sect. 3.2.1.3).
Pale evap:	Weathered chert with spherulitic lutecite or pseudomorphs after evaporites (Sects. 3.2.3.1, 3.2.3.2, 3.2.3.3).
Pale sandy:	Weathered chert with sand grains (Sect. 3.2.1.6).
Pale spic:	Weathered chert with sponge spicules (Sect. 3.2.1.1).

CARBONIFEROUS SHELF CHERTS

Dark undiff chert:	Dark coloured chert of indistinguishable type (microcrystalline), but of probable Carboniferous origin.
Dark bio:	Dark coloured chert with crinoids, bryozoa, foraminifera and brachiopods (Sect. 3.2.1.8).
Dark ool:	Dark coloured chert with ooids (Sect. 3.2.1.9).
Dark dolo:	Dark coloured chert with rhombic pseudomorphs after dolomite (Sect. 3.2.1.10).

Dark lam:	Dark coloured laminated chert (Sect. 3.2.1.11).
Dark spic:	Dark coloured chert with hexaxon and monaxon spicules (Sect. 3.2.1.12).
Dark mottled:	Dark coloured chert with a peloidal texture (Sect. 3.2.1.13).
Dark intra:	Dark coloured chert with intraclasts and rare ooids (Sect. 3.2.1.13).
Dark pellet:	Dark coloured chert with pellets (Sect. 3.2.1.15).
Dark evap:	Dark coloured chert with lenticular or lath-shaped inclusions possibly after evaporite minerals (Sect. 3.2.3.4).
Dark brec:	Dark coloured brecciated chert.

SILICIFIED WOOD

Sili wood:	Silicified wood, source undifferentiated (Sect. 3.2.4.

SILICIFIED BIOCLASTS

Sili bio:	Silicified bioclasts, source undifferentiated. Most silicified clasts are probably from Carboniferous or Jurassic limestones (Sect. 3.2.5).

CULM CHERTS

Radio chert:	Silicified mudstones with radiolaria (Sect. 3.2.2).

SANDSTONES

Sst undiff:	Sandstone pebbles from undifferentiated sources (Sect. 3.2.8).
Quartzite:	Quartz arenite pebbles of probable sedimentary origin (Sects. 3.2.8.1, 3.2.8.4).
Pink quartzite:	Quartz arenite with red colouration (Sect. 3.2.8.1).
Mica sst:	Sandstone with laminae of mica (Sect. 3.2.8.3).
Red sst:	Red-coloured sandstone (Sect. 3.2.8.1, 3.2.8.2, 3.2.8.3).

Siltstone:	Siltstone from undifferentiated sources (Sect. 3.2.8.4).
Cherty sst:	Microcrystalline quartz-cemented sandstones (Sect. 3.2.1.6).
Glauc sst:	Glauconitic sandstones, commonly carbonate cemented (Sect. 3.2.7.2).

IRONSTONES

Ironstone:	Structureless microcrystalline goethite (Sect. 3.2.9.1).
Fe lam:	Microcrystalline goethite with concretionary or sedimentary lamination (Sect. 3.2.1.4).
Fe sst:	Quartz arenites with interstitial microcrystalline goethite (Sect. 3.2.9.5).
Fe ool:	Goethite ooids in microcrystalline goethite matrices (Sect. 3.2.9.2).
Fe bio:	Bioclast casts composed of microcrystalline goethite (Sect. 3.2.9.3).
Fe pellet:	Geothite peloids in microcrystalline goethite matrices (Sect. 3.2.9).

PHOSPHORITES

Phosphorite:	Homogeneous or mottled microcrystalline phosphorites (Sect. 3.2.10.1).
Phos sst:	Glauconitic sand in matrices of microcrystalline phosphate (Sect. 3.2.10.2).
Phos ool:	Ooids of phosphate in phosphate matrices (Sect. 3.2.10.3).
Phos bio:	Fossil casts composed of phosphate-cemented sand or microcrystalline phosphate (Sect. 3.2.10.4).
Phos pellet:	Phosphatic peloids in matrices of phosphate (Sect. 3.2.10).
Bone:	Bone and tooth fragments.

LIMESTONES

Lst undiff:	Limestone of indistinguishable type, but of probable Jurassic origin.
Lst bio g/p:	Bioclastic and oolitic grainstones or packstones (Sects. 3.2.7.3, 3.2.7.4).

Lst bio w/m:	Micritic limestones with bioclasts (Sect. 3.2.7.1).
Lst sst:	Glauconitic and quartzose arenites with matrices of micrite or microspar (Sect. 3.2.7.2).

TOURMALINITES

Qtz+tourm:	Granoblastic quartz with tourmaline (Sects. 3.2.11.1, 3.2.11.2).
Foli tourm:	Foliated tourmaline and microcrystalline quartz (Sects. 3.2.11.2, 3.2.11.3).
Tourm brec:	Pneumatolytic breccia (Sect. 3.2.11.4).

OTHERS

Mylonite:	Mylonites (Sect. 3.2.14.3).
Mylo/cata:	Mylonites or cataclasites (Sect. 3.2.14.3).
Jasper:	Jaspers; red cherts not included in the groups defined above (Sect. 3.2.15).
Sili volc:	Silicified volcanic clasts; foliated and argillic microcrystalline quartz (Sect. 3.2.13).
Quartz veined cht:	Microcrystalline quartz with quartz veins.

Total:	Number of clasts counted or the total weight of all the clasts counted.

Q:C index:	Quartz:Chert index (Sect. 4.1).
Q:S index:	Quartz:Sandstone index (Sect. 4.1).
S:C index:	Sandstone:Chert index (Sect. 4.1).
I:P index:	Ironstone:Phosphorite index (Sect. 4.1).
Dolo-index:	Dolomitic chert index (Sect. 4.1).
Bio-index:	Bioclastic chert index (Sect. 4.1).

Pebble beds sampled from Dorset

LOCALITY: Redcliff, Dorset.
SAMPLE NUMBER: 219pg1
HORIZON: Preston Grit Member, Corallian Group.

Table i.i

GRAIN-SIZE	<-1.0 ø	
LITHOTYPE	FREQ	%FREQ
Opaque quartz	3	7
Pink quartz	1	2
Dark undiff chert	4	9
Dark bio	10	23
Dark dolo	7	16
Dark lam	6	14
Dark mottled	8	18
Dark pellet	2	5
Mylo/cata	1	2
Jasper	1	2
Sili volc	1	2
Total	44	

LOCALITY: Redcliff, Dorset.
SAMPLE NUMBER: 219pg2
HORIZON: Preston Grit Member, Corallian Group.

Table i.ii

GRAIN-SIZE	-1.5 ø		-1.0 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	3	19	16	20
Trans quartz	0	0	20	24
Pink quartz	2	13	1	1
Dark undiff chert	2	13	9	11
Dark bio	3	19	5	6
Dark dolo	2	13	14	17
Dark lam	1	6	2	2
Dark spic	1	6	1	1
Dark mottled	1	6	5	6
Dark evap	0	0	3	4
Sst undiff	0	0	1	1
Siltstone	1	6	0	0
Phosphorite	0	0	1	1
Sili volc	0	0	2	2
Jasper	0	0	2	2
Total	16		82	

LOCALITY: Harden's Quarry, Acton, Dorset.
SAMPLE NUMBER: 253mp22/1
HORIZON: Intermarine Member, Purbeck Formation.

Table i.iii

GRAIN-SIZE	<-1.0 ø	
LITHOTYPE	FREQ	%FREQ
Opaque quartz	4	8
Dark undiff chert	9	18
Dark bio	3	6
Dark ool	1	2
Dark dolo	8	16
Dark lam	7	14
Dark spic	4	8
Dark mottled	6	12
Dark pellet	2	4
Dark evap	1	2
Sst undiff	3	6
Sili volc	3	6
Total	51	

LOCALITY: Durdle Door promontory east, Dorset.
SAMPLE NUMBER: 2cqg3
HORIZON: Coarse Quartz Grit, Wessex Formation.

Table i.iv

GRAIN-SIZE	-3.5 ø		-2.75 ø		-2.5 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	15.8	72	116.1	63	44.6	65
Trans quartz	6.0	28	5.3	3	3.3	5
Pink quartz	0.0	0	3.4	2	1.4	2
Fibrous quartz	0.0	0	19.4	11	2.2	3
Radio chert	0.0	0	19.4	11	10.4	15
Sst undiff	0.0	0	3.7	2	0.0	0
Qtz+tourm	0.0	0	16.5	9	6.2	9
Foli tourm	0.0	0	0.0	0	0.0	0
Jasper	0.0	0	0.0	0	0.5	1
Sili volc	0.0	0	0.0	0	0.0	0
Total	21.8		183.8		68.6	
Q:S index		-		97		-

Table i.v

GRAIN-SIZE	<-3.5 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	101.0	60
Trans quartz	23.7	14
Pink quartz	2.3	1
Fibrous quartz	2.5	1
Radio chert	17.9	11
Sst undiff	0.1	P
Qtz+tourm	19.4	12
Foli tourm	0.4	P
Sili volc	0.1	P
Total	167.4	
Q:S index		100

LOCALITY: Stair Hole, Dorset.
SAMPLE NUMBER: 54cqg1
HORIZON: Coarse Quartz Grit, Wessex Formation.

Table i.vi

GRAIN-SIZE	<-2.75 ø		-2.75 ø		-2.5 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	0	0	84	61	155	60.0
Trans quartz	0	0	6	4	38	14.5
Fibrous quartz	0	0	9	7	17	6.5
Pale undiff chert	0	0	2	1	0	0.0
Radio chert	1	50	13	9	25	9.5
Sst undiff	1	50	9	7	7	2.5
Qtz+tourm	0	0	12	9	8	3.0
Foli tourm	0	0	3	2	9	3.5
Total	2		138		259	
Q:S index		-		92		97

Table i.vii

GRAIN-SIZE	-2.0 ø		-1.5 ø		-1.0 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	265	48.0	159	40.5	138	32.0
Trans quartz	176	32.0	176	45.0	250	58.0
Pink quartz	4	0.5	0	0.0	1	P
Fibrous quartz	8	1.5	0	0.0	0	0.0
Radio chert	48	8.5	32	8.0	21	5.0
Sst undiff	4	0.5	6	1.5	1	P
Qtz+tourm	31	5.5	20	5.0	19	4.5
Foli tourm	13	2.5	0	0.0	0	0.0
Jasper	1	P	0	0.0	0	0.0
Total	550		393		430	
Q:S index		99		98		100

LOCALITY: Lulworth Cove east, Dorset.
SAMPLE NUMBER: 97cqg2
HORIZON: Coarse Quartz Grit, Wessex Formation.

Table i.viii

GRAIN-SIZE	-3.5 ø		-2.75 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	17.1	28	142.6	59
Trans quartz	8.0	13	13.0	5
Fibrous quartz	6.2	10	20.1	8
Radio chert	15.0	25	31.6	13
Quartzite	0.0	0	2.3	1
Qtz+tourm	14.3	24	27.6	11
Foli tourm	0.0	0	5.7	2
Total	60.6		242.9	
Q:S index		<1		99

Table i.ix

GRAIN-SIZE	-2.5 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	50.6	52	99.3	54
Trans quartz	10.7	11	23.6	13
Pink quartz	2.0	2	3.0	2
Fibrous quartz	3.0	3	3.3	2
Radio chert	10.0	10	18.1	10
Sst undiff	1.6	2	0.5	P
Qtz+tourm	13.6	14	26.9	15
Foli tourm	5.1	5	10.5	6
Total	96.6		185.2	
Q:S index		97		99

LOCALITY: Lulworth Cove east, Dorset.
SAMPLE NUMBER: 97cqg4
HORIZON: Coarse Quartz Grit, Wessex Formation.

Table i.x

GRAIN-SIZE	-3.5 ø		-2.75 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	22.3	49	61.6	56
Trans quartz	0.0	0	9.2	8
Pink quartz	0.0	0	0.9	1
Fibrous quartz	18.0	39	10.9	10
Pale undiff chert	0.0	0	1.3	1
Radio chert	3.0	7	13.9	13
Sst undiff	2.4	5	0.7	1
Qtz+tourm	0.0	0	10.1	9
Foli tourm	0.0	0	0.9	1
Jasper	0.0	0	0.9	1
Total	45.7		110.4	
Q:S index		-		89

Table i.xi

GRAIN-SIZE	-2.5 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	18.3	53	41.5	49
Trans quartz	6.1	18	20.1	24
Pink quartz	0.2	1	2.0	2
Fibrous quartz	0.7	2	3.3	4
Pale undiff chert	0.0	0	0.2	P
Radio chert	5.4	16	10.4	12
Sst undiff	0.0	0	0.1	P
Qtz+tourm	3.6	10	5.2	6
Foli tourm	0.0	0	1.2	1
Jasper	0.0	0	0.8	1
Total	34.3		84.8	
Q:S index		-		100

LOCALITY: Mupe Bay, Dorset.
SAMPLE NUMBER: 5cqg3
HORIZON: Coarse Quartz Grit, Wessex Formation.

Table i.xii

GRAIN-SIZE	-3.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	2	33	17.4	47
Radio chert	1	17	3.0	8
Sst undiff	3	50	16.3	44
Total	6		36.7	

Table i.xiii

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	159	72.0	93.4	70.0
Trans quartz	2	1.0	1.4	1.0
Fibrous quartz	11	5.0	8.1	6.0
Dark undiff chert	18	8.0	10.4	8.0
Sst undiff	5	2.5	2.3	1.5
Qtz+tourm	25	11.5	17.0	12.5
Foli tourm	1	0.5	1.3	1.0
Total	221		133.9	
Q:S index		97		98

Table i.xiv

GRAIN-SIZE	-3.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	48	69	59.5	66
Fibrous quartz	6	9	9.1	10
Dark undiff chert	5	7	6.4	7
Dark dolo	2	3	3.5	4
Sst undiff	4	6	5.5	6
Qtz+tourm	3	4	3.3	4
Foli tourm	2	3	2.3	3
Total	70		89.6	

LOCALITY: Worbarrow Bay, Dorset.
SAMPLE NUMBER: 6cqg3
HORIZON: Coarse Quartz Grit, Wessex Formation.

Table i.xv

GRAIN-SIZE	-3.5 ø		-3.0 ø			
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	4	67	74	75	94.6	75
Fibrous quartz	0	0	5	5	6.5	5
Veined quartz	0	0	3	3	3.1	2
Quartz+chlorite	1	17	0	0	0.0	0
Pale undiff chert	1	17	0	0	0.0	0
Pale Rhax	0	0	1	1	1.2	1
Dark undiff chert	0	0	1	1	2.1	2
Dark dolo	0	0	2	2	1.8	1
Dark lam	0	0	2	2	4.6	4
Radio chert	0	0	3	3	3.6	3
Sst undiff	0	0	2	2	2.1	2
Qtz+tourm	0	0	4	4	4.9	4
Foli tourm	0	0	1	1	1.1	1
Sili volc	0	0	1	1	1.0	1
Total	6		99		126.6	
Q:S Index		-		98		98

LOCALITY: Golden Cap, Charmouth, Dorset.
SAMPLE NUMBER: 17g1
HORIZON: Gault Clay Formation.

Table i.xvi

GRAIN-SIZE	<-2.75 ø		-2.0 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	8	67	71	73
Radio chert	1	8	9	9
Sst undiff	0	0	1	1
Quartzite	3	25	10	10
Qtz+tourm	0	0	6	6
Total	12		97	
Q:S Index		-		87

LOCALITY: Golden Cap, Charmouth, Dorset.
SAMPLE NUMBER: 17g2
HORIZON: Gault Clay Formation.

Table i.xvii

GRAIN-SIZE	<-2.75 ø		-2.0 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	7	70	30	71
Radio chert	2	20	4	10
Sst undiff	0	0	1	2
Quartzite	1	10	5	12
Qtz+tourm	0	0	2	5
Total	10		42	

LOCALITY: Golden Cap, Charmouth, Dorset.
SAMPLE NUMBER: 17g3
HORIZON: Gault Clay Formation.

Table i.xviii

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	FREQ	%FREQ
Opaque quartz	78	75
Radio chert	4	4
Sst undiff	1	1
Quartzite	12	12
Qtz+tourm	9	9
Total	104	
Q:C index		86

LOCALITY: Golden Cap, Charmouth, Dorset.
SAMPLE NUMBER: 17g4
HORIZON: Gault Clay Formation.

Table i.xix

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	FREQ	%FREQ
Opaque quartz	104	70
Radio chert	9	6
Sst undiff	2	1
Quartzite	27	18
Qtz+tourm	7	5
Total	149	
Q:C index		79

LOCALITY: Holworth House, Dorset.
SAMPLE NUMBER: 99g1
HORIZON: Gault Clay Formation.

Table i.xx

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	21.7	1
Pale undiff chert	2021.5	92
Radio chert	87.7	4
Quartzite	43.7	2
Ironstone	21.0	1
Total	2195.6	

LOCALITY: Durdle Door promontory west, Dorset.
SAMPLE NUMBER: 3g1
HORIZON: Gault Clay Formation.

Table i.xxi

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	41	62
Pale undiff chert	21	32
Radio chert	1	2
Sst undiff	2	3
Ironstone	1	2
Total	66	

LOCALITY: Durdle Door promontory west, Dorset.
SAMPLE NUMBER: 3g2
HORIZON: Gault Clay Formation.

Table i.xxii

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	14	58
Pale undiff chert	7	29
Radio chert	3	13
Total	24	

LOCALITY: Durdle Door promontory west, Dorset.
SAMPLE NUMBER: 3g3
HORIZON: Gault Clay Formation.

Table i.xxiii

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	8	38
Pale undiff chert	9	43
Radio chert	2	10
Sst undiff	2	10
Total	21	

LOCALITY: Durdle Door promontory west, Dorset.
SAMPLE NUMBER: 3g4
HORIZON: Gault Clay Formation.

Table i.xxiv

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	18	62
Pale undiff chert	4	14
Radio chert	4	14
Sst undiff	3	10
Total	29	

LOCALITY: Durdle Door promontory west, Dorset.
SAMPLE NUMBER: 3gS
HORIZON: Gault Clay Formation.

Table i.xxv

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	223.5	6.5
Pale ool	454.3	13.0
Pale bio	139.0	4.0
Pale Rhax	2461.7	70.5
Dark undiff chert	79.8	2.5
Sst undiff	18.9	0.5
Quartzite	47.0	1.5
Ironstone	20.0	0.5
Qtz+tourm	37.1	1.0
Foli tourm	7.5	P
Total	3488.8	
Q:S index		77

LOCALITY: St. Oswald's Bay east, Dorset.
SAMPLE NUMBER: 1g3
HORIZON: Gault Clay Formation.

Table i.xxvi

GRAIN-SIZE	< -2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	65.4	5
Trans quartz	43.3	3
Pink quartz	10.4	1
Fibrous quartz	6.3	P
Pale bio	7.1	1
Pale ool	812.0	64
Pale Rhax	24.3	2
Radio chert	50.5	4
Sst undiff	180.2	14
Quartzite	24.1	2
Phosphorite	26.1	2
Qtz+tourm	11.1	1
Foli tourm	6.0	P
Total	1266.8	
Q:S index		77

Pebble beds sampled from the Isle of Wight

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12fs2
HORIZON: Ferruginous Sands Formation, 25m beneath the base of the Sandrock Formation.

Table i.xxvii

GRAIN-SIZE	-3.5 ø		-2.75 ø		-2.5 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Sili bio	0.0	0	0.3	1	0.0	0
Ironstone	15.0	59	11.0	35	1.5	43
Phosphorite	10.3	41	20.1	64	2.0	57
Total	25.3		31.4		3.5	

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12fs4
HORIZON: Pebble bed RC1, Ferruginous Sands Formation, 16m beneath the base of the Sandrock Formation.

Table i.xxviii

GRAIN-SIZE	-3.5 ø		-2.75 ø		-2.5 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	11.5	9	18.2	12.0	1.1	7
Trans quartz	0.0	0	2.2	1.5	0.0	0
Fibrous quartz	0.0	0	1.3	1.0	0.0	0
Pale evap	5.9	5	3.2	2.0	0.2	1
Dark undiff chert	2.1	2	1.4	1.0	0.0	0
Dark bio	7.6	6	4.1	2.5	0.0	0
Ironstone	16.8	13	68.5	44.5	10.3	65
Fe sst	0.0	0	3.1	2.0	0.0	0
Phosphorite	82.0	65	51.2	33.5	4.2	27
Total	125.9		153.2		15.8	
Q:C index		-		80		-

Table i.xxix

GRAIN-SIZE	-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	0.4	2
Trans quartz	0.3	2
Pale evap	0.6	3
Ironstone	13.2	68
Phosphorite	5.0	26
Total	19.5	

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12fs5
HORIZON: Pebble bed RC2, Ferruginous Sands Formation, 15m beneath the base of the Sandrock Formation.

Table i.xxx

GRAIN-SIZE	-5.5 ø		-4.5 ø		-3.5 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Pale evap	0.0	0	78.9	29	0.0	0
Dark undiff chert	0.0	0	0.0	0	3.1	0.5
Ironstone	202.8	100	68.1	25	130.6	29.5
Fe sst	0.0	0	0.0	0	10.2	2.5
Phosphorite	0.0	0	79.6	29	298.9	67.5
Mylonite	0.0	0	48.3	18	0.0	0.0
Total	202.8		274.9		442.8	

Table i.xxxi

GRAIN-SIZE	-2.75 ø		-2.5 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	0.7	1	0.0	0	0.0	0
Trans quartz	0.0	0	0.0	0	0.2	1
Dark dolo	0.0	0	0.0	0	0.1	1
Dark mottled	0.0	0	0.0	0	0.1	1
Ironstone	37.5	39	0.0	0	11.3	72
Fe sst	4.2	4	3.4	50	0.4	3
Phosphorite	48.8	50	2.9	43	3.6	23
Bone	5.5	6	0.5	7	0.0	0
Total	96.7		6.8		15.7	

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12fs6
HORIZON: Pebble bed RC3, Ferruginous Sands Formation, 11m beneath the base of the Sandrock Formation.

Table i.xxxii

GRAIN-SIZE	-3.5 ø		-2.75 ø		-2.5 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	0.0	0	0.5	1	0.0	0
Dark dolo	0.0	0	1.2	2	0.0	0
Ironstone	199.4	100	36.1	67	11.2	90
Phosphorite	0.6	P	16.3	30	1.3	10
Total	200.0		54.1		12.5	

Table i.xxxiii

GRAIN-SIZE	-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	0.5	P
Dark dolo	1.2	0.5
Ironstone	258.1	92.0
Phosphorite	20.3	7.0
Total	280.1	

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12fs7
HORIZON: Pebble bed RC4, Ferruginous Sands Formation, 10m beneath the base of the Sandrock Formation.

Table i.xxxiv

GRAIN-SIZE	-2.75 ø		-2.5 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	2.0	5	0.9	2	0.0	0
Trans quartz	0.0	0	0.8	2	0.0	0
Dark chert undiff	0.9	2	0.0	0	0.0	0
Dark bio	0.0	0	0.6	1	0.0	0
Dark ool	0.0	0	0.6	1	0.0	0
Ironstone	13.1	34	22.1	54	105.9	72
Fe sst	0.9	2	1.0	2	0.0	0
Phosphorite	21.2	54	15.2	37	40.6	28
Phos sst	0.9	2	0.0	0	0.9	1
Total	39.0		41.2		147.4	

LOCALITY: Compton Bay, Isle of Wight.
SAMPLE NUMBER: 10sr6/1
HORIZON: Pebble bed CB5, Sandrock Formation, 5m beneath the base of the Carstone Member.

Table i.xxxv

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	85	47.0	46.8	44.5
Trans quartz	8	4.5	4.5	4.5
Sheared quartz	3	1.5	2.5	2.5
Pink quartz	1	0.5	0.4	0.5
Dark quartz	1	0.5	0.5	0.5
Fibrous quartz	3	1.5	1.7	1.5
Granular quartz	10	5.5	5.1	5.0
Dark undiff chert	10	5.5	6.4	6.0
Dark bio	24	13.0	12.9	12.0
Dark ool	1	0.5	0.6	0.5
Dark dolo	3	1.5	1.6	1.5
Dark lam	2	1.0	1.0	1.0
Dark spic	5	3.0	4.6	4.5
Dark mottled	3	1.5	1.8	1.5
Dark intra	3	1.5	2.0	2.0
Dark evap	1	0.5	0.7	0.5
Radio chert	1	0.5	0.5	0.5
Sst undiff	10	5.5	7.7	7.5
Siltstone	1	0.5	0.7	0.5
Qtz+tourm	3	1.5	2.1	2.0
Sili volc	2	1.0	1.3	1.2
Total	180		105.4	
Q:C index		68		66
Q:S index		91		88
S:C index		17		21
Dolo-index		6		5
Bio-index		46		41

LOCALITY: Compton Bay, Isle of Wight.
SAMPLE NUMBER: 10sr6/2
HORIZON: Pebble bed CB5, Sandrock Formation, 5m beneath the base of the Carstone Member.

Table i.xxxvi

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	13	2.7	10
Dark bio	2	25	4.4	16
Dark dolo	1	13	3.8	14
Dark lam	3	38	12.4	47
Sst undiff	1	13	3.6	13
Total	8		26.9	

Table i.xxxvii

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	4	8	5.9	10
Sheared quartz	3	6	4.4	7
Dark quartz	1	2	1.2	2
Fibrous quartz	1	2	1.8	3
Dark undiff chert	4	8	4.6	7
Dark bio	14	29	20.0	32
Dark ool	1	2	0.5	1
Dark dolo	1	2	2.0	3
Dark lam	9	19	9.4	15
Dark mottled	2	4	1.9	3
Dark intra	2	4	2.4	4
Sst undiff	3	6	4.6	7
Fe sst	1	2	0.8	1
Qtz+tourm	1	2	1.6	3
Sili volc	1	2	0.8	1
Total	48		61.9	

Table i.xxxviii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	98	57.5	61.5	60.0
Trans quartz	4	2.5	2.4	2.5
Sheared quartz	4	2.5	2.1	2.0
Pink quartz	1	0.5	0.3	0.5
Dark quartz	1	0.5	0.5	0.5
Fibrous quartz	2	1.0	1.5	1.5
Granular quartz	3	2.0	1.5	1.5
Pale undiff chert	3	2.0	0.8	1.0
Dark undiff chert	6	3.5	3.0	3.0
Dark bio	20	12.0	12.2	12.0
Dark ool	2	1.0	1.2	1.0
Dark dolo	6	3.5	3.4	3.5
Dark lam	2	1.0	1.1	1.0
Dark spic	4	2.5	1.7	1.5
Dark mottled	4	2.5	2.4	2.5
Dark intra	1	0.5	0.4	0.5
Dark pellet	1	0.5	1.1	1.0
Sst undiff	5	3.0	4.0	4.0
Fe sst	1	0.5	0.4	0.5
Qtz+tourm	1	0.5	0.5	0.5
Jasper	1	0.5	0.5	0.5
Total	170		102.5	
Q:C index		71		72
Q:S index		96		95
S:C index		10		13
Dolo-index		13		13
Bio-index		43		46

Table i.xxxix

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	96	54.0	37.0	56.0
Trans quartz	15	8.5	4.9	7.5
Pink quartz	1	0.5	0.5	1.0
Sheared quartz	5	3.0	1.9	3.0
Fibrous quartz	1	0.5	0.5	1.0
Granular quartz	13	7.5	5.2	8.0
Pale undiff chert	1	0.5	1.5	2.5
Dark undiff chert	4	2.0	1.5	2.5
Dark bio	9	5.0	3.3	5.0
Dark dolo	8	4.5	2.2	3.5
Dark lam	6	3.5	2.1	3.0
Dark spic	1	0.5	0.4	0.5
Dark mottled	7	4.0	2.1	3.0
Dark pellet	1	0.5	0.4	0.5
Sst undiff	6	3.5	1.3	2.0
Fe sst	1	0.5	0.3	0.5
Sili volc	3	1.5	1.1	1.5
Total	178		66.2	
Q:C index		78		81
Q:S index		96		97
S:C index		14		10
Dolo-index		22		19
Bio-index		25		28

Table i.xl

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	578	63.5	115.3	66.5
Trans quartz	108	12.0	17.8	10.0
Pink quartz	18	2.0	3.6	2.0
Sheared quartz	12	1.5	2.0	1.0
Dark quartz	2	P	0.3	P
Fibrous quartz	13	1.5	2.7	1.5
Granular quartz	30	3.5	5.3	3.0
Dark undiff chert	29	3.0	5.6	3.0
Dark bio	35	4.0	5.2	3.0
Dark ool	4	0.5	1.0	0.5
Dark dolo	27	3.0	5.3	3.0
Dark lam	10	1.0	1.9	1.0
Dark mottled	7	1.0	1.3	1.0
Dark pellet	3	0.5	0.7	0.5
Sst undiff	12	1.5	2.5	1.5
Fe sst	6	1.0	0.8	0.5
Qtz+tourm	10	1.0	2.0	1.0
Sili volc	3	0.5	0.5	0.5
Total	907		173.8	
Q:C index		87		88
Q:S index		98		98
S:C index		9		11
Dolo-index		23		25
Bio-index		30		25

LOCALITY: Compton Bay, Isle of Wight.
SAMPLE NUMBER: 10sr6/3
HORIZON: Pebble bed CB5, Sandrock Formation, 5m beneath the base of the Carstone Member.

Table i.xli

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	10	26	13.1	26
Sheared quartz	1	3	2.2	4
Pink quartz	1	3	2.1	4
Fibrous quartz	1	3	1.0	2
Granular quartz	2	5	2.8	6
Pale bio	1	3	0.6	1
Dark undiff chert	1	3	0.6	1
Dark bio	6	15	6.6	13
Dark dolo	7	18	9.8	20
Dark lam	1	3	1.5	3
Dark spic	4	10	4.2	8
Dark mottled	3	8	4.2	8
Sili volc	1	3	0.8	2
Total	39		49.5	

Table i.xlii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	100	55.5	56.1	55.0
Trans quartz	5	3.0	2.8	3.0
Sheared quartz	2	1.0	0.9	1.0
Pink quartz	2	1.0	1.5	1.5
Dark quartz	4	2.0	2.0	2.0
Fibrous quartz	2	1.0	1.2	1.0
Granular quartz	5	3.0	2.7	2.5
Pale undiff chert	2	1.0	1.3	1.5
Dark undiff chert	3	1.5	1.3	1.5
Dark bio	17	9.5	9.6	9.5
Dark ool	3	1.5	2.1	2.0
Dark dolo	6	3.5	2.6	2.5
Dark lam	7	4.0	4.1	4.0
Dark spic	6	3.5	3.6	3.5
Dark mottled	5	3.0	2.5	2.5
Dark intra	1	0.5	0.6	0.5
Dark pellet	2	1.0	1.2	1.0
Sst undiff	2	1.0	1.9	2.0
Fe sst	1	0.5	0.4	0.5
Sili volc	5	3.0	3.5	3.5
Total	180		101.9	
Q:C index		71		71
Q:S index		98		97
S:C index		4		6
Dolo-index		12		9
Bio-index		34		35

LOCALITY: Compton Bay, Isle of Wight.
SAMPLE NUMBER: 10sr13
HORIZON: Pebble bed CB4, Sandrock Formation, 33m beneath the base of the Carstone Member.

Table i.xliii

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	3	50	8.6	38
Pale undiff chert	1	17	4.0	18
Sst undiff	1	17	4.0	18
Qtz+tourm	1	17	6.1	27
Total	6		22.7	

Table i.xliv

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	47	72	58.7	71
Trans quartz	4	6	5.3	6
Pink quartz	1	2	2.0	2
Fibrous quartz	2	3	2.1	3
Pale undiff chert	1	2	1.3	2
Dark bio	2	3	2.2	3
Radio chert	1	2	1.9	2
Sst undiff	5	8	7.4	9
Qtz+tourm	2	3	2.2	3
Total	65		83.1	

Table i.xlv

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	244	82.5	154.7	81.5
Trans quartz	16	5.5	10.1	5.5
Pink quartz	1	0.5	0.6	0.5
Fibrous quartz	5	1.5	3.7	2.0
Pale undiff chert	1	0.5	0.7	0.5
Dark undiff chert	3	1.0	2.5	1.5
Dark dolo	1	0.5	0.5	0.5
Dark lam	1	0.5	1.1	0.5
Sst undiff	22	7.5	14.8	8.0
Qtz+tourm	1	0.5	0.8	0.5
Total	295		189.5	
Q:C index		98		98
Q:S index		92		92
S:C index		81		78
Dolo-index		20		12

Table i.xlvi

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	136	77.5	50.0	75.0
Trans quartz	25	14.0	10.3	15.5
Pink quartz	2	1.0	0.8	1.0
Fibrous quartz	7	4.0	3.0	4.5
Dark undiff chert	4	2.5	1.8	2.5
Dark mottled	1	0.5	0.4	0.5
Sili volc	1	0.5	0.3	0.5
Total	176		66.6	
Q:C index		97		97

Table i.xlvii

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	211	82.5	44.3	72.5
Trans quartz	23	9.0	8.3	13.5
Fibrous quartz	4	1.5	1.4	2.5
Pale undiff chert	5	2.0	0.3	0.5
Dark undiff chert	1	0.5	1.3	2.0
Sst undiff	7	2.5	3.3	5.5
Qtz+tourm	4	1.5	2.0	3.5
Total	255		60.9	
Q:C index		100		98
Q:S index		97		94
S:C index		88		72

LOCALITY: Compton Bay, Isle of Wight.
SAMPLE NUMBER: 10sr10/6
HORIZON: Pebble bed CB5, Sandrock Formation, 5m beneath the base of the Carstone Member.

Table i.xlviii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	82	45.5	44.6	43.0
Trans quartz	11	6.0	5.5	5.5
Sheared quartz	2	1.0	1.2	1.0
Pink quartz	1	0.5	0.4	0.5
Dark quartz	1	0.5	0.5	0.5
Fibrous quartz	3	1.5	1.7	1.5
Granular quartz	10	5.5	5.1	5.0
Dark undiff chert	10	5.5	6.4	6.0
Dark bio	24	13.5	12.9	12.5
Dark ool	1	0.5	0.6	1.0
Dark dolo	3	1.5	1.6	1.5
Dark lam	2	1.0	1.0	1.0
Dark spic	5	3.0	4.6	4.5
Dark mottled	3	1.5	1.8	1.5
Dark intra	3	1.5	2.0	2.0
Dark pellet	1	0.5	0.7	0.5
Radio chert	1	0.5	0.5	0.5
Sst undiff	5	3.0	4.4	4.0
Quartzite	5	3.0	3.3	3.0
Siltstone	1	0.5	0.7	0.5
Qtz+tourm	3	1.5	2.1	2.0
Mylo/cata	1	0.5	1.3	1.0
Sili volc	2	1.0	1.3	1.0
Total	180		104.2	
Q:C index		68		65
Q:S index		91		88
S:C index		17		21
Dolo-index		6		5
Bio-index		46		41

LOCALITY: Coombe Farm , Isle of Wight.
SAMPLE NUMBER: 50sr1
HORIZON: Pebble bed CF1, Sandrock Formation, 9m beneath the base of the Carstone Member.

Table i.il

GRAIN-SIZE		-4.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	20	9.2	27
Pale undiff chert	2	40	12.7	38
Dark undiff chert	2	40	11.7	35
Total	5		33.6	

Table i.l

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	3	9	6.5	7
Dark undiff chert	8	25	21.9	24
Dark bio	6	19	12.0	13
Dark dolo	1	3	2.8	3
Dark lam	1	3	2.9	3
Dark spic	5	16	12.1	13
Dark mottled	3	9	11.8	13
Radio chert	1	3	3.2	4
Sst undiff	4	13	17.9	20
Total	32		91.1	

Table i.li

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	32	36	44.4	37
Trans quartz	2	2	2.4	2
Fibrous quartz	2	2	2.3	2
Dark undiff chert	22	24	29.0	24
Dark bio	14	16	16.6	14
Dark dolo	6	7	9.6	8
Dark lam	1	1	1.2	1
Dark spic	3	3	2.6	2
Dark mottled	3	3	3.7	3
Sst undiff	5	6	7.1	6
Total	90		118.9	

Table i.lii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	68	57	49.3	58
Trans quartz	10	8	7.2	8
Sheared quartz	2	2	2.0	2
Pink quartz	1	1	1.3	2
Fibrous quartz	1	1	1.2	1
Dark undiff chert	16	13	9.5	11
Dark bio	10	8	5.4	6
Dark dolo	3	2	1.7	2
Dark lam	1	1	1.0	1
Dark spic	3	2	2.4	3
Dark mottled	1	1	0.7	1
Radio chert	3	2	2.3	3
Sst undiff	1	1	0.9	1
Total	120		84.9	
Q:C index		71		75
Q:S index		99		99
S:C index		3		4
Dolo-index		9		8
Bio-index		29		26

Table i.liii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	21	58	8.2	55
Trans quartz	4	11	1.9	13
Dark undiff chert	4	11	1.7	11
Dark dolo	2	6	1.0	7
Dark spic	3	8	1.0	7
Sst undiff	2	6	1.0	7
Total	36		14.8	

Table i.liv

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	43	62	9.5	64
Trans quartz	5	7	1.2	8
Fibrous quartz	1	1	0.4	3
Dark undiff chert	14	20	2.6	18
Dark bio	3	4	0.4	3
Dark dolo	2	3	0.5	3
Dark spic	1	1	0.2	1
Total	69		14.8	

LOCALITY: Monks Bay, Isle of Wight.
SAMPLE NUMBER: 59sr1
HORIZON: Pebble bed MB1, Sandrock Formation.

Table i.lv

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	16	3.1	16
Trans quartz	2	6	1.2	6
Pale undiff chert	1	3	0.9	5
Dark undiff chert	13	42	8.1	43
Dark ool	1	3	0.6	3
Dark lam	2	6	1.1	6
Dark mottled	1	3	0.3	2
Sst undiff	2	6	1.5	8
Ironstone	1	3	1.0	5
Phosphorite	1	3	0.5	3
Sili volc	2	6	0.7	4
Total	31		19.0	

Table i.lvi

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	7	13	2.1	15
Trans quartz	7	13	2.1	15
Dark quartz	1	2	0.3	2
Pale undiff chert	2	4	0.7	5
Pale ool	1	2	0.3	2
Pale Rhax	2	4	0.5	4
Dark undiff chert	26	50	5.9	42
Dark ool	1	2	0.9	6
Dark dolo	2	4	0.6	4
Dark spic	1	2	0.2	1
Sst undiff	1	2	0.3	2
Phosphorite	1	2	0.3	2
Total	52		14.2	

Table i.lvii

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	121	42.5	19.3	42.0
Trans quartz	89	31.0	14.2	31.0
Dark quartz	1	0.5	0.2	0.5
Fibrous quartz	1	0.5	0.1	P
Pale undiff chert	9	3.0	1.4	3.0
Pale Rhax	1	0.5	0.2	0.5
Dark undiff chert	39	13.5	6.2	13.5
Dark dolo	4	1.5	0.7	1.5
Dark lam	5	1.5	0.9	2.0
Sst undiff	1	0.5	0.2	0.5
Ironstone	2	0.5	0.3	0.5
Phosphorite	13	4.5	2.1	4.5
Total	286		45.8	
Q:C index		82		81
Q:S index		100		99
S:C index		2		3
I:P index		13		13
Dolo-index		8		9

LOCALITY: Compton Bay, Isle of Wight.
SAMPLE NUMBER: 10c1
HORIZON: Pebble bed CB6, Carstone Member, at the base of the Carstone Member.

Table i.lviii

GRAIN-SIZE	-3.5 ø		-2.75 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	6	15	25	21	16	35
Trans quartz	5	13	42	35	19	41
Fibrous quartz	6	15	0	0	0	0
Dark undiff chert	5	13	20	17	5	11
Dark bio	0	0	4	3	3	7
Dark ool	2	5	2	2	0	0
Dark dolo	0	0	1	1	0	0
Dark lam	5	13	4	3	0	0
Dark spic	5	13	13	11	2	4
Dark mottled	2	5	0	0	0	0
Dark intra	0	0	1	1	0	0
Sst undiff	3	8	5	4	1	2
Phosphorite	0	0	3	2	0	0
Total	39		120		46	
Q:C index		-		60		-
Q:S index		-		93		-
S:C index		-		10		-
Dolo-index		-		2		-
Bio-index		-		9		-

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12c3
HORIZON: Pebble bed RC5, Carstone Member, 19m above the base of the Carstone Member.

Table i.lix

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	13	35	8.7	34
Trans quartz	9	24	5.8	22
Quartz+pyrite	1	3	1.0	4
Dark undiff chert	5	14	3.1	12
Dark bio	2	5	1.9	7
Dark dolo	2	5	1.7	7
Dark lam	1	3	0.4	2
Dark spic	1	3	1.7	7
Sst undiff	2	5	0.9	3
Phosphorite	1	3	0.6	2
Total	37		25.8	

Table i.lx

GRAIN-SIZE	-2.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	25	45	9.4	45
Trans quartz	18	33	6.8	33
Sheared quartz	2	4	0.8	4
Quartz+pyrite	1	2	0.4	2
Dark undiff chert	4	7	1.6	8
Dark bio	1	2	0.4	2
Dark dolo	3	5	1.2	6
Phosphorite	1	2	0.3	1
Total	55		20.9	

Table i.lxi

GRAIN-SIZE	-2.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	26	30	7.9	30
Trans quartz	27	31	8.2	31
Sheared quartz	3	3	0.9	3
Pink quartz	2	2	0.6	2
Fibrous quartz	2	2	0.5	2
Dark undiff chert	7	8	2.2	8
Dark bio	3	3	0.9	3
Dark dolo	2	2	0.5	2
Dark lam	2	2	0.4	2
Dark spic	1	1	0.4	2
Sst undiff	6	7	1.8	7
Ironstone	4	5	1.3	5
Phosphorite	2	2	0.5	2
Total	87		26.1	

LOCALITY: Redcliff, Isle of Wight.
SAMPLE NUMBER: 12c4
HORIZON: Pebble bed RC5, Carstone Member, 19m above the base of the Carstone Member.

Table i.lxii

GRAIN-SIZE	-2.75 ø		-2.5 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	93.7	40.5	15.1	19	9.1	26
Trans quartz	47.1	20.5	4.5	6	10.0	28
Sheared quartz	7.1	3.0	0.0	0	0.5	1
Pink quartz	0.0	0.0	0.0	0	1.1	3
Fibrous quartz	5.0	2.0	0.4	P	0.4	1
Pale undiff chert	0.0	0.0	0.4	P	0.4	1
Dark undiff chert	31.7	14.0	4.0	5	5.1	15
Dark bio	13.6	6.0	8.6	11	1.6	5
Dark ool	1.0	0.5	3.0	4	0.2	1
Dark dolo	9.6	4.0	0.0	0	0.4	1
Dark lam	5.8	2.5	0.0	0	0.0	0
Dark spic	2.1	1.0	0.0	0	0.0	0
Dark mottled	1.6	0.5	41.3	51	0.0	0
Radio chert	0.7	0.5	0.4	P	0.4	1
Sst undiff	5.1	2.0	0.8	1	0.6	2
Ironstone	1.6	0.5	1.8	2	4.0	11
Phosphorite	1.3	0.5	0.0	0	0.9	3
Qtz+tourm	1.0	0.5	0.0	0	0.0	0
Sili volc	2.0	1.0	0.0	0	0.4	1
Total	230.0		80.3		35.1	
Q:C index		70		-		-
Q:S index		97		-		-
S:C index		7		-		-
I:P index		55		-		-
Dolo-index		15		-		-
Bio-index		21		-		-

LOCALITY: Coombe Farm, Isle of Wight.
SAMPLE NUMBER: 50c1
HORIZON: Pebble bed CF2, Carstone Member, at the base of the Carstone Member.

Table i.lxiii

GRAIN-SIZE	-4.5 ø		-3.5 ø		-2.75 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	0	0	0	0	21	14
Trans quartz	0	0	0	0	25	16
Pink quartz	0	0	0	0	1	1
Fibrous quartz	0	0	0	0	2	1
Pale undiff chert	0	0	1	10	0	0
Pale bio	1	100	2	20	0	0
Pale ool	0	0	1	10	0	0
Dark undiff chert	0	0	6	60	63	41
Dark bio	0	0	0	0	6	4
Dark ool	0	0	0	0	4	3
Dark dolo	0	0	0	0	4	3
Dark lam	0	0	0	0	8	5
Dark spic	0	0	0	0	14	9
Sili wood	0	0	0	0	1	1
Sst undiff	0	0	0	0	3	2
Total	1		10		152	
Q:C index		-		-		33
Q:S index		-		-		94
S:C index		-		-		3
Dolo-index		-		-		4
Bio-index		-		-		6

Table i.lxiv

GRAIN-SIZE	-2.5 ø	
LITHOTYPE	FREQ	%FREQ
Opaque quartz	18	20
Trans quartz	36	40
Pink quartz	2	2
Fibrous quartz	2	2
Dark undiff chert	21	23
Dark bio	4	4
Dark ool	4	4
Dark lam	3	3
Dark spic	1	1
Total	91	

Pebble beds sampled from the Weald

LOCALITY: Compton, Surrey.
SAMPLE NUMBER: 176bb1
HORIZON: Bargate Beds Formation.

Table i.lxv

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark bio	1	13	1.6	7
Dark mottled	1	13	8.2	33
Ironstone	2	25	4.5	18
Phosphorite	4	50	10.2	42
Total	8		24.5	

Table i.lxvi

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	5	8	6.1	7
Dark bio	6	10	7.3	9
Dark dolo	2	3	2.1	3
Dark spic	2	3	3.3	4
Dark mottled	3	5	5.3	6
Dark pellet	1	2	4.1	5
Dark evap	1	2	1.0	1
Ironstone	13	22	15.9	19
Phosphorite	25	42	34.9	42
Sili volc	2	3	3.2	4
Total	60		83.2	

Table i.lxvii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	6	4	4.0	5
Trans quartz	1	1	0.6	1
Dark undiff chert	15	11	9.4	11
Dark bio	7	5	4.5	5
Dark dolo	5	4	2.2	3
Dark lam	6	4	3.9	5
Dark spic	2	1	1.1	1
Dark mottled	4	3	2.8	3
Sst undiff	1	1	0.8	1
Ironstone	38	28	21.3	25
Phosphorite	52	38	32.4	39
Bone	1	1	0.6	1
Total	138		83.6	
Q:C index		15		16
Q:S index		88		85
S:C index		3		3
I:P index		42		40
Dolo-index		13		9
Bio-index		18		19

Table i.lxviii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	4	3	1.4	3
Trans quartz	1	1	0.8	2
Dark undiff chert	8	6	2.7	6
Dark bio	8	6	2.7	6
Dark dolo	12	9	5.5	11
Dark lam	3	2	1.0	2
Dark spic	1	1	0.2	P
Dark mottled	10	8	3.8	8
Sst undiff	1	1	0.6	1
Ironstone	44	33	15.1	32
Phosphorite	39	30	13.6	28
Bone	1	1	0.5	1
Total	132		47.9	
Q:C index		11		12
Q:S index		83		79
S:C index		2		4
I:P index		52		52
Dolo-index		29		35
Bio-index		19		17

Table i.lxix

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	32	4.5	5.2	4.0
Trans quartz	5	0.5	0.9	0.5
Sheared quartz	2	0.5	0.5	0.5
Pink quartz	2	0.5	0.4	0.5
Dark undiff chert	102	14.0	17.9	14.0
Dark bio	24	3.0	5.3	4.0
Dark ool	5	0.5	1.0	1.0
Dark dolo	38	5.0	6.8	5.5
Dark lam	9	1.0	1.6	1.0
Dark spic	2	0.5	0.2	P
Dark mottled	14	2.0	3.0	2.5
Sst undiff	3	0.5	0.5	0.5
Ironstone	333	46.0	58.4	45.0
Phosphorite	151	21.0	27.4	21.0
Bone	3	0.5	0.4	0.5
Total	725		129.5	
Q:C index		17		16
Q:S index		93		93
S:C index		2		1
I:P index		68		68
Dolo-index		20		19
Bio-index		12		15

LOCALITY: Compton, Surrey.
SAMPLE NUMBER: 176bb2
HORIZON: Bargate Beds Formation.

Table i.lxx

GRAIN-SIZE	-3.5 ø	
LITHOTYPE	FREQ	%FREQ
Phos sst	1	100
Total	1	

Table i.lxxi

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	2	5	2.6	5
Dark bio	2	5	2.6	5
Dark ool	1	2	0.9	2
Dark dolo	2	5	2.2	4
Dark lam	4	10	5.2	10
Dark spic	1	2	0.8	2
Dark mottled	2	5	3.3	6
Ironstone	10	24	12.3	23
Phosphorite	15	37	20.9	40
Bone	1	2	1.1	2
Lst undiff	1	2	1.0	2
Total	41		52.9	

Table i.lxxii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	6	4.0	4.9	4.5
Trans quartz	1	0.5	0.6	0.5
Dark undiff chert	12	7.5	7.9	7.5
Dark bio	8	5.0	3.9	4.0
Dark dolo	11	7.0	7.2	7.0
Dark lam	5	3.0	3.5	3.5
Dark spic	1	0.5	0.6	0.5
Dark mottled	8	5.0	6.1	6.0
Sst undiff	1	0.5	0.4	0.5
Quartzite	1	0.5	0.7	0.5
Ironstone	40	25.0	23.9	23.0
Phosphorite	62	39.0	41.8	40.0
Sili volc	3	2.0	2.2	2.0
Total	159		103.7	
Q:C index		13		16
Q:S index		78		83
S:C index		4		4
I:P index		39		36
Dolo-index		24		25
Bio-index		18		13

Table i.lxxiii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	3.0	2.0	3.0
Trans quartz	2	1.0	0.7	1.0
Sheared quartz	1	0.5	0.3	0.5
Dark undiff chert	15	8.5	5.9	9.0
Dark bio	5	3.0	1.6	2.5
Dark ool	1	0.5	0.4	0.5
Dark dolo	5	3.0	1.6	2.5
Dark lam	6	3.5	2.8	4.5
Dark spic	2	1.0	0.7	1.0
Dark mottled	5	3.0	1.6	2.5
Dark evap	2	1.0	0.6	1.0
Sst undiff	1	0.5	0.5	1.0
Ironstone	67	38.5	23.8	36.5
Phosphorite	58	33.0	22.7	35.0
Total	175		65.2	
Q:C index		16		16
Q:S index		89		86
S:C index		2		3
I:P index		54		51
Dolo-index		12		11
Bio-index		12		11

Table i.lxxiv

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	42	5.0	9.2	6.0
Trans quartz	10	1.0	1.7	1.0
Pink quartz	1	P	0.1	P
Dark undiff chert	45	5.5	7.5	5.0
Dark bio	39	4.5	7.7	5.0
Dark ool	9	1.0	1.8	1.0
Dark dolo	65	7.5	11.2	7.0
Dark lam	19	2.0	3.2	2.0
Dark spic	8	1.0	1.6	1.0
Dark mottled	25	3.0	6.4	4.0
Dark intra	4	0.5	0.7	0.5
Sili wood	1	P	0.1	P
Ironstone	392	46.0	68.9	44.0
Phosphorite	183	21.5	34.2	22.0
Sili volc	11	1.5	2.1	1.5
Total	854		156.4	
Q:C index		20		21
I:P index		68		67
Dolo-index		30		28
Bio-index		18		19

LOCALITY: Huntingford Bridge, Hampshire.
SAMPLE NUMBER: 92fb1
HORIZON: Folkestone Beds Formation.

Table i.lxxv
GRAIN-SIZE <-2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	15	28	3.4	23
Trans quartz	21	40	5.2	35
Dark undiff chert	16	30	6.1	41
Ironstone	1	2	0.3	2
Total	53		15.0	

LOCALITY: Huntingford Bridge, Hampshire.
SAMPLE NUMBER: 92fb2
HORIZON: Folkestone Beds Formation.

Table i.lxxvi
GRAIN-SIZE <-2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	13	15	3.6	16
Trans quartz	35	41	6.2	28
Fibrous quartz	1	1	0.2	1
Dark undiff chert	27	32	10.4	46
Ironstone	9	11	2.1	9
Total	85		22.5	

LOCALITY: Huntingford Bridge, Hampshire.
SAMPLE NUMBER: 92fb3
HORIZON: Folkestone Beds Formation.

Table i.lxxvii
GRAIN-SIZE <-2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	7	18	2.1	15
Trans quartz	13	33	2.8	20
Dark undiff chert	19	48	8.1	59
Ironstone	1	3	0.7	5
Total	40		13.7	

LOCALITY: Huntingford Bridge, Hampshire.
SAMPLE NUMBER: 92fb4
HORIZON: Folkestone Beds Formation.

Table i.lxxviii
GRAIN-SIZE <-2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	6	13	1.5	11
Trans quartz	15	33	3.2	24
Dark undiff chert	22	49	7.8	58
Ironstone	2	4	1.0	7
Total	45		13.5	

LOCALITY: Huntingford Bridge, Hampshire.
SAMPLE NUMBER: 92fb5
HORIZON: Folkestone Beds Formation.

Table i.lxxix
GRAIN-SIZE -2.75 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	6	17	3.3	10
Trans quartz	5	14	3.8	12
Sheared quartz	1	3	0.6	2
Pink quartz	1	3	0.6	2
Dark undiff chert	10	29	15.7	49
Dark bio	3	9	2.5	8
Dark ool	1	3	0.5	2
Dark dolo	5	14	3.0	9
Dark lam	1	3	0.6	2
Sst undiff	1	3	0.7	2
Phosphorite	1	3	0.6	2
Total	35		31.9	

Table i.lxxx
GRAIN-SIZE -2.5 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	6	16	2.1	14
Trans quartz	15	39	6.1	41
Dark undiff chert	11	29	4.1	28
Dark ool	1	3	0.4	3
Dark dolo	1	3	0.4	3
Ironstone	2	5	0.8	5
Sili volc	2	5	0.9	6
Total	38		14.8	

Table i.lxxxi
GRAIN-SIZE -2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	38	27	7.6	26
Trans quartz	51	36	9.5	32
Sheared quartz	1	1	0.4	1
Dark undiff chert	28	20	6.5	22
Dark bio	9	6	2.1	7
Dark dolo	1	1	0.3	1
Dark lam	3	2	0.6	2
Ironstone	9	6	2.0	7
Phosphorite	1	1	0.5	2
Total	141		29.5	
Q:C index		69		65
I:P index		90		80
Dolo-index		2		3
Bio-index		22		22

LOCALITY: Chilworth, Surrey.
SAMPLE NUMBER: 183fb1
HORIZON: Folkestone Beds Formation.

Table i.lxxxii
GRAIN-SIZE <-2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	7	6	9.2	5
Pale undiff chert	2	2	3.0	2
Dark undiff chert	10	8	22.0	13
Dark bio	13	11	26.3	16
Dark ool	2	2	5.6	3
Dark dolo	10	8	11.9	7
Dark lam	10	8	16.2	10
Dark spic	8	7	13.9	8
Dark mottled	14	12	21.1	13
Sst undiff	1	1	1.1	1
Ironstone	43	36	35.1	21
Sili volc	1	1	2.0	1
Total	121		167.4	

LOCALITY: Chilworth, Surrey.
SAMPLE NUMBER: 183fb2
HORIZON: Folkestone Beds Formation.

Table i.lxxxiii
GRAIN-SIZE -3.5 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	1	10	3.0	10
Dark bio	3	30	9.6	32
Dark ool	1	10	3.4	11
Dark dolo	1	10	3.3	11
Dark spic	1	10	3.8	13
Dark mottled	1	10	2.3	8
Ironstone	2	20	4.3	14
Total	10		29.7	

Table i.lxxxiv
GRAIN-SIZE -3.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	2	6	3.2	6
Dark bio	4	11	6.1	12
Dark ool	2	6	3.6	7
Dark dolo	3	9	3.9	8
Dark lam	3	9	6.1	12
Dark mottled	5	14	7.6	15
Ironstone	9	26	11.0	22
Fe lam	2	6	2.1	4
Fe sst	5	14	6.9	14
Total	35		50.5	

Table i.lxxxv
GRAIN-SIZE -2.75 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	8	3.6	9
Dark undiff chert	4	6	2.1	5
Dark bio	3	5	2.8	7
Dark dolo	4	6	2.5	6
Dark lam	2	3	1.6	4
Dark spic	1	2	0.6	1
Dark mottled	3	5	1.5	4
Fe lam	6	9	4.2	10
Fe sst	35	55	22.9	54
Fe bio	1	2	0.5	1
Total	64		42.3	

Table i.lxxxvi
GRAIN-SIZE -2.5 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	3	6	1.3	7
Dark undiff chert	1	2	0.2	1
Dark bio	2	4	0.8	4
Siltstone	1	2	0.4	2
Fe lam	13	24	4.8	25
Fe sst	34	63	11.9	61
Total	54		19.4	

Table i.lxxxvii
GRAIN-SIZE -2.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	8	3.5	1.5	3.5
Dark undiff chert	4	2.0	1.0	2.5
Dark bio	11	5.0	1.8	4.0
Dark dolo	6	2.5	1.2	2.5
Dark lam	4	2.0	0.7	1.5
Dark spic	2	1.0	0.5	1.0
Dark mottled	4	2.0	0.7	1.5
Sst undiff	1	0.5	0.2	0.5
Fe lam	95	42.0	19.3	43.5
Fe sst	89	39.5	17.2	38.5
Sili volc	1	0.5	0.3	0.5
Total	225		44.4	
Q:C index		21		20
Q:S index		89		88
S:C index		3		3
Dolo-index		19		20
Bio-index		35		31

LOCALITY: Moorhouse, Westerham, Kent.
SAMPLE NUMBER: 186fb1
HORIZON: Folkestone Beds Formation.

Table i.lxxxviii
GRAIN-SIZE -3.0 ø

LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	20	1.7	31
Pink quartz	1	20	1.4	26
Sst undiff	3	60	2.3	43
Total	5		5.4	

Table i.lxxxix

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	17	2.3	17
Pink quartz	1	3	0.4	3
Dark quartz	1	3	1.0	7
Dark undiff chert	5	17	2.8	20
Dark bio	2	7	1.1	8
Dark dolo	3	10	1.3	9
Dark spic	1	3	0.4	3
Radio chert	1	3	0.7	5
Sst undiff	7	24	2.2	16
Ironstone	2	7	0.7	5
Sili volc	1	3	0.9	7
Total	29		13.8	

Table i.xc

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	10	28	3.5	32
Sheared quartz	1	3	0.2	2
Pink quartz	1	3	0.2	2
Dark quartz	1	3	0.3	3
Dark undiff chert	7	19	1.8	17
Dark dolo	2	6	0.6	6
Dark spic	2	6	0.8	7
Sst undiff	7	19	1.0	9
Ironstone	5	14	2.4	22
Total	36		10.8	

Table i.xci

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	208	53.0	32.9	54.5
Trans quartz	23	6.0	3.9	6.5
Sheared quartz	3	1.0	0.5	1.0
Pink quartz	4	1.0	0.6	1.0
Dark quartz	3	1.0	0.6	1.0
Fibrous quartz	3	1.0	0.5	1.0
Granular quartz	5	1.5	1.0	1.5
Dark undiff chert	32	8.0	3.6	6.0
Dark bio	10	3.0	1.4	2.5
Dark dolo	8	2.0	1.2	2.0
Dark lam	2	0.5	0.4	0.5
Dark spic	3	1.0	0.4	0.5
Dark mottled	3	1.0	0.5	1.0
Dark intra	1	0.5	0.2	0.5
Sst undiff	36	9.0	5.5	9.0
Mica sst	13	3.5	1.4	2.5
Siltstone	6	1.5	0.8	1.5
Ironstone	25	6.5	3.9	6.5
Fe sst	1	0.5	0.2	0.5
Qtz+tourm	2	0.5	0.4	0.5
Sili volc	3	1.0	0.5	1.0
Total	394		60.4	
Q:C index		81		84
Q:S index		82		84
S:C index		48		50
Dolo-index		14		16
Bio-index		17		18

LOCALITY: Moorhouse, Westerham, Kent.
SAMPLE NUMBER: 186fb3
HORIZON: Folkestone Beds Formation.

Table i.xcii

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Sst undiff	1	100	2.5	100
Total	1		2.5	

Table i.xciii

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Trans quartz	2	20	1.7	15
Sst undiff	8	80	10.0	85
Total	10		11.7	

Table i.xciv

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	18	3.0	20
Trans quartz	2	7	0.9	6
Fibrous quartz	1	4	0.8	5
Dark bio	2	7	1.1	7
Dark ool	1	4	0.6	4
Dark dolo	1	4	0.5	3
Dark lam	1	4	0.8	5
Dark spic	1	4	0.7	5
Sst undiff	14	50	6.6	44
Total	28		15.0	

Table i.xcv

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	15	45	3.8	43
Dark undiff chert	8	24	2.7	31
Dark dolo	2	6	0.5	6
Dark mottled	1	3	0.4	5
Sst undiff	2	6	0.4	5
Mica sst	5	15	1.0	11
Total	33		8.8	

Table i.xcvi

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	121	54.5	19.2	50.5
Trans quartz	13	6.0	2.4	6.5
Sheared quartz	1	0.5	0.3	1.0
Pink quartz	4	2.0	1.0	2.5
Fibrous quartz	2	1.0	0.6	1.5
Granular quartz	2	1.0	0.4	1.0
Dark undiff chert	22	10.0	3.5	9.0
Dark bio	9	4.0	1.4	3.5
Dark ool	2	1.0	0.4	1.0
Dark dolo	7	3.0	1.1	3.0
Dark lam	2	1.0	0.6	1.5
Dark spic	2	1.0	0.7	2.0
Dark mottled	2	1.0	0.5	1.5
Dark evap	1	0.5	0.5	1.5
Sst undiff	30	13.5	4.7	12.5
Sili volc	2	1.0	0.6	1.5
Total	222		37.9	
Q:C index		75		73
Q:S index		83		84
S:C index		39		35
Dolo-index		15		13
Bio-index		19		16

LOCALITY: Moorhouse, Westerham, Kent.
SAMPLE NUMBER: 186fb6
HORIZON: Folkestone Beds Formation.

Table i.xcvii

GRAIN-SIZE		-3.5 ø
LITHOTYPE	FREQ	%FREQ
Opaque quartz	1	50
Dark dolo	1	50
Total	2	

Table i.xcviii

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	13	41	15.2	43
Sheared quartz	3	9	3.4	10
Pink quartz	1	3	0.9	3
Granular quartz	2	6	3.0	8
Dark undiff chert	1	3	1.1	3
Dark bio	1	3	0.7	2
Dark ool	1	3	1.6	5
Dark dolo	3	9	2.5	7
Dark lam	1	3	1.6	5
Dark spic	3	9	2.7	8
Sst undiff	3	9	2.7	8
Total	32		35.4	

Table i.xcix

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	24	33	13.1	37
Sheared quartz	3	4	1.4	4
Dark quartz	1	1	0.5	1
Dark undiff chert	8	11	3.0	8
Dark bio	4	6	2.3	7
Dark dolo	2	3	0.6	2
Dark lam	2	3	1.0	3
Dark spic	4	6	1.4	4
Dark mottled	1	1	0.6	2
Sst undiff	23	32	11.4	32
Total	72		35.3	

Table i.c

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	45	41	15.5	46
Trans quartz	7	6	2.2	6
Sheared quartz	2	2	0.6	2
Dark quartz	1	1	0.5	1
Fibrous quartz	1	1	0.2	1
Dark undiff chert	22	20	5.7	17
Dark bio	4	4	1.3	4
Dark ool	1	1	0.2	1
Dark dolo	3	3	0.8	2
Dark lam	2	2	0.8	2
Dark spic	2	2	0.6	2
Dark mottled	2	2	0.4	1
Sst undiff	14	13	3.7	11
Ironstone	1	1	0.2	1
Qtz+tourm	1	1	0.2	1
Sili volc	3	3	1.0	3
Total	111		33.9	
Q:C index		61		66
Q:S index		80		84
S:C index		28		27
Dolo-index		8		8
Bio-index		11		13

Table i.ci

GRAIN-SIZE			-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	340	57.0	57.3	61.5
Trans quartz	86	14.5	11.8	12.5
Sheared quartz	1	P	0.2	P
Pink quartz	10	1.5	1.5	1.5
Dark quartz	3	0.5	0.5	0.5
Fibrous quartz	7	1.0	1.4	1.5
Dark undiff chert	66	11.0	8.3	9.0
Dark bio	12	2.0	2.0	2.0
Dark ool	2	0.5	0.4	0.5
Dark dolo	13	2.0	2.0	2.0
Dark lam	4	0.5	0.8	1.0
Dark spic	1	P	0.2	P
Dark mottled	13	2.0	1.2	1.5
Dark evap	1	P	0.4	0.5
Sst undiff	28	4.5	3.8	4.0
Siltstone	1	P	0.3	0.5
Ironstone	6	1.0	0.8	1.0
Sili volc	2	0.5	0.5	0.5
Total	596		93.4	
Q:C index		80		83
Q:S index		94		95
S:C index		21		21
Dolo-index		12		13
Bio-index		11		13

LOCALITY: Lenham Heath, Kent.
SAMPLE NUMBER: 189fb1
HORIZON: Folkestone Beds Formation.

Table i.cii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	6	0.5	7
Dark undiff chert	1	6	0.3	4
Dark spic	1	6	0.4	6
Sst undiff	12	71	4.9	71
Sili volc	2	12	0.8	12
Totals	17		6.9	

Table i.ciii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	4	50	1.6	55
Dark undiff chert	1	13	0.3	10
Sst undiff	3	38	1.0	34
Total	8		2.9	

Table i.civ

GRAIN-SIZE			-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	20	30	4.5	35
Trans quartz	2	3	0.5	4
Quartz+chlorite	1	1	0.3	2
Dark undiff chert	6	9	1.2	10
Dark bio	1	1	0.2	2
Dark dolo	1	1	0.1	1
Dark intra	1	1	0.2	2
Sst undiff	31	46	5.3	41
Siltstone	4	6	0.7	5
Total	67		13.0	

LOCALITY: Lenham Heath, Kent.
SAMPLE NUMBER: 189fb2
HORIZON: Folkestone Beds Formation.

Table i.cv

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	100	2.2	100
Total	1		2.2	

Table i.cvi

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	2	15	0.9	15
Dark undiff chert	1	8	0.6	10
Sst undiff	8	62	3.8	61
Ironstone	2	15	0.9	15
Total	13		6.2	

Table i.cvii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	3	27	1.0	26
Dark undiff chert	1	9	0.4	11
Sst undiff	5	45	1.8	47
Ironstone	1	9	0.3	8
Sili volc	1	9	0.3	8
Total	11		3.8	

Table i.cviii

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	35	74	5.6	71
Trans quartz	3	6	0.5	6
Pink quartz	1	2	0.2	3
Dark undiff chert	2	4	0.4	5
Dark bio	1	2	0.2	3
Dark dolo	3	6	0.5	6
Dark spic	1	2	0.2	3
Dark mottled	1	2	0.3	4
Total	47		7.9	

LOCALITY: Baker's Gap, Folkestone, Kent.
SAMPLE NUMBER: 174fb1/8
HORIZON: Folkestone Beds Formation.

Table i.cix

GRAIN-SIZE			<-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	16	46	2.4	33
Pink quartz	2	6	0.4	6
Dark undiff chert	1	3	0.1	1
Sst undiff	13	37	1.8	25
Phosphorite	1	3	0.2	3
Phos sst	2	6	2.3	32
Total	35		7.2	

LOCALITY: Baker's Gap, Folkestone, Kent.
SAMPLE NUMBER: 174fb1/9
HORIZON: Folkestone Beds Formation.

Table i.cx

GRAIN-SIZE			<-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	25	30	4.4	28
Trans quartz	4	5	0.7	4
Dark quartz	1	1	0.2	1
Dark undiff chert	3	4	1.2	8
Dark bio	2	2	0.8	5
Dark dolo	2	2	0.8	5
Dark spic	1	1	0.5	3
Sst undiff	39	47	6.2	39
Phosphorite	4	5	0.8	5
Sili volc	2	2	0.4	3
Total	83		16.0	

LOCALITY: Aldersnapp Farm, Hampshire.
SAMPLE NUMBER: 104g3
HORIZON: Gault Clay Formation.

Table i.cxi

GRAIN-SIZE			<-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	103	68	13.9	53
Pink quartz	1	1	0.2	1
Granular quartz	2	1	0.5	2
Pale undiff chert	1	1	0.2	1
Dark undiff chert	20	13	2.3	9
Dark bio	7	5	2.7	10
Dark ool	1	1	0.2	1
Dark dolo	7	5	1.2	5
Dark lam	1	1	1.7	7
Dark mottled	1	1	0.5	2
Dark evap	1	1	0.3	1
Sst undiff	1	1	0.7	3
Ironstone	4	3	0.5	2
Phosphorite	1	1	0.9	3
Sili volc	1	1	0.2	1
Total	152		26.0	
Q:C index		74		62
Q:S index		99		95
S:C index		3		7
I:P index		80		36
Dolo-index		18		13
Bio-index		18		30

LOCALITY: Burton School, Sussex.
SAMPLE NUMBER: 107g1
HORIZON: Gault Clay Formation.

Table i.cxii

GRAIN-SIZE			<-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	11	20	2.3	19
Pink quartz	17	31	3.5	28
Dark undiff chert	23	42	5.5	45
Sst undiff	4	7	1.0	8
Total	55		12.3	

LOCALITY: Burton School, Sussex.
SAMPLE NUMBER: 107g2
HORIZON: Gault Clay Formation.

Table i.cxiii

GRAIN-SIZE		<-2.0 ø
LITHOTYPE	FREQ	%FREQ
Opaque quartz	5	42
Pink quartz	2	17
Dark undiff chert	5	42
Total	12	

Pebble beds sampled from Wiltshire and Oxfordshire

LOCALITY: Swindon, Wiltshire.
SAMPLE NUMBER: 71bscpbl
HORIZON: Basal Swindon Clay pebble bed (Lower Lydite Bed?).

Table i.cxiv

GRAIN-SIZE	-2.75 ø		-2.5 ø		-2.0 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	0.0	0	0.3	4	1.0	11
Trans quartz	0.0	0	0.0	0	0.2	2
Dark undiff chert	2.8	49	3.8	51	4.8	51
Dark bio	1.9	33	0.9	12	0.9	9
Dark dolo	1.0	18	0.0	0	1.2	13
Dark lam	0.0	0	1.7	23	0.5	5
Dark spic	0.0	0	0.0	0	0.5	5
Dark mottled	0.0	0	0.8	11	0.3	3
Phosphorite	0.0	0	0.0	0	0.1	1
Total	5.7		7.5		9.5	

LOCALITY: Swindon, Wiltshire.
SAMPLE NUMBER: 71ulb2
HORIZON: Upper Lydite Bed, Portland Group.

Table i.cxv

GRAIN-SIZE	-3.5 ø		-2.75 ø		-2.5 ø	
LITHOTYPE	WEIGHT	%WT	WEIGHT	%WT	WEIGHT	%WT
Opaque quartz	0.0	0	1.0	1	0.0	0
Dark undiff chert	3.3	6	17.7	19	5.7	22
Dark bio	0.0	0	3.2	3	0.9	4
Dark ool	0.0	0	0.0	0	0.7	3
Dark dolo	0.0	0	0.5	1	0.8	3
Dark lam	0.0	0	1.7	2	0.7	3
Dark spic	0.0	0	1.6	2	0.0	0
Dark mottled	0.0	0	1.8	2	0.7	3
Sst undiff	0.0	0	0.0	0	0.0	0
Phosphorite	49.0	94	67.1	71	12.5	49
Phos sst	0.0	0	0.0	0	0.5	2
Phos bio	0.0	0	0.0	0	2.9	11
Total	52.3		94.6		25.4	
Q:C index		-		4		-
Dolo-index		-		2		-
Bio-index		-		12		-

Table i.cxvi

GRAIN-SIZE	-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	1.5	4
Trans quartz	0.3	1
Dark undiff chert	8.6	21
Dark bio	0.3	1
Dark ool	0.3	1
Dark dolo	0.0	0
Dark lam	0.0	0
Dark spic	0.0	0
Dark mottled	0.3	1
Sst undiff	0.3	1
Phosphorite	27.7	68
Phos sst	0.5	1
Phos bio	0.8	2
Total	40.6	
Q:C index		16
Q:S index		86
S:C index		3
Bio-index		3

LOCALITY: Littleworth, Oxfordshire.
SAMPLE NUMBER: 193ulb3
HORIZON: Upper Lydite Bed, Portland Group.

Table i.cxvii

GRAIN-SIZE	-4.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	1	50	7.0	46
Dark bio	1	50	8.2	54
Total	2		15.2	

Table i.cxviii

GRAIN-SIZE	-3.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	5	36	19.9	39
Dark bio	4	29	14.2	28
Dark ool	1	7	2.6	5
Dark spic	3	21	11.5	22
Dark mottled	1	7	3.0	6
Total	14		51.2	

Table i.cxix

GRAIN-SIZE	-3.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	2	1.0	1
Trans quartz	1	2	1.1	1
Dark undiff chert	9	17	13.5	18
Dark bio	7	13	9.2	12
Dark ool	1	2	1.7	2
Dark dolo	9	17	12.4	16
Dark lam	11	21	13.1	17
Dark spic	3	6	5.1	7
Dark mottled	5	10	8.5	11
Dark intra	1	2	2.8	4
Phosphorite	2	4	2.9	4
Sili volc	2	4	4.0	5
Total	52		75.3	

Table i.cxx

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	3	2	2.3	3
Dark quartz	2	2	1.0	1
Dark undiff chert	20	15	13.9	15
Dark bio	19	15	13.1	14
Dark ool	4	3	3.6	4
Dark dolo	34	26	23.9	26
Dark lam	20	15	14.0	15
Dark spic	10	8	6.5	7
Dark mottled	13	10	9.0	10
Phosphorite	4	3	1.7	2
Sili volc	1	1	2.0	2
Total	130		91.0	
Q:C index		4		4
Dolo-index		28		28
Bio-index		16		16

Table i.cxxi

GRAIN-SIZE	-2.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	7	10	1.9	7
Trans quartz	2	3	0.8	3
Dark undiff chert	12	18	5.1	20
Dark bio	8	12	3.4	13
Dark ool	1	1	0.3	1
Dark dolo	13	19	4.9	19
Dark lam	4	6	1.6	6
Dark spic	2	3	0.7	3
Dark mottled	9	13	3.1	12
Dark intra	1	1	0.6	2
Dark evap	2	3	0.8	3
Sili bio	1	1	0.3	1
Phosphorite	4	6	1.2	5
Sili volc	2	3	0.7	3
Total	68		25.4	

Table i.cxxii

GRAIN-SIZE	-2.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	17	7.5	3.6	8.0
Trans quartz	7	3.0	1.0	2.0
Pink quartz	2	1.0	0.5	1.0
Dark undiff chert	185	83.0	38.3	83.5
Dark ool	2	1.0	0.6	1.5
Phosphorite	10	4.5	2.0	4.5
Total	223		46.0	
Q:C index		12		12

LOCALITY: Wicklesham, Faringdon, Oxfordshire.
SAMPLE NUMBER: 130fsg3
HORIZON: Faringdon Sponge Gravel.

Table i.cxxiii

GRAIN-SIZE	-5.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Lst bio w/m	1	100	121.5	100
Total	1		121.5	

Table i.cxxiv

GRAIN-SIZE	-4.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Phosphorite	2	50	108.6	70
Lst bio g/p	1	25	42.2	27
Lst sst	1	25	5.3	3
Total	4		156.1	

Table i.cxxv

GRAIN-SIZE	-3.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Pale undiff chert	1	4	2.9	2
Phosphorite	4	16	39.9	32
Lst bio g/p	5	20	27.4	22
Lst bio w/m	10	40	35.7	28
Lst sst	5	20	20.4	16
Total	25		126.3	

Table i.cxxvi

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	11	12	10.7	11
Trans quartz	3	3	4.2	4
Pale undiff chert	1	1	0.7	1
Dark undiff chert	11	12	15.1	16
Dark bio	4	4	2.6	3
Dark ool	2	2	1.3	1
Dark dolo	8	9	5.2	5
Dark lam	3	3	3.7	4
Phosphorite	16	18	21.4	22
Lst bio g/p	2	2	3.3	3
Lst bio w/m	4	4	3.8	4
Lst sst	26	29	25.4	26
Total	91		97.4	
Q:C index		35		36
Dolo-index		29		19
Bio-index		14		9

Table i.cxxvii

GRAIN-SIZE	-2.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	14	23	5.2	26
Trans quartz	1	2	0.3	2
Dark undiff chert	12	20	4.2	21
Dark ool	2	3	1.3	7
Dark dolo	1	2	0.3	2
Dark lam	1	2	0.5	3
Dark spic	6	10	0.6	3
Dark mottled	1	2	0.4	2
Phosphorite	4	7	1.4	7
Lst bio g/p	1	2	0.3	2
Lst bio w/m	5	8	1.3	7
Lst sst	13	21	4.0	20
Total	61		19.8	

Table i.cxxviii

GRAIN-SIZE			-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	39	34	7.8	37
Fibrous quartz	1	1	0.1	P
Dark undiff chert	32	28	6.0	28
Dark bio	2	2	0.3	1
Dark dolo	5	4	0.7	3
Dark spic	1	1	0.2	1
Dark mottled	1	1	0.2	1
Sst undiff	1	1	0.2	1
Phosphorite	9	8	1.6	8
Lst bio g/p	1	1	0.3	1
Lst bio w/m	8	7	1.1	5
Lst sst	16	14	2.7	13
Total	116		21.2	
Q:C index		49		52
Q:S index		98		98
S:C index		2		3
Dolo-index		12		9
Bio-index		5		4

LOCALITY: Wicklesham, Faringdon, Oxfordshire.
SAMPLE NUMBER: 130fsg5
HORIZON: Faringdon Sponge Gravel.

Table i.cxxix

GRAIN-SIZE	-4.5 ø	
LITHOTYPE	FREQ	%FREQ
Phosphorite	1	100
Total	1	

Table i.cxxx

GRAIN-SIZE			-3.5 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	6	32	40.9	34
Ironstone	1	5	4.3	4
Phosphorite	6	32	42.5	36
Lst bio g/p	1	5	13.6	11
Lst sst	5	26	18.4	15
Total	19		119.7	

Table i.cxxxi

GRAIN-SIZE			-2.75 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	16	23	11.7	17
Dark undiff chert	14	20	17.9	25
Dark dolo	3	4	2.2	3
Dark spic	3	4	2.3	3
Dark mottled	3	4	4.8	7
Sst undiff	1	1	0.9	1
Phosphorite	11	15	12.5	18
Lst bio g/p	1	1	0.7	1
Lst bio w/m	1	1	1.6	2
Lst sst	18	25	15.6	22
Total	71		70.2	

Table i.cxxxii

GRAIN-SIZE			-2.5 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	16	27	5.0	25
Dark undiff chert	7	12	4.5	23
Dark ool	1	2	0.5	3
Dark dolo	2	3	0.7	4
Dark lam	2	3	0.8	4
Phosphorite	8	13	2.7	14
Lst bio w/m	1	2	0.2	1
Lst sst	23	38	5.5	28
Total	60		19.9	

LOCALITY: Seend, Wiltshire.
SAMPLE NUMBER: 58sil
HORIZON: Seend Ironsand, Lower Greensand Group.

Table i.cxxxiii

GRAIN-SIZE	<-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	62.2	48
Trans quartz	10.0	8
Pink quartz	2.5	2
Dark undiff chert	13.8	11
Dark bio	9.1	7
Dark dolo	2.6	2
Dark lam	2.1	2
Dark spic	4.4	3
Dark mottled	0.6	P
Sst undiff	0.4	P
Ironstone	6.1	5
Phosphorite	2.8	2
Sili volc	11.9	9
Total	128.5	
Q:C index		70
Q:S index		99
S:C index		1
I:P index		69
Dolo-index		8
Bio-index		28

LOCALITY: Hurst Hill, Culmnor, Oxfordshire.
SAMPLE NUMBER: 129hs1
HORIZON: Hurst Hill Sands, Lower Greensand Group.

Table i.cxxxiv

GRAIN-SIZE	<-1.5 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	6.4	62
Trans quartz	3.6	35
Dark undiff chert	0.1	1
Sst undiff	0.3	3
Total	10.4	

LOCALITY: Hurst Hill, Culmnor, Oxfordshire.
SAMPLE NUMBER: 129hs2
HORIZON: Hurst Hill Sands, Lower Greensand Group.

Table i.cxxxv

GRAIN-SIZE			-2.5 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	33	0.5	38
Trans quartz	2	67	0.8	62
Total	3		1.3	

Table i.cxxxvi

GRAIN-SIZE			-2.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	16	55	2.3	58
Trans quartz	6	21	0.9	23
Dark undiff chert	4	14	0.5	13
Sst undiff	1	3	0.2	5
Phosphorite	2	7	0.1	3
Total	29		4.0	

Table i.cxxxvii

GRAIN-SIZE	-1.5 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	10.9	48
Trans quartz	9.9	44
Dark undiff chert	1.5	7
Dark bio	0.3	1
Ironstone	0.1	P
Total	22.7	

LOCALITY: Hurst Hill, Culmnor, Oxfordshire.
SAMPLE NUMBER: 129hs4
HORIZON: Hurst Hill Sands, Lower Greensand Group.

Table i.cxxxviii

GRAIN-SIZE	< 1.5 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	8.9	60
Trans quartz	6.0	40
Total	14.9	

LOCALITY: Haredene Woods, Tisbury, Wiltshire.
SAMPLE NUMBER: 63g1
HORIZON: Gault Clay Formation.

Table i.cxxxix

GRAIN-SIZE	-2.75 ø		-2.5 ø	
LITHOTYPE	FREQ	%FREQ	FREQ	%FREQ
Opaque quartz	4	17	13	19
Trans quartz	8	35	16	23
Fibrous quartz	0	0	4	6
Dark undiff chert	4	17	31	44
Sst undiff	2	9	5	7
Ironstone	4	17	1	1
Qtz+tourm	1	4	0	0
Total	23		70	

LOCALITY: Haredene Woods, Tisbury, Wiltshire.
SAMPLE NUMBER: 63g2
HORIZON: Gault Clay Formation.

Table i.cxl

GRAIN-SIZE			-4.0 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	31	47.2	32
Dark undiff chert	3	19	29.9	20
Dark bio	3	19	25.8	17
Dark lam	1	6	14.6	10
Dark mottled	1	6	6.0	4
Radio chert	1	6	12.1	8
Phosphorite	1	6	7.3	5
Sili volc	1	6	6.9	5
Total	16		149.8	

Table i.cxli

GRAIN-SIZE			-3.5 ø	
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	44	43	156.7	41
Pink quartz	2	2	7.2	2
Fibrous quartz	4	4	13.6	4
Dark undiff chert	20	20	73.9	19
Dark bio	11	11	46.8	12
Dark ool	1	1	4.1	1
Dark dolo	2	2	6.3	2
Dark lam	3	3	15.8	4
Dark spic	8	8	31.6	8
Dark mottled	1	1	4.7	1
Radio chert	1	1	3.5	1
Sst undiff	4	4	13.3	3
Sili volc	1	1	6.2	2
Total	102		383.7	
Q:C index		52		49
Q:S index		93		93
S:C index		8		7
Dolo-index		24		26
Bio-index		4		3

Table i.cxlii

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	67	49	128.1	49
Trans quartz	3	2	5.1	2
Sheared quartz	2	1	4.4	2
Pink quartz	1	1	3.2	1
Fibrous quartz	3	2	7.1	3
Dark undiff chert	14	10	24.0	9
Dark bio	12	9	22.0	8
Dark ool	3	2	5.9	2
Dark dolo	4	3	8.3	3
Dark lam	6	4	11.3	4
Dark spic	2	1	3.0	1
Dark mottled	8	6	15.7	6
Sst undiff	4	3	6.9	3
Qtz+tourm	5	4	8.9	3
Mylo/cata	2	1	2.6	1
Sili volc	2	1	3.4	1
Total	138		259.9	
Q:C index		61		62
Q:S index		95		96
S:C index		8		7
Dolo-index		2		9
Bio-index		24		24

Table i.cxliii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	9	53	6.5	45
Trans quartz	1	6	1.0	7
Fibrous quartz	1	6	0.7	5
Dark undiff chert	2	12	1.9	13
Dark lam	1	6	1.2	8
Sst undiff	1	6	1.2	8
Ironstone	1	6	0.7	5
Phosphorite	1	6	1.1	8
Total	17		14.3	

Pebble beds sampled from Bedfordshire and Cambridgeshire

LOCALITY: Haddenham, Cambridgeshire.
SAMPLE NUMBER: 198ws1
HORIZON: Woburn Sands, Lower Greensand Group.

Table i.cxliv

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark dolo	1	50	1.2	46
Dark lam	1	50	1.4	54
Total	2		2.6	

Table i.cxlv

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	20	0.4	19
Dark dolo	2	40	0.8	38
Dark lam	1	20	0.4	19
Fe sst	1	20	0.5	24
Total	5		2.1	

Table i.cxlvi

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	11	0.3	11
Trans quartz	1	11	0.4	15
Dark undiff chert	1	11	0.3	11
Dark bio	2	22	0.5	19
Dark ool	1	11	0.3	11
Dark dolo	2	22	0.6	22
Fe sst	1	11	0.3	11
Total	9		2.7	

Table i.cxlvii

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	33	29	5.5	28
Granular quartz	1	1	0.3	2
Dark undiff chert	15	13	2.4	12
Dark bio	22	19	4.1	21
Dark dolo	9	8	1.3	7
Dark lam	5	4	0.9	5
Dark spic	3	3	0.4	2
Dark mottled	4	4	0.9	5
Dark intra	1	1	0.2	1
Dark pellet	5	4	0.9	5
Sst undiff	1	1	0.1	1
Ironstone	8	7	1.2	6
Fe sst	3	3	0.9	5
Phosphorite	1	1	0.2	1
Sili volc	2	2	0.4	2
Total	113		19.7	

LOCALITY: Haddenham, Cambridgeshire.
SAMPLE NUMBER: 198ws2
HORIZON: Woburn Sands, Lower Greensand Group.

Table i.cxlviii

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	50	4.8	56
Dark dolo	1	50	3.7	44
Total	2		8.5	

Table i.cxlix

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Fe sst	1	50	1.1	44
Sili volc	1	50	1.4	56
Total	2		2.5	

Table i.cl

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark bio	4	29	2.6	27
Dark dolo	2	14	1.1	12
Dark spic	4	29	2.5	26
Dark mottled	1	7	0.7	7
Sst undiff	1	7	0.6	6
Fe sst	1	7	1.0	11
Sili volc	1	7	1.0	11
Total	14		9.5	

Table i.cli

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	11	17	4.4	18
Dark undiff chert	14	22	4.7	19
Dark bio	8	12	3.2	13
Dark ool	1	2	0.2	1
Dark dolo	12	18	5.0	20
Dark lam	4	6	1.7	7
Dark spic	1	2	0.2	1
Dark mottled	6	9	1.9	8
Ironstone	1	2	0.3	1
Fe sst	6	9	2.8	11
Phos sst	1	2	0.4	2
Total	65		24.8	

Table i.clii

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	119	27.0	19.1	24.5
Trans quartz	22	5.0	2.9	4.0
Sheared quartz	1	P	0.1	P
Fibrous quartz	1	P	0.1	P
Granular quartz	15	3.5	2.6	3.5
Dark undiff chert	64	14.5	11.4	15.0
Dark bio	57	13.0	11.3	14.5
Dark ool	2	0.5	0.4	0.5
Dark dolo	52	12.0	9.2	12.0
Dark lam	15	3.5	3.1	4.0
Dark spic	20	4.5	4.0	5.0
Dark mottled	37	8.5	6.5	8.5
Dark intra	2	0.5	0.6	1.0
Dark pellet	9	2.0	1.8	2.5
Ironstone	13	3.0	1.9	2.5
Fe sst	9	2.0	1.5	2.0
Sili volc	3	0.5	0.7	1.0
Total	441		77.2	
Q:C index		38		34
Dolo-index		20		19
Bio-index		22		23

LOCALITY: Billington Crossing sandpit, Leighton Buzzard, Bedfordshire.
SAMPLE NUMBER: 195ws1
HORIZON: Woburn Sands, Lower Greensand Group.

Table i.cliii

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	1	20	2.1	18
Dark lam	1	20	3.3	28
Fe sst	3	60	6.3	54
Total	5		11.7	

Table i.cliv

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	3	4	4.0	4
Dark undiff chert	8	11	10.5	11
Dark bio	16	23	26.6	27
Dark dolo	4	6	4.8	5
Dark lam	1	1	1.7	2
Dark spic	5	7	8.3	8
Dark mottled	5	7	10.8	11
Dark pellet	1	1	1.1	1
Radio chert	1	1	3.0	3
Sst undiff	1	1	2.1	2
Fe lam	13	18	12.5	13
Fe sst	13	18	12.5	13
Total	71		97.9	

Table i.clv

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	44	21.0	25.7	19.0
Sheared quartz	3	1.5	2.4	2.0
Granular quartz	1	0.5	1.7	1.5
Dark undiff chert	21	10.0	13.8	10.0
Dark bio	29	13.5	20.8	15.5
Dark ool	1	0.5	0.7	0.5
Dark dolo	7	3.5	4.0	3.0
Dark lam	7	3.5	4.5	3.5
Dark spic	4	2.0	3.4	2.5
Dark mottled	10	4.5	5.5	4.0
Dark intra	2	1.0	1.8	1.5
Dark evap	1	0.5	0.6	0.5
Radio chert	1	0.5	0.5	0.5
Sst undiff	8	4.0	5.4	4.0
Ironstone	28	13.5	16.3	12.0
Fe sst	41	19.5	25.3	18.5
Sili volc	3	1.5	3.0	2.0
Total	211		135.4	
Q:C index		37		35
Q:S index		86		85
S:C index		11		9
Dolo-index		9		7
Bio-index		35		38

LOCALITY: Double Arches sandpit, Leighton Buzzard, Bedfordshire.
SAMPLE NUMBER: 196ws2
HORIZON: Woburn Sands, Lower Greensand Group.

Table i.clvi

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	2	29	3.0	29
Dark bio	1	14	1.4	13
Dark lam	2	29	2.9	28
Sst undiff	1	14	1.5	14
Sili volc	1	14	1.6	15
Total	7		10.4	

Table i.clvii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	8	38	5.1	41
Dark undiff chert	1	5	0.3	2
Dark bio	5	24	2.8	23
Dark dolo	2	10	0.9	7
Dark spic	1	5	0.4	3
Dark mottled	2	10	1.4	11
Sst undiff	1	5	0.6	5
Sili volc	1	5	0.8	7
Total	21		12.3	

Table i.clviii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	12	38	4.3	41
Dark undiff chert	3	9	0.8	8
Dark bio	7	22	2.1	20
Dark ool	1	3	0.4	4
Dark dolo	5	16	1.6	15
Dark lam	1	3	0.4	4
Dark mottled	2	6	0.6	6
Dark intra	1	3	0.2	2
Total	32		10.4	

Table i.clix

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	199	55.5	33.6	57.0
Trans quartz	31	8.5	5.2	9.0
Pink quartz	4	1.0	0.7	1.0
Dark quartz	1	0.5	0.1	P
Granular quartz	1	0.5	0.1	P
Dark undiff chert	23	6.5	4.5	7.5
Dark bio	34	9.5	4.8	8.0
Dark ool	5	1.5	0.7	1.0
Dark dolo	19	5.5	2.8	4.5
Dark lam	8	2.0	1.5	2.5
Dark spic	6	1.5	0.8	1.5
Dark mottled	12	3.5	1.8	3.0
Dark intra	1	0.5	0.2	0.5
Dark pellet	8	2.0	1.3	2.0
Dark evap	1	0.5	0.2	0.5
Sst undiff	2	0.5	0.3	0.5
Fe sst	1	0.5	0.2	0.5
Sili volc	2	0.5	0.3	0.5
Total	358		59.1	
Q:C index		67		68
Q:S index		99		99
S:C index		2		2
Dolo-index		16		15
Bio-index		29		25

LOCALITY: Double Arches sandpit, Leighton Buzzard, Bedfordshire.
SAMPLE NUMBER: 196gl
HORIZON: Gault Clay Formation.

Table i.clx

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark dolo	1	100	4.3	100
Total	1		4.3	

Table i.clxi

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	9	6.4	9
Dark undiff chert	9	17	13.4	19
Dark bio	13	24	15.9	22
Dark ool	1	2	1.3	2
Dark dolo	8	15	10.1	14
Dark lam	11	20	12.9	18
Dark spic	5	9	8.9	13
Sili volc	2	4	2.2	3
Total	54		71.1	

Table i.clxii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	43	16.0	24.9	15.5
Trans quartz	4	1.5	2.4	1.5
Pink quartz	3	1.0	1.4	1.0
Dark quartz	2	1.0	1.4	1.0
Dark undiff chert	39	14.5	23.9	15.0
Dark bio	44	16.5	26.8	16.5
Dark ool	1	0.5	0.4	P
Dark dolo	44	16.5	25.7	16.0
Dark lam	26	10.0	16.0	10.0
Dark spic	19	7.0	13.2	8.0
Dark mottled	26	10.0	14.6	9.0
Dark intra	1	0.5	0.9	0.5
Sst undiff	1	0.5	1.0	0.5
Sili volc	12	4.5	7.5	4.5
Total	265		160.1	
Q:C index		21		20
Q:S index		98		97
S:C index		<1		<1
Dolo-index		22		21
Bio-index		22		22

Table i.clxiii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	110	34.5	41.0	34.0
Trans quartz	15	4.5	4.8	4.0
Pink quartz	5	1.5	2.2	2.0
Fibrous quartz	1	0.5	0.4	0.5
Dark undiff chert	28	9.0	9.1	7.5
Dark bio	33	10.5	13.3	11.0
Dark ool	1	0.5	0.4	0.5
Dark dolo	53	16.5	21.0	17.5
Dark lam	25	8.0	9.7	8.0
Dark spic	16	5.0	6.2	5.0
Dark mottled	18	5.5	6.4	5.5
Dark intra	5	1.5	2.2	2.0
Sst undiff	4	1.5	1.6	1.5
Sili volc	6	2.0	2.8	2.5
Total	320		121.1	
Q:C index		42		41
Q:S index		97		97
S:C index		2		2
Dolo-index		30		31
Bio-index		18		19

Table i.clxiv

GRAIN-SIZE		-2.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1091	53.0	200.5	52.0
Trans quartz	301	14.5	53.6	14.0
Pink quartz	28	1.5	5.2	1.5
Fibrous quartz	1	P	0.3	P
Dark undiff chert	637	31.0	125.0	32.5
Sst undiff	5	P	0.8	P
Qtz+tourm	1	P	0.2	P
Total	2064		385.6	
Q:C index		69		67
Q:S index		100		100
S:C index		<1		<1

LOCALITY: Billington Crossing sandpit, Leighton Buzzard, Bedfordshire.
SAMPLE NUMBER: 195gl
HORIZON: Gault Clay Formation.

Table i.clxv

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	8	1.5	8
Dark undiff chert	2	15	3.9	22
Dark bio	2	15	3.9	22
Dark lam	2	15	2.5	14
Dark spic	1	8	1.5	8
Fe lam	3	23	3.0	17
Fe sst	2	15	1.8	10
Total	13		18.1	

Table i.clxvi

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	15	26	9.9	23
Sheared quartz	1	2	2.0	5
Granular quartz	1	2	2.2	5
Dark undiff chert	9	16	6.8	16
Dark bio	4	7	3.2	7
Dark ool	2	4	1.0	2
Dark dolo	12	21	7.0	16
Dark lam	3	5	2.6	6
Dark spic	1	2	0.8	2
Dark mottled	5	9	3.9	9
Dark intra	3	5	2.4	6
Phosphorite	1	2	1.7	4
Total	57		43.5	

Table i.clxvii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	21	33	8.8	34
Trans quartz	3	5	1.0	4
Dark undiff chert	32	50	12.7	49
Sst undiff	1	2	0.4	2
Ironstone	6	9	2.3	9
Phosphorite	1	2	0.5	2
Total	64		25.7	

Pebble beds sampled from the East Midlands

LOCALITY: Donington-on-Bain, Lincolnshire.
SAMPLE NUMBER: 206msnb2
HORIZON Mid-Spilsby Nodule Bed.

Table i.clxviii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Trans quartz	1	2	0.2	1
Pink quartz	1	2	0.2	1
Dark undiff chert	5	8	1.9	8
Dark bio	12	19	5.0	20
Dark ool	1	2	0.4	2
Dark dolo	14	23	5.4	22
Dark lam	8	13	2.9	12
Dark spic	5	8	2.3	9
Dark mottled	6	10	2.2	9
Dark intra	2	3	2.0	8
Dark pellet	2	3	1.0	4
Phosphorite	4	6	1.0	4
Phos bio	1	2	0.5	2
Total	62		25.0	

Table i.clxix

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	10	9	3.5	10
Dark undiff chert	20	17	5.6	16
Dark bio	16	14	4.6	13
Dark ool	3	3	1.0	3
Dark dolo	21	18	6.3	18
Dark lam	18	15	5.4	15
Dark spic	2	2	0.7	2
Dark mottled	9	8	3.0	9
Dark intra	10	9	2.9	8
Dark pellet	2	2	0.7	2
Dark evap	2	2	0.5	1
Sst undiff	1	1	0.3	1
Glauc sst	1	1	0.2	1
Sili volc	2	2	0.5	1
Total	117		35.2	
Q:C index		9		10
Q:S index		91		92
S:C index		<1		<1
Dolo-index		20		21
Bio-index		16		15

LOCALITY: Woods Hill, Nettleton, Lincolnshire.
SAMPLE NUMBER: 204cil
HORIZON: Claxby Ironstone Formation.

Table i.clxx

GRAIN-SIZE	-3.5 ø	
LITHOTYPE	FREQ	%FREQ
Dark bio	1	100
Total	1	

Table i.clxxi

GRAIN-SIZE	-3.0 ø	
LITHOTYPE	FREQ	%FREQ
Dark dolo	4	50
Dark lam	1	13
Dark pellet	1	13
Phos sst	2	25
Total	8	

Table i.clxxii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	5	8	2.2	7
Dark undiff chert	10	17	4.5	15
Dark bio	6	10	3.3	11
Dark ool	1	2	0.3	1
Dark dolo	14	24	7.2	24
Dark lam	5	8	2.4	8
Dark spic	2	3	0.9	3
Dark mottled	5	8	2.4	8
Sst undiff	1	2	0.5	2
Phos sst	10	17	6.4	21
Total	59		30.1	

Table i.clxxiii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	11	4.0	3.5	4.0
Trans quartz	1	0.5	0.5	0.5
Dark undiff chert	41	14.5	12.2	14.5
Dark bio	25	9.0	7.6	9.0
Dark ool	4	1.5	1.0	1.0
Dark dolo	76	27.0	21.7	26.0
Dark lam	27	9.5	7.6	9.0
Dark spic	11	4.0	3.0	3.5
Dark mottled	43	15.0	12.1	14.5
Dark intra	1	0.5	0.5	0.5
Phosphorite	1	0.5	0.4	0.5
Phos sst	36	12.5	11.8	14.0
Sili volc	6	2.0	1.8	2.0
Total	283		83.7	
Q:C index		5		6
Dolo-index		59		33
Bio-index		20		12

LOCALITY: Hunstanton, Norfolk
SAMPLE NUMBER: 199cl
HORIZON: Carstone Member.

Table i.clxxiv

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	5	1.1	2
Dark undiff chert	4	21	8.5	16
Dark bio	9	47	24.6	47
Dark dolo	1	5	5.8	11
Dark spic	1	5	3.3	6
Dark mottled	1	5	2.2	4
Ironstone	1	5	4.0	8
Phosphorite	1	5	2.9	6
Total	19		52.4	

Table i.clxxv

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	18	18	23.4	19
Pale undiff chert	1	1	0.6	P
Dark undiff chert	16	16	19.5	15
Dark bio	23	23	31.1	25
Dark ool	4	4	4.2	3
Dark dolo	5	5	4.8	4
Dark lam	4	4	4.7	4
Dark spic	5	5	5.7	5
Dark mottled	3	3	4.0	3
Dark intra	2	2	2.1	2
Sst undiff	2	2	3.8	3
Ironstone	3	3	3.2	3
Fe sst	7	7	9.9	8
Fe ool	2	2	2.1	2
Phosphorite	2	2	4.0	3
Sili volc	1	1	2.8	2
Total	98		125.9	

Table i.clxxvi

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	60	29.0	32.5	29.5
Trans quartz	5	2.5	2.6	2.5
Sheared quartz	1	0.5	0.6	0.5
Granular quartz	1	0.5	0.3	0.5
Dark undiff chert	27	13.0	14.0	13.0
Dark bio	20	9.5	9.9	9.0
Dark ool	3	1.5	2.6	2.5
Dark dolo	11	5.5	5.0	4.5
Dark lam	5	2.5	2.7	2.5
Dark spic	2	1.0	1.2	1.0
Dark mottled	5	2.5	2.6	2.5
Dark evap	1	0.5	0.7	0.5
Sst undiff	1	0.5	1.4	1.5
Ironstone	4	2.0	1.7	1.5
Fe sst	31	15.0	2.5	2.5
Fe ool	5	2.5	16.4	15.0
Phosphorite	22	10.5	11.6	11.0
Sili volc	2	1.0	1.3	1.0
Total	206		109.6	
Q:C index		48		48
Q:S index		99		96
S:C index		1		3
I:P index		65		64
Dolo-index		15		13
Bio-index		27		26

LOCALITY: Nettleton Bottom, Lincolnshire.
SAMPLE NUMBER: 205cl
HORIZON: Carstone Member.

Table i.clxxvii

GRAIN-SIZE		-4.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Lst bio g/p	1	100	24.3	100
Total	1		24.3	

Table i.clxxviii

GRAIN-SIZE		-4.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	1	20	7.0	12
Phosphorite	4	80	50.5	88
Total	5		57.5	

Table i.clxxix

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	2	18	6.7	17
Dark lam	1	9	4.0	10
Fe sst	4	36	13.1	33
Phos sst	2	18	8.2	21
Phos ool	2	18	7.8	20
Total	11		39.8	

Table i.clxxx

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	7	15	10.2	11
Fibrous quartz	1	2	1.6	2
Dark undiff chert	11	23	23.4	25
Dark bio	2	4	4.3	5
Dark dolo	1	2	2.1	2
Ironstone	2	4	4.3	5
Fe sst	4	9	8.5	9
Fe ool	8	17	17.0	18
Phosphorite	10	21	21.3	22
Phos ool	1	2	2.1	2
Total	47		94.8	

Table i.clxxxi

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	19	14	13.5	14
Trans quartz	2	2	1.3	1
Sheared quartz	1	1	0.8	1
Pink quartz	1	1	0.8	1
Dark undiff chert	5	4	3.9	4
Dark bio	7	5	5.0	5
Dark dolo	2	2	1.2	1
Dark lam	2	2	1.3	1
Dark spic	1	1	0.6	1
Dark mottled	2	2	3.0	3
Sst undiff	1	1	1.3	1
Ironstone	34	26	23.6	24
Fe sst	18	14	12.2	12
Fe ool	21	16	14.4	15
Phos sst	13	10	11.9	12
Phos ool	2	2	3.1	3
Sili volc	1	1	0.7	1
Total	132		98.6	
Q:C index		55		52
Q:S index		96		93
S:C index		5		8
I:P index		83		77
Dolo-index		11		8
Bio-index		37		33

Table i.clxxxii

GRAIN-SIZE	-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	29.3	37
Dark undiff chert	7.2	9
Sst undiff	1.1	1
Ironstone	40.6	51
Phosphorite	1.0	1
Total	79.2	

LOCALITY: Nettleton Bottom, Lincolnshire.
SAMPLE NUMBER: 205c2
HORIZON: Carstone Member.

Table i.clxxxiii

GRAIN-SIZE		-4.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Phos sst	2	100	93.0	100
Total	2		93.0	

Table i.clxxxiv

GRAIN-SIZE		-4.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	4	17	31.6	13
Ironstone	2	8	15.7	6
Phosphorite	18	75	195.0	80
Total	24		242.3	

Table i.clxxxv

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	2	2	8.5	2
Dark undiff chert	13	12	31.6	8
Dark bio	13	12	51.6	13
Dark ool	1	1	4.9	1
Dark dolo	4	4	14.1	4
Dark lam	6	5	20.4	5
Dark spic	5	4	16.3	4
Dark mottled	2	2	4.6	1
Dark intra	1	1	2.8	1
Fe lam	7	6	22.8	6
Fe sst	9	8	32.8	8
Fe ool	6	5	19.9	5
Phosphorite	6	5	23.4	6
Phos sst	36	32	137.5	35
Phos ool	1	1	3.7	1
Phos bio	1	1	2.7	1
Total	113		397.6	
Q:C index		4		5
I:P index		33		31
Dolo-index		9		10
Bio-index		29		35

Table i.clxxxvi

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	42	10.5	59.2	9.5
Trans quartz	2	0.5	2.4	0.5
Pink quartz	1	P	2.8	0.5
Granular quartz	2	0.5	2.4	0.5
Dark undiff chert	37	9.0	44.4	7.0
Dark bio	33	8.0	51.4	8.0
Dark ool	1	P	1.0	P
Dark dolo	7	1.5	13.6	2.0
Dark lam	4	1.0	5.5	1.0
Dark spic	7	1.5	8.2	1.5
Dark mottled	5	1.0	8.7	1.5
Sst undiff	4	1.0	5.3	1.0
Siltstone	1	P	0.8	P
Ironstone	2	0.5	2.5	0.5
Fe lam	98	24.0	152.1	24.0
Fe sst	36	9.0	57.5	9.0
Fe ool	23	5.5	31.8	5.0
Phosphorite	1	P	2.3	0.5
Phos sst	90	22.0	171.8	27.0
Phos ool	6	1.5	8.2	1.5
Sili volc	3	0.5	3.5	0.5
Total	405		635.4	
Q:C index		33		33
Q:S index		90		92
S:C index		5		4
I:P index		62		57
Dolo-index		7		10
Bio-index		35		39

Table i.clxxxvii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	126	13.5	86.1	13.5
Trans quartz	18	2.0	11.3	2.0
Sheared quartz	2	P	1.3	P
Pink quartz	1	P	0.8	P
Granular quartz	10	1.0	7.0	1.0
Dark undiff chert	75	8.0	37.8	6.0
Dark bio	43	4.5	27.4	4.5
Dark ool	2	0.5	1.4	P
Dark dolo	12	1.5	7.8	1.0
Dark lam	3	0.5	2.0	0.5
Dark spic	6	0.5	3.8	0.5
Dark mottled	8	1.0	5.0	1.0
Dark intra	2	P	1.5	P
Dark evap	2	P	1.5	P
Sst undiff	10	1.0	7.1	1.0
Fe lam	343	36.5	241.0	38.0
Fe sst	21	2.0	14.7	2.5
Fe ool	78	8.5	46.7	7.5
Fe pellet	1	P	0.5	P
Phosphorite	6	0.5	5.0	1.0
Phos sst	156	16.5	120.6	19.0
Phos ool	5	0.5	4.0	0.5
Phos bio	3	0.5	2.3	0.5
Sili volc	2	P	1.3	P
Total	935		637.9	
Q:C index		51		55
Q:S index		94		94
S:C index		6		7
I:P index		72		70
Dolo-index		8		9
Bio-index		28		31

LOCALITY: South Ferriby, Humberside.
SAMPLE NUMBER: 203c1
HORIZON: Carstone Member (lower).

Table i.clxxxviii

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Fe lam	3	60	11.4	59
Phosphorite	1	20	5.3	28
Phos sst	1	20	2.5	13
Total	5		19.2	

Table i.clxxxix

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Fe lam	5	29	6.9	30
Fe ool	3	18	2.6	11
Phosphorite	7	41	10.3	44
Phos sst	1	6	2.5	11
Phos ool	1	6	1.0	4
Total	17		23.3	

Table i.cxc

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	10	21	5.2	16
Dark undiff chert	1	2	0.5	2
Ironstone	12	25	7.9	24
Fe sst	2	4	1.0	3
Fe ool	7	15	3.3	10
Phosphorite	12	25	10.7	33
Phos sst	2	4	1.8	6
Phos ool	2	4	2.2	7
Total	48		32.6	

Table i.cxci

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	34	48	11.1	44
Dark undiff chert	3	4	1.4	5
Ironstone	12	17	4.5	18
Fe sst	7	10	2.6	10
Fe ool	1	1	0.4	2
Phosphorite	7	10	2.8	11
Phos sst	5	7	1.7	7
Phos ool	2	3	1.0	4
Total	71		25.5	

Table i.cxcii

GRAIN-SIZE	-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	65.2	67
Dark undiff chert	3.4	3
Ironstone	22.2	23
Phosphorite	7.1	7
Total	97.9	

LOCALITY: South Ferriby, Humberside.
SAMPLE NUMBER: 203c2
HORIZON: Carstone Member (upper).

Table i.cxciii

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Phos sst	1	100	3.2	100
Total	1		3.2	

Table i.cxciv

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Dark undiff chert	1	7	1.1	5
Ironstone	6	43	10.5	47
Fe sst	1	7	1.1	5
Fe ool	2	14	2.1	9
Phos sst	4	29	7.6	34
Total	14		22.4	

Table i.cxcv

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	8	20	4.6	17
Dark quartz	1	2	0.7	3
Dark undiff chert	1	2	0.5	2
Ironstone	15	37	10.7	39
Fe sst	2	5	1.6	6
Fe ool	9	22	5.8	21
Phos sst	3	7	2.8	10
Phos ool	1	2	0.6	2
Phos pellet	1	2	0.4	1
Total	41		27.7	

Table i.cxcvi

GRAIN-SIZE	-2.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	9	20	3.3	16.0
Trans quartz	8	18	2.9	14.0
Dark undiff chert	2	5	0.9	4.0
Sst undiff	1	2	0.6	3.0
Ironstone	14	32	8.1	40.0
Fe sst	1	2	0.6	3.0
Fe ool	9	20	3.8	19.0
Total	44		20.2	

Table i.cxcvii

GRAIN-SIZE	-2.0 ø	
LITHOTYPE	WEIGHT	%WT
Opaque quartz	24.6	48
Trans quartz	7.0	14
Sheared quartz	0.1	P
Fibrous quartz	0.2	P
Granular quartz	0.3	1
Dark undiff chert	1.9	4
Sst undiff	0.2	P
Ironstone	7.5	15
Fe sst	4.6	9
Fe ool	2.4	5
Phos sst	2.0	4
Phos ool	0.2	P
Total	51.0	

LOCALITY: Clixby, Lincolnshire.
SAMPLE NUMBER: 202cpb2
HORIZON: Mid-Spilsby Nodule Bed or the basal Claxby Ironstone Formation pebble bed.

Table i.cxcviii

GRAIN-SIZE	-3.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Glauc sst	1	100	1.4	100
Total	1		1.4	

Table i.cic

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	13	12	4.1	10
Dark undiff chert	17	16	6.4	16
Dark bio	11	10	4.6	12
Dark ool	3	3	1.1	3
Dark dolo	32	30	10.8	27
Dark lam	11	10	4.5	11
Dark spic	4	4	1.8	5
Dark mottled	11	10	4.1	10
Dark pellet	1	1	0.5	1
Dark evap	1	1	0.4	1
Sili wood	1	1	0.5	1
Glauc sst	1	1	0.8	2
Total	106		39.6	
Q:C index		12		11
Dolo-index		35		31
Bio-index		12		13

Table i.cc

GRAIN-SIZE	-2.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	49	15.5	13.3	14.5
Trans quartz	1	0.5	0.3	0.5
Dark undiff chert	73	23.0	20.0	21.5
Dark bio	18	5.5	5.1	5.5
Dark ool	5	1.5	1.4	1.5
Dark dolo	62	19.5	18.6	20.0
Dark lam	25	8.0	8.5	9.0
Dark spic	14	4.5	4.0	4.5
Dark mottled	37	11.5	10.6	11.5
Dark intra	1	0.5	0.6	0.5
Dark pellet	16	5.0	4.4	5.0
Dark evap	1	0.5	0.5	0.5
Sst undiff	1	0.5	0.3	0.5
Phosphorite	11	3.5	3.5	4.0
Sili volc	3	1.0	1.1	1.0
Total	317		92.2	
Q:C index		17		16
Q:S index		98		98
S:C index		<1		<1
Dolo-index		25		25
Bio-index		7		7

Pebble beds sampled from Normandy

LOCALITY: Vache Noires, Villers-sur-Mer, France.
SAMPLE NUMBER: 220g2
HORIZON: Gault Clay Formation.

Table i.cci

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	122	53.0	85.0	50.5
Trans quartz	15	6.5	9.2	5.5
Sheared quartz	11	5.0	18.4	11.0
Pink quartz	6	2.5	5.3	3.0
Dark quartz	4	1.5	3.1	2.0
Fibrous quartz	16	7.0	11.2	6.5
Granular quartz	3	1.5	2.2	1.5
Quartz+chlorite	8	3.5	6.6	4.0
Pale bio	2	1.0	1.3	1.0
Pale Rhax	4	1.5	1.6	1.0
Pale sandy	1	0.5	0.5	0.5
Pale spic	2	1.0	1.7	1.0
Dark lam	1	0.5	0.7	0.5
Dark mottled	2	1.0	1.1	0.5
Dark evap?	2	1.0	1.1	0.5
Quartz-veined cht	5	2.0	3.0	2.0
Sst undiff	11	5.0	7.3	4.5
Cherty sst	1	0.5	0.7	0.5
Phos sst	7	3.0	4.3	2.5
Phos ool	2	1.0	0.8	0.5
Phos pellet	1	0.5	0.4	P
Tourm brec	1	0.5	0.5	0.5
Mylo/cata	2	1.0	0.5	0.5
Jasper	1	0.5	0.4	P
Sili volc	1	0.5	1.6	1.0
Total	231		168.5	
Q:S index		94		95

LOCALITY: Cap de Hêve, Le Havre, France.
SAMPLE NUMBER: 221pf1
HORIZON: Poudingue Ferrugineux (base of).

Table i.ccii

GRAIN-SIZE	-4.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Granular quartz	1	50	57.5	69
Dark undiff chert	1	50	26.0	31
Total	2		83.5	

Table i.cciii

GRAIN-SIZE	-4.0 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	20	9.3	19
Pale undiff chert	2	40	13.9	28
Dark bio	1	20	11.7	24
Phosphorite	1	20	14.8	30
Total	5		49.7	

Table i.cciv

GRAIN-SIZE	-3.5 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	16	52	59.6	53
Trans quartz	1	3	3.0	3
Sheared quartz	2	6	7.8	7
Pale spic	2	6	8.0	7
Dark bio	1	3	3.7	3
Dark brec	1	3	3.1	3
Sst undiff	2	6	5.7	5
Red sst	1	3	2.0	2
Phosphorite	3	10	11.9	11
Mylonite	1	3	3.2	3
Sili volc	1	3	5.0	4
Total	31		113.0	

Table i.ccv

GRAIN-SIZE	-2.75 ø			
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	117	63.5	85.3	63.0
Trans quartz	9	5.0	6.8	5.0
Sheared quartz	5	2.5	3.3	2.5
Pink quartz	3	1.5	1.5	1.0
Dark quartz	1	0.5	0.6	0.5
Fibrous quartz	20	11.0	16.9	12.5
Granular quartz	1	0.5	0.9	0.5
Dark undiff chert	1	0.5	0.7	0.5
Dark bio	2	1.0	1.3	1.0
Dark lam	2	1.0	1.4	1.0
Quartz veined cht	3	1.5	2.6	2.0
Sst undiff	14	7.5	10.2	7.5
Pink quartzite	1	0.5	0.8	0.5
Phosphorite	4	2.0	2.4	2.0
Tourm brec	1	0.5	0.6	0.5
Total	184		135.3	
Q:S index		91		91

LOCALITY: Cauville, France.
SAMPLE NUMBER: 222pf1
HORIZON: Poudingue Ferrugineux.

Table i.ccvi

GRAIN-SIZE	-3.5 ø	
LITHOTYPE	FREQ	%FREQ
Granular quartz	1	50
Phosphorite	1	50
Total	2	

Table i.ccvii

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	17	41	26.4	42
Fibrous quartz	6	15	9.3	15
Granular quartz	1	2	1.2	2
Quartz+chlorite	1	2	1.8	3
Dark bio	2	5	3.0	5
Dark lam	1	2	1.8	3
Dark spic	1	2	1.7	3
Dark mottled	1	2	2.1	3
Dark brec	1	2	1.3	2
Sst undiff	2	5	3.1	5
Fe lam	1	2	0.8	1
Phos sst	5	12	6.6	11
Mylonite	1	2	1.7	3
Sili volc	1	2	1.7	3
Total	41		62.5	
Q:S index		93		93

Table i.ccviii

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	31	42	20.9	42
Trans quartz	4	5	2.8	6
Sheared quartz	4	5	2.6	5
Fibrous quartz	9	12	5.3	11
Granular quartz	5	7	3.9	8
Pale spic	1	1	0.5	1
Dark undiff chert	1	1	0.8	2
Dark lam	1	1	0.7	1
Dark mottled	2	3	1.5	3
Dark intra	1	1	0.8	2
Sst undiff	2	3	1.3	3
Ironstone	1	1	0.9	2
Fe lam	5	7	2.8	6
Fe sst	1	1	0.6	1
Phosphorite	1	1	0.6	1
Phos sst	4	5	2.5	5
Mylonite	1	1	1.0	2
Total	74		49.5	
Q:S index		96		96

LOCALITY: St. Jouin, France.
SAMPLE NUMBER: 223pf1
HORIZON: Poudingue Ferrugineux.

Table i.ccix

GRAIN-SIZE		-3.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	1	50	2.8	48
Granular quartz	1	50	3.0	52
Total	2		5.8	

Table i.ccx

GRAIN-SIZE		-3.0 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	4	50	6.1	56
Fibrous quartz	1	13	0.9	8
Dark bio	1	13	1.2	11
Phosphorite	1	13	1.6	15
Phos sst	1	13	1.1	10
Total	8		10.9	

Table i.ccxi

GRAIN-SIZE		-2.75 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	14	33	8.8	33
Trans quartz	1	2	0.5	2
Sheared quartz	1	2	0.6	2
Dark quartz	1	2	0.5	2
Fibrous quartz	2	5	1.0	4
Granular quartz	3	7	1.9	7
Pale spic	1	2	0.3	1
Dark mottled	1	2	0.7	3
Dark brec	2	5	1.3	5
Sst undiff	5	12	3.8	14
Fe lam	2	5	1.0	4
Fe sst	6	14	4.4	16
Phos sst	2	5	1.5	6
Sili volc	1	2	0.7	3
Total	42		27.0	

Table i.ccxii

GRAIN-SIZE		-2.5 ø		
LITHOTYPE	FREQ	%FREQ	WEIGHT	%WT
Opaque quartz	24	40	7.8	37
Trans quartz	7	12	2.3	11
Sheared quartz	3	5	1.1	5
Pink quartz	2	3	0.7	3
Fibrous quartz	6	10	2.7	13
Granular quartz	2	3	0.9	4
Dark bio	1	2	0.3	1
Dark lam	1	2	0.3	1
Dark mottled	1	2	0.3	1
Sst undiff	1	2	0.4	2
Fe lam	5	8	1.6	8
Fe sst	5	8	2.1	10
Phos sst	1	2	0.4	2
Sili volc	1	2	0.4	2
Total	60		21.3	

APPENDIX II

CLASSIFICATIONS, SAMPLE PREPARATION AND PETROGRAPHICAL INVESTIGATION METHODS

APPENDIX II

CLASSIFICATIONS, SAMPLE PREPARATION AND PETROGRAPHICAL INVESTIGATION METHODS

Phenoclasts were studied by a variety of methods following their preparation. Samples were dried and sieved down to +3.5 ø (0.088mm) using a "Ro-tap" shaker. Sieve divisions of 0.25 ø were used for fractions greater than 0 ø (1mm) and 0.5 ø sieve divisions for the coarser-grained fractions. Each sieve load was weighed. Grains of less than -2.0 ø (greater than 4mm) were removed for further study. The Udden-Wentworth grain-size classification for sediment grains (after Pettijohn et al., 1972) has been modified to subdivide the pebble fraction (-2 to -6 ø) into four divisions (Fig. ii.ia).

The samples were examined by size-fraction groups using a binocular microscope with reflected-light facilities. After initial laboratory examinations, each fraction group was separated into lithological categories. Clast roundness and sphericity were estimated using the visual aid charts of Krumbein (1941) and Powers (1953). Roundness estimates calculated by both analytical and visual chart methods have been shown to be inaccurate (Folk, 1955, 1972) and little improvement was noted with the use of more detailed charts. However, visual differences in clast roundness certainly exist. It was considered suitable, therefore, to make rapid estimations of roundness and for this purpose Powers' roundness divisions (Fig. ii.ib) were used in preference to Krumbein's.

Clast sphericity was approximated by the use of the "Form Triangle" of Sneed & Folk (1958; Fig. ii.iia). More accurate calculations of clast shape were made from a random selection of clasts from a sample population. The maximum projection sphericity, form index and oblate-prolate index of the clasts were calculated by the method of Sneed & Folk (1958) and Dobkin & Folk (1970; Fig. ii.iib).

The limestone, chert, ironstone and phosphorite clasts have been classified according to the terminology of Dunham (1962; Fig. ii.iii) for the reasons defined in Chapter II. Sandstone clasts have been defined using a combination of the Crook (1960) and Dott (1964) classifications (Fig. ii.iv).

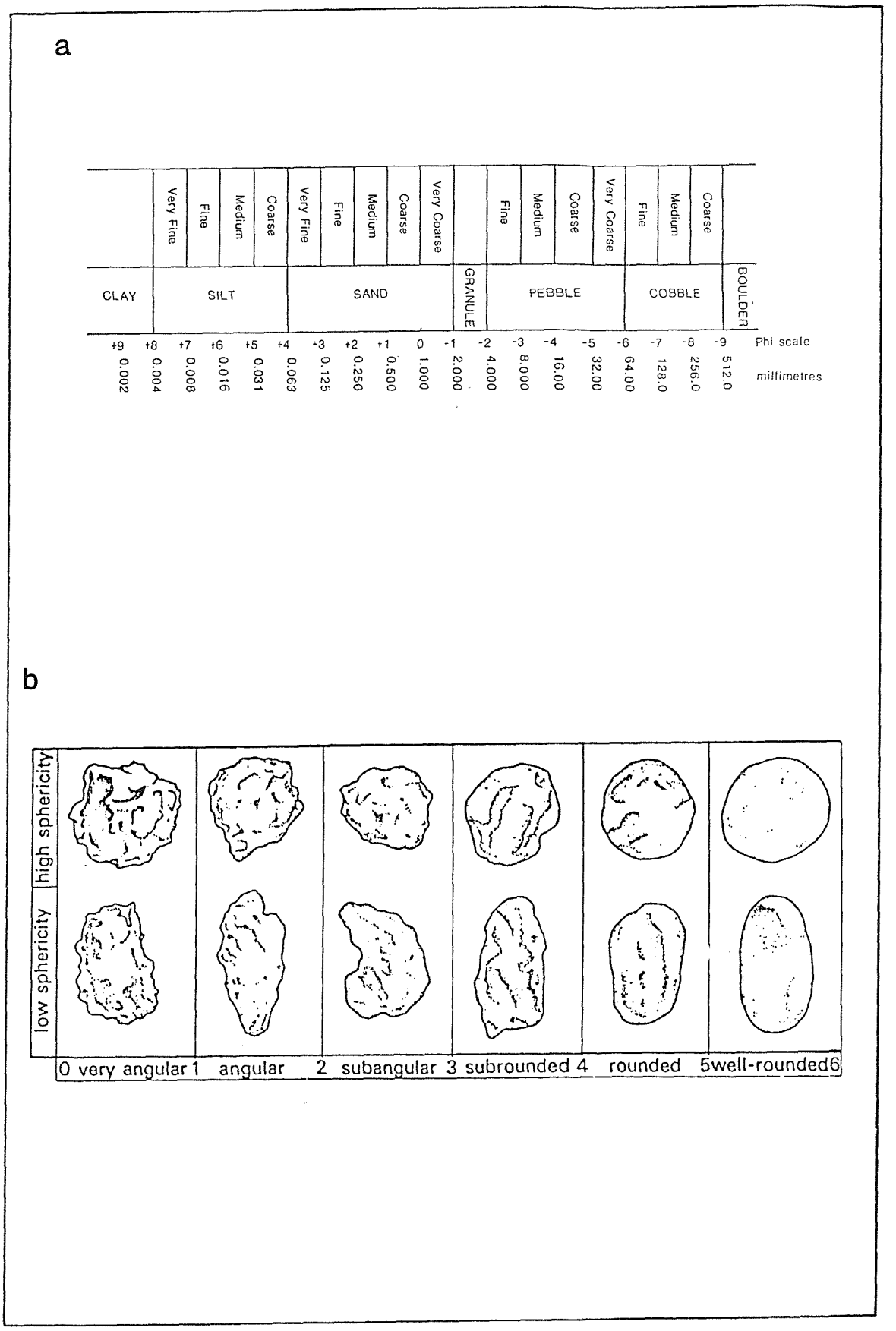


Figure ii.i Categories of particle grain-size classification (a; modified from the Wentworth-Udden scale) and roundness for sediment grains (b; after Powers, 1953).

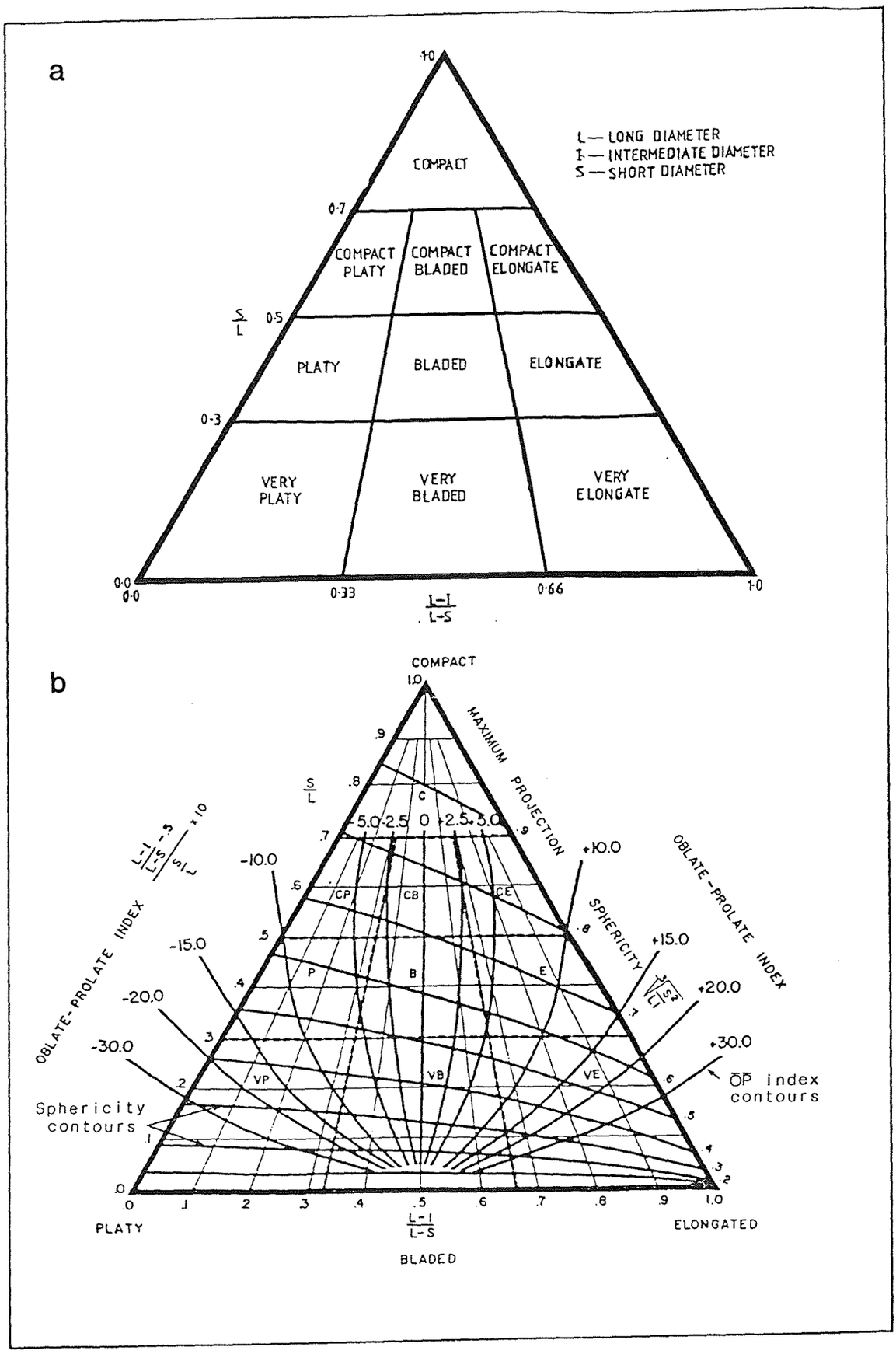


Figure ii.ii Form triangle for the classification of sediment grains (a; after Sneed & Folk, 1958), and the shape-measurement diagram, with sphericity and $\bar{OP}$ index contours (b; after Dobkin & Folk, 1970).

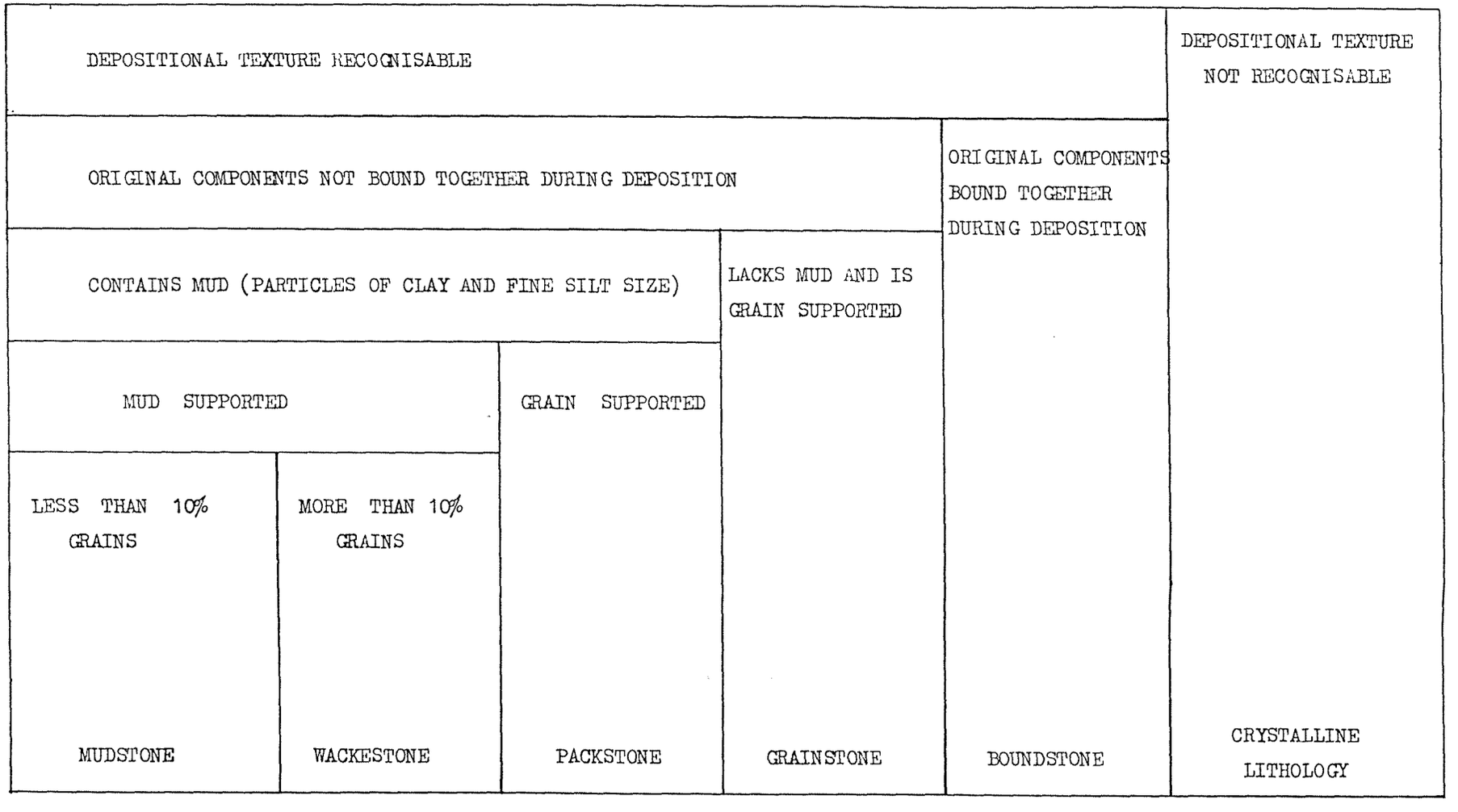


Figure ii.iii Classification of carbonate and replaced carbonate rocks by depositional texture (after Dunham, 1962).

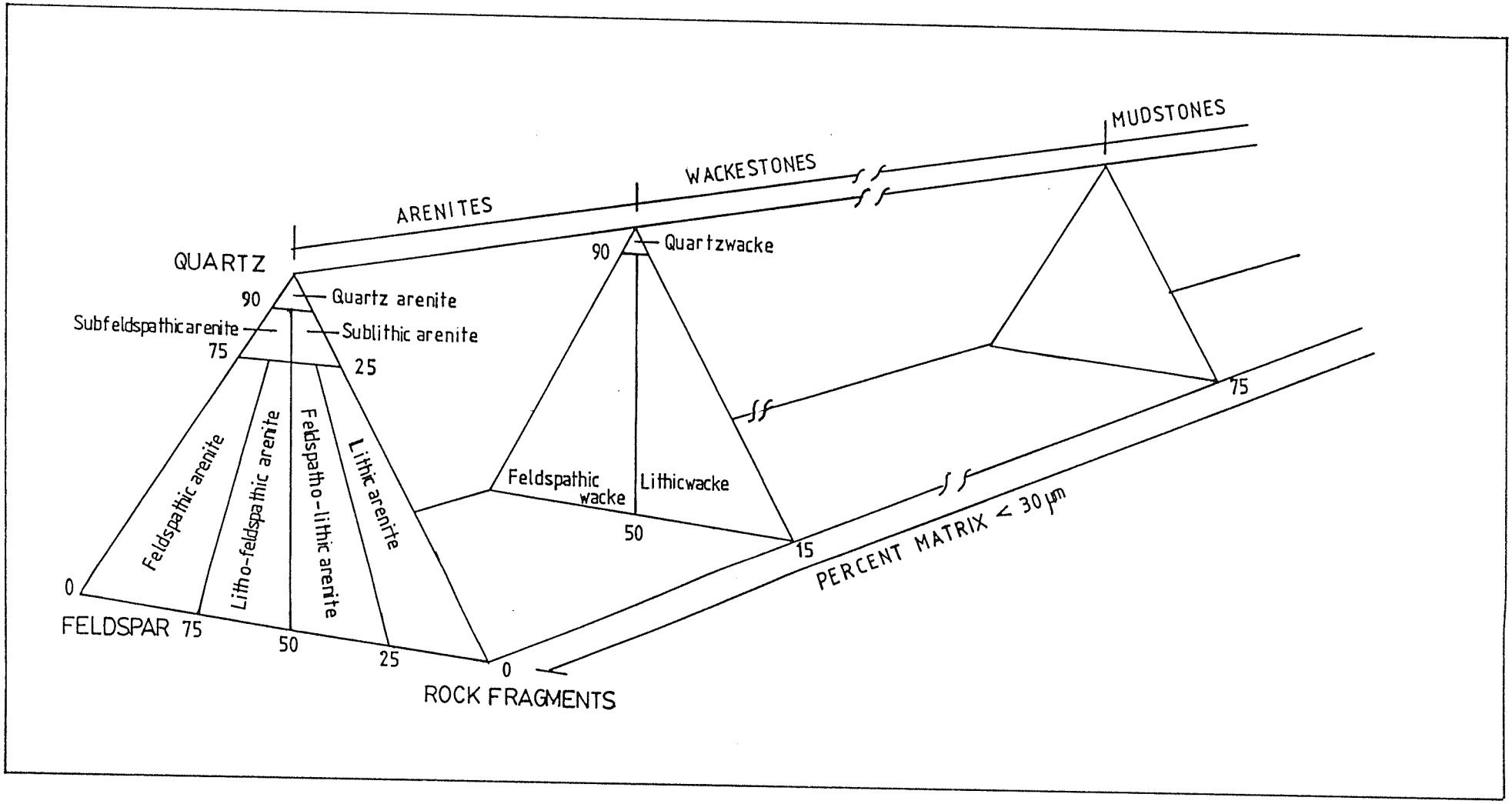


Figure ii.iv Classification of arenaceous rocks (after Crook, 1960; Dott, 1964).

Having completed the initial description of the pebble suite, chert and unidentified clasts were etched in dilute hydrofluoric acid. Hydrofluoric acid etching was carried out in order to enhance the surface textures of the cherts. Clasts were etched in 20% HF for two minutes, removed and washed in distilled water. The pebbles were then placed in dilute sodium hydroxide solution for two minutes and then rewashed in flowing tap water for several minutes.

Chalcedony etches more rapidly than microquartz (Pl. 7-6) and megaquartz is typically unaffected by the etching technique (Pl. 7-4, 7-6). After completing the etching, chert pebbles were separated into subgroups using the binocular microscope. Dark vein-quartz, tourmalinites and silicified volcanics generally were unaffected by this process.

The abundances of the phenoclast types in the suites were calculated from the groupings made by binocular microscopy. The frequency and weight of the clast types were calculated as percentages of the total population. Samples were then selected for more detailed investigation (Sect. 4.1.1). The methods used included the examination of cut and polished samples by reflected or transmitted light microscopy. Where necessary, samples were examined by scanning electron microscopy (S.E.M.) techniques. S.E.M. studies were made using an I.S.I. 60a scanning electron microscope with energy dispersive X-ray analyser (E.D.X.) attachment and back-scatter facility. X-ray diffraction (X.R.D.) investigations were made using a Philips 1010 X-ray diffractometer. Clay fractions and pebble bed iron cements were examined by X.R.D. in addition to selected pebbles. An investigation of quartz crystallinity in chert nodules and pebbles was made and the techniques and results are described in Appendix IV.

A comprehensive study of phenoclasts and potential source rocks was carried out by transmitted light microscopy. Thin sections of standard thickness were used. Staining of the thin sections was carried out by Dickson's method (1965).

APPENDIX III

NATIONAL GRID REFERENCES OF SAMPLE AND TEXT LOCALITIES

APPENDIX III

NATIONAL GRID REFERENCES OF SAMPLE AND TEXT LOCALITIES

The location and national reference of the pebble-bed and potential source-rock sample localities are given here. In addition, other localities as described in the text are also listed. Abbreviations for the sample horizon or horizons are also given.

AVON

Black Rock Quarry (B.R.L.), (ST 561 746).
Black Down (H.G.), (ST 474 574).
Burrington Combe (B.R.L.), (ST 477 584).
Great Quarry (C.D.L.), (ST 564 741).
Leigh Woods (B.R.L.), (ST 559 744).
Middle Hope (B.R.L.), (ST 339 666).
Worlebury (C.D.L.), (ST 377 633).

BEDFORDSHIRE

Billington Crossing Sandpit,
Leighton Buzzard (W.S, G.C.F.), (SP 931 240).
Double Arches Sandpit,
Leighton Buzzard (W.S, G.C.F.), (SP 940 288).
Tiddensfoot Sandpit,
Leighton Buzzard (W.S.), (SP 913 236).

CAMBRIDGESHIRE

Haddenham (W.S.), (TL 469 755).

CORNWALL

Fire Beacon Point (F.B.C.), (SX 108 924).
Pillaton (C.F.), (SX 371 643).
Trebarwith Strand, (SX 049 870).

DERBYSHIRE

Dirtlow Rake (Q.R.),	(SK 149 818).
Pindale Quarry (P.L.),	(SK 161 824).

DEVON

Ashburton Down (C.F.),	(SX 771 727).
Budleigh Salterton (B.S.P.B.),	(SY 051 816).
Burrator Quarry (T.R.),	(SX 545 678).
Overton Quarry (C.F.),	(SS 573 294).
Tawstock (C.F.),	(SS 552 298).

DORSET

Acton Quarries, Acton (m.P.F.),	(SY 989 783).
Black Ven, Charmouth (G.C.F.),	(SY 358 933).
Burning Cliff, Ringstead (P.L.F.),	(SY 762 816).
Durlston Bay, central (P.F.),	(SZ 036 783).
Durlston Bay, north (P.F.),	(SZ 040 786).
Dungy Head (P.L.F.),	(SY 816 800).
Durdle Door promontory, east (W.F., G.C.F.),	(SY 807 803).
Durdle Door promontory, west (W.F.),	(SY 806 803).
Fossil Forest (P.F.),	(SY 832 797).
Friar Wadden (P.L.F., P.F),	(SY 641 861).
Golden Cap, Charmouth (G.C.F.),	(SY 406 920).
Harden's Quarry, Acton (P.F.),	(SY 799 793).
Holworth House (P.L.F., P.F., W.F.),	(SY 762 806).
Houns-Tout Cliff (P.L.F.),	(SY 951 773).
Kingsbarrow Quarry, Portland (P.L.F., P.F.),	(SY 687 727).
Lulworth Cove (P.L.F., P.F., W.F.),	(SY 829 799).
Mupe Bay (W.F.),	(SY 844 800).
Osmington Mills (C.G., G.C.F.),	(SY 735 818).
Portesham Quarry, Portesham (P.F.),	(SY 611 859).
Poxwell Quarry, Poxwell (P.L.F., P.F.),	(SY 743 836).
Punfield Cove (G.C.F.),	(SZ 039 812).
Redcliff (C.G.),	(SY 708 819).
Ringstead Bay (K.C.F.),	(SY 760 815).
St. Alban's Head (P.L.F.),	(SY 959 757).
St. Oswald's Bay (W.F., G.C.F.),	(SY 816 800).
Stair Hole (P.F., W.F.),	(SY 824 798).
Stonebarrow (G.C.F.),	(SY 377 930).

Swanage Bay (W.F.), (SZ 036 807).
Thorncombe Beacon (G.C.F.), (SY 435 914).
Upway Quarry, Upway (SY 671 851).
West Weare, Portland (P.L.F.), (SY 681 719).
Winspit Quarry (P.L.F.), (SY 978 762).
Worbarrow Bay (W.F.), (SY 864 803).
Worbarrow Tout (P.F.), (SY 869 796).

GWENT

Trefil (O.H.L., Q.C.), (SQ 123 134).

HAMPSHIRE

Aldersnapp Farm, Petersfield (G.C.F.), (SU 728 244).
Holly Hill, Liss (F.B.F.), (SU 823 313).
Huntingford Bridge Sandpit,
Haslemere (F.B.F.), (SU 821 389).

HUMBERSIDE

Rifle Butts Quarry, Market Weighton (H.M.), (SE 898 426).
South Ferriby Quarry, South Ferriby (C.M., H.M.), (SE 204 994).

ISLE OF WIGHT

Coombe Farm Sandpit, Brightling (S.F., C.M.), (SZ 429 838).
Compton Bay (P.B., F.S.F., S.F., C.M.), (SZ 367 852).
Monks Bay (S.F., C.M.), (SZ 579 780).
Redcliff (P.B., F.S.F., C.M.), (SZ 621 857).
Rock (S.F., C.M.), (SZ 425 839).

KENT

Addington (F.B.F.), (TQ 651 596).
Baker's Gap, Folkestone (F.B.F., G.C.F.), (TR 249 364).
Brabourne Lees (F.B.F., G.C.F.), (TR 090 402).
Lenham Heath Sandpit, Lenham Heath (F.B.F.), (TQ 911 498).
Moorhouse Sandpit, Moorhouse (F.B.F.), (TQ 418 536).

LINCOLNSHIRE

Clixby (C.P.B.), (TA 103 044).
Donington-on-Bain (M.S.N.B.), (TF 245 822).
Ludford (C.M.), (TF 181 888).
Moses Farm, (S.S.F.), (TF 249 812).
Nettleton Bottom Chalk Pit, Nettleton (C.M., H.M.), (TF 126 982).
North Wilmington (S.S.F.), (TF 176 884).
Woods Hill Sandpit, Nettleton (S.S.F., C.I.F.), (TF 108 994).
Red Hill, Goulceby (C.M., H.M.), (TF 665 807).

MID GLAMORGAN

Little Island, Barry (P.B.L.), (SS 167 644).
Trwyn-y-Witch (P.B.L.), (SS 886 727).

NORFOLK

Hunstanton (C.M., H.M.), (TF 674 418).
Snettisham (C.M.), (TF 686 348).

OXFORDSHIRE

Cothill Quarry, Cothill (C.G.), (SU 468 997).
Hurst Hill, Oxford (H.H.S.), (SP 476 042).
Littleworth Pit, Oxford (U.L.B.), (SP 589 055).
Stanford Sandpit, Stanford (C.G.), (SU 327 942).
Wicklesham Pit, Faringdon (F.S.G.), (SU 294 943).

POWYS

Cribarth, Abercrave (O.H.L.), (SN 832 142).
Ystradfellte (O.H.L.), (SN 923 135).

SOMERSET

Cheddar Gorge (H.L.), (ST 471 541).
Dulcote Hill (C.D.L.), (ST 572 441).
Simon's Combe (H.G.), (ST 132 423).
Woolston Quarry (B.S.P.B.), ST 094 401).
Wormister Sleight (M.M.G.), (ST 577 432).
Wurt Pit (H.B.), (ST 559 539).

SURREY

Chilworth road-cutting, Chilworth (F.B.F.), (TQ 021 484).
Compton Sandpit, Guildford (B.B.F.), (SU 956 474).
Easing (H.B.F.), (SU 948 436).
Nutfield (H.B.F.), (TQ 313 501).
Steadhill, Godalming (H.B.F.), (SU 965 432).

SUSSEX

Burton School (G.C.F.), (SU 974 173).
Duncton road-cutting, Duncton (G.C.F.), (SU 961 175).
Fittleworth Station Sandpit,
Fittleworth (G.C.F.), (TQ 007 181).

WEST GLAMORGAN

Three Cliffs Bay (P.B.L.), (SS 535 879).

WILTSHIRE

Coate Reservoir, Swindon (U.L.B.), (SU 173 828).
Haredene Woods, Tisbury (G.C.F.), (ST 964 290).
Seend Sandpit, Seend (S.I.), (ST 937 600).
Swindon railway-cutting, Swindon (B.S.C.P.B., U.L.B.), (SU 152 831 - SU 150 830).
Upper Chicksgrove Quarry (P.L.F., P.F.), (ST 962 295).
Wardour Castle (G.C.F.), (ST 934 268).

YORKSHIRE

North Grimstone (C.G.), (SE 847 674).

BOULONNAIS (FRANCE)

Cap de Gris Nez (C.G.N.).
Pointe de la Rochette (R.C.).
Wimereux (T.C.).

CALVADOS (FRANCE)

Caen Chateau (C.C.).
Hennequeville (C.H.).
Pont en Bassin (C.B.).
Villers-sur-Mer (G.C.F.).

CAUX (FRANCE)

Cap de Hève (Sa.F., P.F.).
Cauville (Sa.F., P.F.).
Octeville (P.F.).
St. Jouin (P.F.).

Abbreviations of sample horizons

B.B.F.	-	Bargate Beds Formation, Cretaceous System.
B.R.L.	-	Black Rock Limestone, Carboniferous System.
B.S.P.B.	-	Budleigh Salterton Pebble Bed, Triassic System.
C.C.	-	Calcaire de Caen, Bathonian Stage, Jurassic System.
C.G.N.	-	Calcaire de Gris Nez, Oxfordian Stage, Jurassic System.
C.H.	-	Calcaire de Hennequeville, Oxfordian Stage, Jurassic System.
C.M.	-	Carstone Member, Cretaceous System.
C.F.	-	Chert Formation, Carboniferous System.
C.I.F.	-	Claxby Ironstone Formation, Cretaceous System.
C.D.L.	-	Clifton Down Limestone, Carboniferous System.
C.P.B.	-	Clixby Pebble Bed, Cretaceous System.
C.G.	-	Corallian Group, Jurassic System.
F.S.G.	-	Faringdon Sponge Gravel, Cretaceous System.
F.S.F.	-	Ferruginous Sands Formation, Cretaceous System.
F.B.C.F.	-	Fire Beacon Chert Formation, Carboniferous System.
F.B.F.	-	Folkestone Beds Formation, Cretaceous System.
G.C.F.	-	Gault Clay Formation, Cretaceous System.
H.G.	-	Hangman Grit, Devonian System.
H.B.	-	Harptree Beds, Triassic or Jurassic System.
H.T.L.	-	High Tor Limestone, Carboniferous System.

H.L.	-	Hotwells Limestone, Carboniferous System.
H.M.	-	Hunstanton Member, Cretaceous System.
H.H.S.	-	Hurst Hill Sands, Cretaceous System.
H.B.F.	-	Hythe Beds Formation, Cretaceous System.
K.C.F.	-	Kimmeridge Clay Formation, Jurassic System.
M.M.G.	-	Mercian Mudstone Group, Triassic System.
M.S.N.B.	-	Mid-Spilsby Nodule Bed, Cretaceous System.
O.H.L.	-	Oxwich Head Limestone, Carboniferous System.
P.B.L.	-	Penmaen Burrows Limestone, Carboniferous System.
P.B.	-	Perna Bed, Cretaceous System.
P.L.	-	Pindale Limestone, Carboniferous System.
P.L.S.	-	Portland Limestone Formation, Jurassic System.
P.F.	-	Poudingue Ferrugineux, Cretaceous System.
P.G.M.	-	Preston Grit Member, Corallian Group, Jurassic System.
P.F.	-	Purbeck Formation, Jurassic and Cretaceous System.
Q.C.	-	Quartz conglomerate, Carboniferous System.
Q.R.	-	Quartz rock, Carboniferous or Permian System.
R.C.	-	Rochette conglomerate, Portlandian Stage, Jurassic System.
Sa.F.	-	Sable Ferrugineux, Cretaceous System.
S.F.	-	Sandrock Formation, Cretaceous System.
S.I.	-	Seend Ironsand, Cretaceous System.
S.S.F.	-	Spilsby Sandstone Formation, Jurassic and Cretaceous Systems.
T.C.	-	Tour de Croi, Kimmeridgian Stage, Jurassic System.
T.R.	-	Tourmalinized rock, Carboniferous or Permian System.
U.L.B.	-	Upper Lydite Bed, Jurassic System.
W.F.	-	Wessex Formation, Cretaceous System.
W.S.	-	Woburn Sands, Cretaceous System.
W.D.B.	-	Woo Dale Beds, Carboniferous System.

APPENDIX IV

CHERT CRYSTALLINITY AND THE DISTINCTION BETWEEN CHERT TYPES BY X-RAY DIFFRACTION

APPENDIX IV

CHERT CRYSTALLINITY AND THE DISTINCTION BETWEEN CHERT TYPES BY X-RAY DIFFRACTION

Cherts form a significant proportion of the coarse-grained detrital suites studied and are distinguished by their petrographical characteristics and clast morphology (size, roundness and sphericity). An X-ray diffraction (X.R.D.) investigation of the detrital and source cherts was made as a complementary technique to standard petrographical methods. Previous work on siliceous rocks by X.R.D. has concentrated upon the transition from opaline silica, through the metastable opal-CT phase to α-quartz (Mizutani, 1970). This transition occurs normally over a relatively short geological time interval (a few million years). The British Jurassic and Carboniferous cherts studied do not contain detectable opal, but opaline silica has been reported from Upper Cretaceous flints in southern England (Jeans, 1978; Clayton, 1984) and in Corallian Group mudrocks (Milodowski & Wilmot, 1984).

In the present study, an attempt to distinguish between different chert types was made using silica-crystallinity. The work was based on the hypothesis that the silica crystallinity in cherts increases with age or depth of burial and therefore would be a potential method for distinguishing Palaeozoic and Mesozoic cherts.

The silica-crystallinities of the cherts investigated have been estimated by two techniques:

1. the Quartz Crystallinity Index (QCI) of Murata & Norman (1976);
2. the $20.85^{\circ}2\theta$ α-quartz peak index (20.85° index; detailed later in this appendix).

Methods

The chert samples were crushed and hand picked to remove as much of the host limestone, chert cortices and patina as possible. Samples were then ground in an agate pestle and passed through a 63μm mesh sieve. The results indicated that there was minimal variation of crystallinity in powders finer than 120μm.

Samples were run in triplicate for both crystallinity-estimation

techniques, at a scan speed 1/40 min. with nickel filtered K_α copper radiation. A chart speed of 1.27 mm/min, and a time constant of two were used.

The QCI was calculated from the 68° quintuplet of peaks by scanning from 66.5° to 70.5° 2θ at 1x10 counts/sec. To calculate the index, the ratio between the height of the 67.74° 2θ peak above the base level is taken (Fig. iv.ia, Equation iv.iii). The ratio is multiplied by ten and a constant to give a sample of rock-crystal a QCI value of 10 (Equation iv.iv). The peak shape varies with crystallinity from a broad hump to five sharply defined peaks (Fig. iv.iia).

The 20.85° 2θ index was developed, since the QCI did not clearly distinguish between the Carboniferous and Jurassic chert types studied. The 20.85° index was recorded by scanning from 19.00° to 21.50° 2θ at 1x10 counts/sec. The crystallinity was measured from the 20.85° 2θ peak by taking the ratio of peak height to peak width at the half peak height position (Fig. iv.ib, Equation iv.i). A maximum crystallinity was taken from a sample of inclusion-free euhedral rock-crystal. Its crystallinity ratio was raised to ten by using a constant (G) divided by ten (Equation iv.ii). The 20.85° index may also be estimated by calculating the asymmetry of the peak at half peak-height width, or the area under the peak from 19.00° to 21.50° 2θ.

Jurassic cherts and an Upper Cretaceous flint produced broad and positively skewed medium-size 20.85° 2θ peaks with a low mound between 19.00° and 20.50°. Carboniferous limestone cherts produced higher and more symmetrical 20.85° 2θ peaks without a pre-peak mound. Samples of quartz crystals and some probable hydrothermal cherts produced traces with very sharp, tall peaks. The QCI produced similar but less conclusive results. The Jurassic cherts in general gave less well defined peaks (lower QCI) than the Carboniferous cherts.

Results

This analysis was made principally on chert nodules and bedded cherts but a number of chert pebbles from Lower Cretaceous pebble beds were also examined.

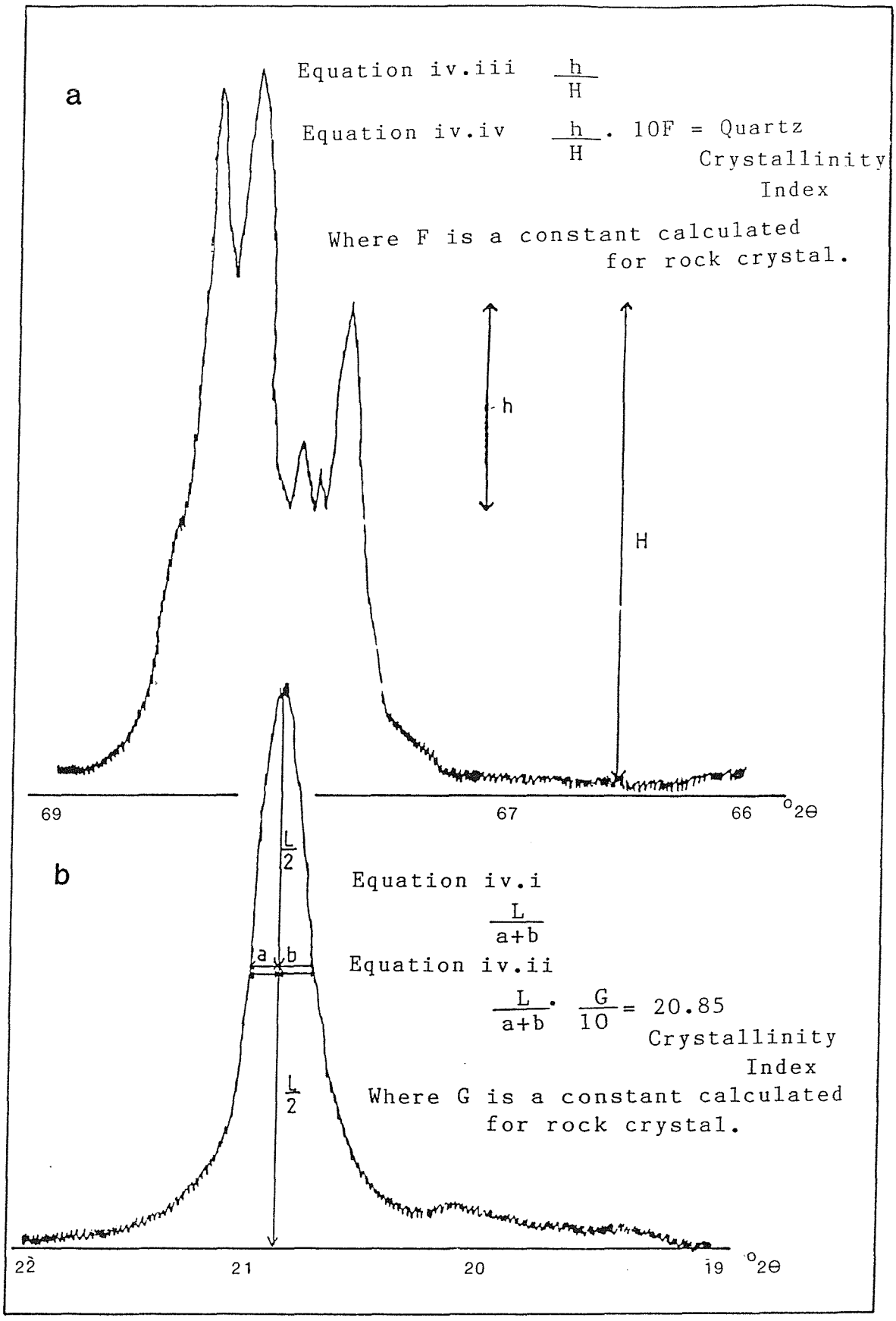


Figure iv.i Spectrometer traces for the 68° 2θ α-quartz quintuplet of peaks (a), with parameters used for the calculation of the Quartz Crystallinity Index and for the 20.85° 2θ α-quartz peak (b), with parameters used for the calculation of the 20.85° Crystallinity.

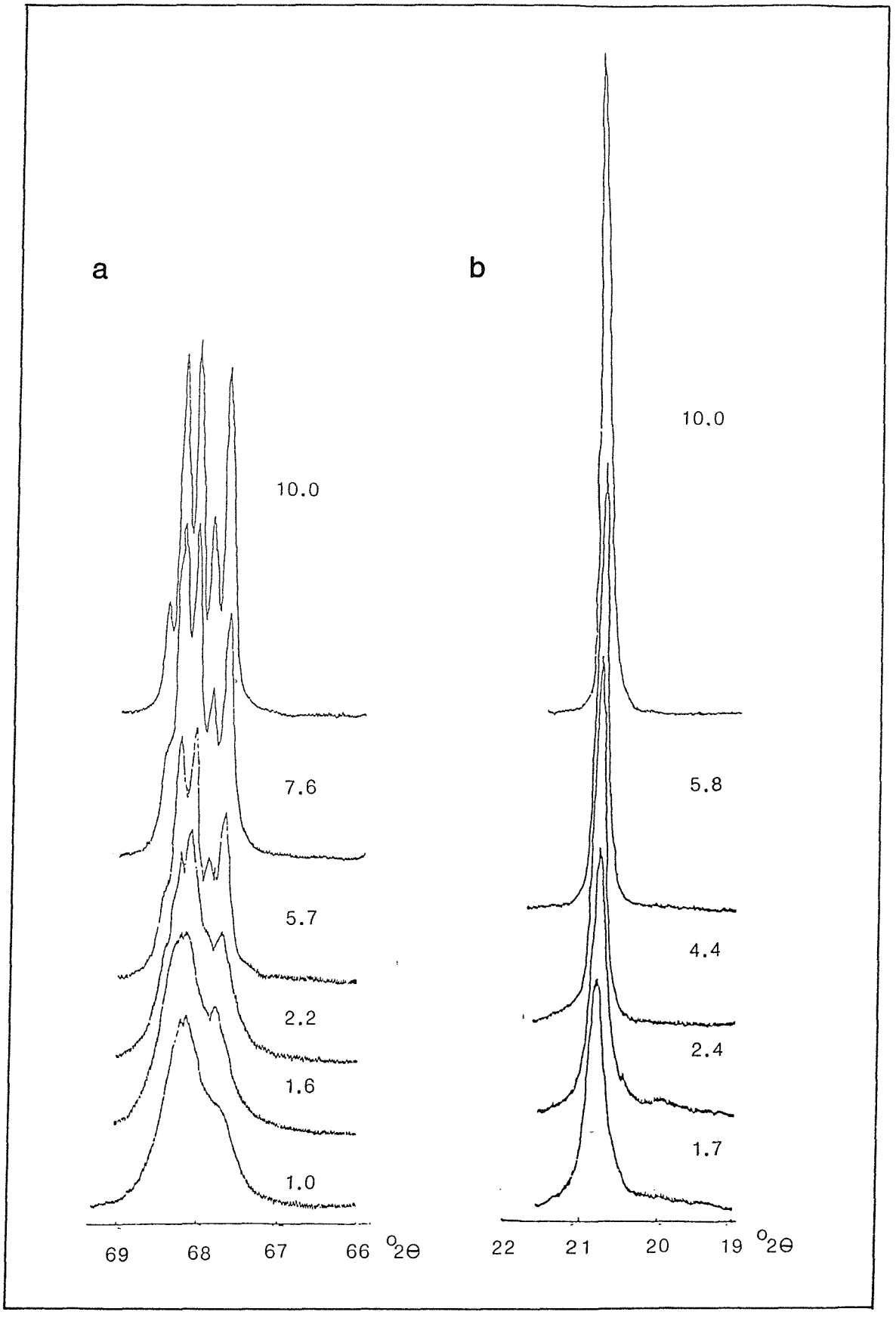


Figure iv.ii Spectrometer tracings of the 68° 2θ quintuplet peaks (a) and the 20.85° 2θ peak (b), in the order of increasing quartz crystallinity.

The X.R.D. investigation has shown that the cherts studied may be separated into at least four groups;

1. Jurassic cherts (possibly including Cretaceous flint),
2. Carboniferous limestone cherts,
3. Culm chert, and
4. metasomatically silicified Upper Triassic and Jurassic rocks.

The X.R.D. traces appear to separate the different siliceous rocks, but they must be used in conjunction with petrographical studies in order to ascertain their full significance. The Jurassic cherts tend to have low QCI and 20.85° index values (QCI, 1.0 to 2.7; 20.85° index, 0.9 to 4.2, Fig. iv.iiia). The Carboniferous limestone cherts plot with slightly higher QCI and 20.85° index values (QCI, 2.2 to 3.5; 20.85° index, 3.0 to 5.0; Fig. iv.iiia), but overlap the Jurassic chert field. Carboniferous basinal cherts from Devon and Somerset have moderate QCI and 20.85° index values and appear to plot as a separate group (QCI 5.0 to 7.0; 20.85° index, 7.5 to 11.0; Fig. iv.iiia). Samples from the Harptree Beds (silicified Lower Lias) have very high crystallinity values (QCI 9.0 to 11.0; 20.85° index, 10.0 to 12.0; Fig. iv.iiia).

The Carboniferous limestone cherts were from the Black Rock Limestone (Chadian Stage) and the Clifton Down Limestone (Holkerian Stage) in the Mendips and from the Pindale Limestone (Asbian Stage) in Derbyshire. The Black Rock Limestone cherts are crinoidal and brachiopodal packstones and spicular packstones. The bioclasts are replaced by flamboyant megaquartz or microflamboyant microquartz. The groundmass is of microquartz. The Clifton Down Limestone cherts are foraminiferal and brachiopodal packstones and wackestones, some of which contain Lithostrotion corals. The fabrics are similar to those of the Black Rock Limestone, but the corals may be replaced by coarsely crystalline megaquartz. Brachiopodal grainstones cemented by chalcedonite were also sampled from the Clifton Down Limestone. The Pindale Limestone cherts are foraminiferal, crinoidal and brachiopodal wackestones and packstones, with similar silica fabrics to those described above. The Carboniferous limestone cherts contain variable amounts of organic matter and pyrite but a negligible quantity of clay. Calcite is often found in small amounts, especially in crinoidal cherts. In such cherts, ossicles were

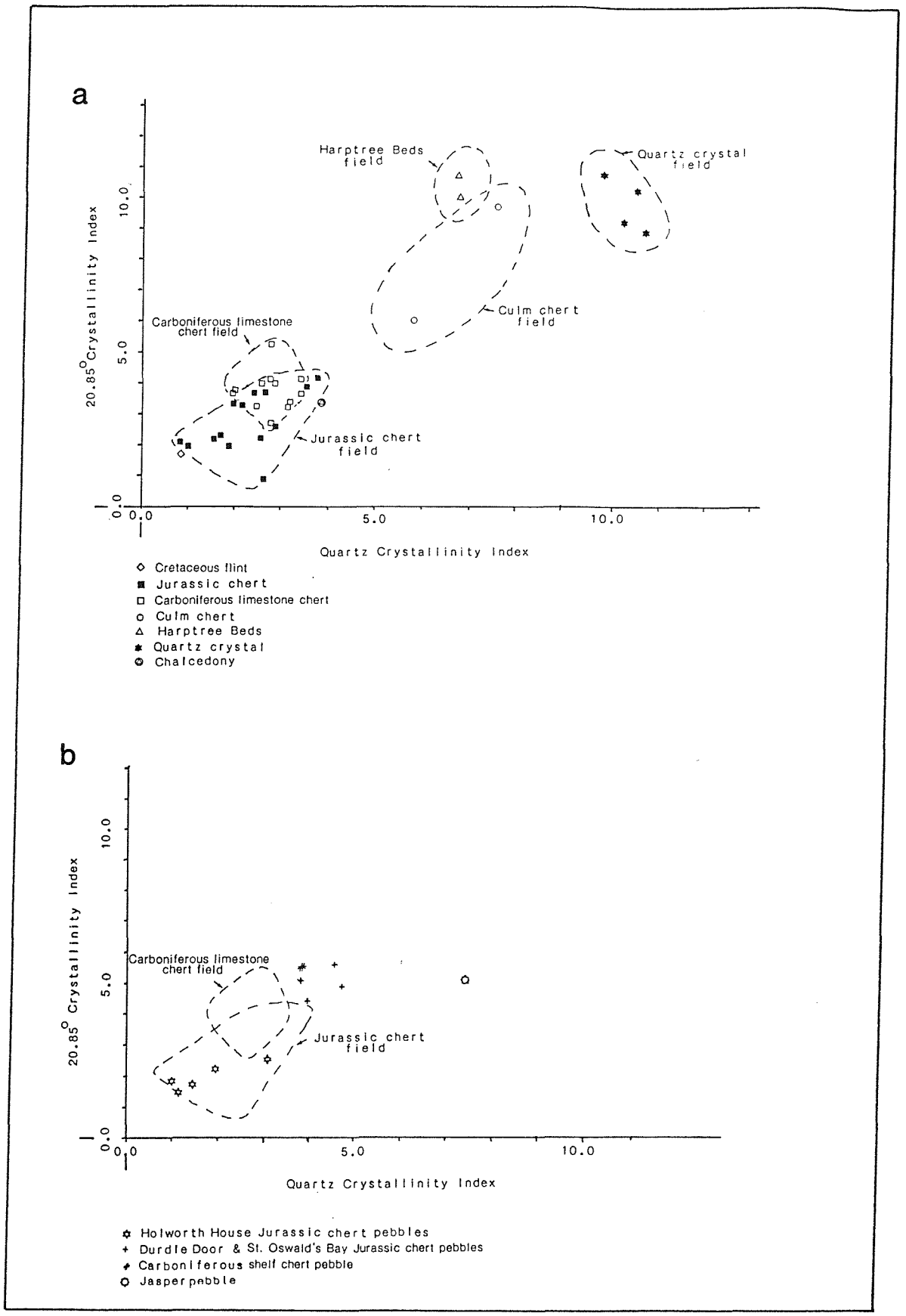


Figure iv.iii Cross-plot of Quartz Crystallinity Index and 20.85° Index, for chert and quartz samples (a) and for phenoclast samples (b).

resistant to replacement.

Jurassic cherts have been collected from the Portland Limestone and Purbeck Formations. The Portland Limestone Formation cherts include oolitic, spicular and bioclastic grainstones with megaquartz cements. The bioclasts are replaced by megaquartz, chalcedony or microflamboyant microquartz and the ooids are replaced by micro- or megaquartz. Bioclastic and Rhaxella packstones and wackestones with microquartz matrices were also sampled. The Purbeck Formation cherts include silicified bioclastic packstones with similar fabrics to those of the Portland Limestone Formation cherts. Samples of silicified evaporites from the basal Purbeck Formation containing lutecite, quartzine and chalcedonite replacements were included in the suite studied.

The cherts from the Lower Carboniferous rocks of Devon and Somerset are typically dark grey, laminated siliceous mudstones with radiolaria, sponge spicules and rhombic-pseudomorphs after dolomite. These cherts contain minor amounts of chlorite. Sponge spicules and radiolaria are replaced by chalcedony or megaquartz. The chert matrices are of microquartz. The crystallite size of the microquartz is comparable to that of the Carboniferous and Jurassic silicified limestones. Quartz-veins cross-cut the cherts.

The Harptree Beds (silicified Lower Lias; Green & Welch, 1965) sampled are composed of quartz sand grains supported in matrices of microquartz. Bioclasts were not recognised. The microquartz crystallites in the matrix are slightly larger than those of the Carboniferous and Jurassic cherts but are less than 20μm in diameter.

Phenoclasts

Relatively few detrital clasts were studied by these X.R.D. methods, but those that were examined displayed interesting variations.

Nine samples of Jurassic chert clasts from the basal Gault Clay Formation in Dorset have been examined. The cherts were cleaned but the clast cortices were not removed prior to the analysis. When plotted (Fig. iv.iiib), the clasts form two groups.

1. clasts with low crystallinity values which plot in the Jurassic

chert field (see above; Fig. iv.iiib). These are from the basal Gault Clay Formation at Holworth House and include skeletal packstones and wackestones. The cherts are relatively unaltered, dark grey and black with vitreous cores. The pebbles differ little in appearance from cherts in situ.

2. clasts with moderate to high crystallinity values (QCI 3.8 to 4.8; 20.85° index 5.2 to 6.7; Fig. iv.iiib), greater than those of the Jurassic or Carboniferous limstone cherts. This suite of Jurassic chert phenoclasts is from the basal Gault Clay Formation at Durdle Door promontory and St. Oswald's Bay. The cherts are Rhaxella packstones and oolitic and bioclastic grainstones. The clasts are iron stained and weathered with white surfaces and pale grey centres.

Relatively few Carboniferous chert pebbles were examined because of their small size. However, those studied generally have higher crystallinity values than the Jurassic and Carboniferous limestone chert nodules.

Discussion

The Carboniferous, Jurassic and Cretaceous chert types display a general trend of increasing crystallinity with increasing age. However, the Culm chert and the Harptree Beds have discrepantly high crystallinity values. A trend of increasing quartz crystallinity with age was also recognised by Murata & Norman (1976). However in a study of silicified wood, Stein (1982) did not confirm the pattern. Murata & Norman (1976) ascribed the increasing crystallinity trend of aggrading crystallite size with burial, but also noted that crystallinity values were higher for cherts of hydrothermal origin.

The Portland Limestone Formation and Carboniferous limestone cherts differ in their allochthonous components, but both types are the replacements of shallow-marine limestones. The Jurassic cherts more frequently contain chalcedonic cements and replacements compared with the samples of Carboniferous limestone chert. In the latter, replacement of bioclasts is by length-slow or length-fast chalcedony and undulose megaquartz, and megaquartz cements are more common than chalcedony cements. It is probably the presence of less well ordered chalcedony in the Jurassic cherts which results in their lower crystallinity values. Note that the sample of chalcedony has

significantly lower QCI and 20.85° index values than the rock crystal (Fig. iv.iiib).

The two groups of Jurassic chert phenoclasts may be separated by three criteria:

1. location,
2. petrographic fabrics and
3. state of preservation.

The sample sites at Durdle Door promontory and St. Oswald's Bay are in an area where the Gault Clay Formation is overturned and faulted. In contrast, the Holworth House area is folded into a gentle anticline (Phillips, 1964). Whether or not the tectonic event could have resulted in physical changes in the chert is uncertain, but the evidence indicates that it is doubtful. There is evidence for cementation of the chalk along the middle limb of the Purbeck Monocline (Mimran, 1975; Jones et al., 1984), but there is no evidence of similar effects in the Gault Clay or Wessex Formations.

The petrographical variation between the two groups is a result of differing source areas and this may also be important. Samples from Durdle Door promontory and St. Oswald's Bay included a greater proportion of grainstones than the Holworth House samples. The grainstones have megaquartz and chalcedonite cements and the higher crystallinities may be due to the greater crystallite size. However, finely crystalline Rhaxella packstones from these localities also have high crystallinity values.

The third factor which distinguishes the two suites is the state of weathering of the clasts. A feature typical of the Jurassic detritus present in the Lower Cretaceous pebble beds in Dorset and the Isle of Wight is the rough surface texture of the clasts and the thick white cortices (Tripolite; Keller, 1978). The Jurassic chert pebbles weather more readily than the Carboniferous shelf chert pebbles in the Lower Greensand Group pebble beds of the Isle of Wight and the Culm chert pebbles in the Cretaceous pebble beds of Dorset. It is possible that the selective weathering of certain components in the chert results in a higher crystallinity value. The weathered cherts show a series of stages of alteration from the chert margin to core. The initial phase of alteration is the colouration of spherulitic chalcedonite. The chalcedonite becomes increasingly brown, turbid and indistinct. The commencement of alteration of the

chalcedonite is followed by the microquartz of the matrix becoming more turbid. This proceeds until the individual crystallites are no longer recognisable. Chalcedonic-overlay cement and microquartz replacement of bioclasts are more resistant to alteration. Megaquartz is unaffected by weathering. The weathering appears to affect the chalcedonic form of silica most readily. This is possibly associated with the greater water content in chalcedony relative to megaquartz (Folk & Weaver, 1952; Folk, 1974). Included water in silica is also likely to increase the degree of disorder in the quartz crystal lattice and therefore reduces the crystallinity of the cherts. If weathering caused water to be released from the chalcedony then the overall crystallinity of the chert may increase. This implies that the crystallinity of quartz may be a measure of its ordering in addition to crystallite size. Hence, during burial, water-bearing silica in chert may mature by dewatering and become more highly ordered.

Conclusions

The preliminary investigation of cherts of Carboniferous and Jurassic age by X.R.D. has shown that the method is potentially a useful tool in differentiating between chert types incorporated into pebble beds. A tentative positive correlation between chert-age and crystallinity is suggested. This possibly results from aggrading neomorphism of the silica or its increased ordering with time and depth of burial. Very high crystallinity values in cherts possibly result from metamorphism or hydrothermal alteration.