9. The provenancing of flint artefacts using palynological techniques

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The provenancing of flint artefacts has proved problematic in the past. Acid maceration to extract age-diagnostic organic-walled microplankton from sedimentary materials is a technique routinely employed in both industrial hydrocarbon exploration and Quaternary studies. Here we assess the application of this technique to provenance determination of flint nodules from three locations (two in southern England and one in the Inner Hebrides, Scotland), each of which has abundant local evidence of flint utilization for artefact manufacture in prehistory. We show that, whilst not all flint nodules yield abundant or well preserved organic-walled microfossil assemblages, there is a significant potential for the use of this technique, which deserves further investigation.

Introduction

Archaeological studies of chert and flint sourcing properties

For most of prehistory, tools with sharp and durable edges were made by flaking stone. Material requirements for the most effective flaked stone tools are hardness, fine-grained texture, and a homogeneous and isotropic structure. Natural glasses, notably obsidian, were therefore highly prized as raw materials in prehistory, but outcrops tend to be scarce and highly localized. Chert and flint are also high quality raw materials for flaked stone tool making, for similar reasons. In western Europe, chert and flint are relatively abundant and were therefore used for the majority of prehistoric stone tools. There is much interest in determining the specific sources of raw materials used for tool making, when tools are recovered from archaeological sites. Tracking the human transport of raw materials and finished tools across the landscape can give us insights into both individual and group mobility, and trade and exchange networks. However, the same conditions of formation of chert and flint which make it highly prized as a raw material also make it relatively difficult to source to specific outcrops and secondary sources. Considerable ingenuity has therefore been applied to attempts to provenance chert and flint artefacts in the archaeological record (Luedtke 1992).

Petrographic techniques include macroscopic characterization by colour, texture, and visible inclusions (e.g. Larick 1986), and microfacies analysis of thin sections (Surmely *et al.* 1998). Chemical analyses have included studies of major and trace element composition by X-ray fluorescence spectroscopy (Markham and Floyd 1998 – Cornish Neolithic greenstone artefacts), atomic emission spectroscopy (e.g. Sieveking *et al.* 1970), atomic absorption spectroscopy (e.g. Craddock *et al.* 1983) and neutron activation analysis (e.g. Sieveking *et al.* 1972; Aspinall and Feather 1972; de Bruin *et al.* 1972; Luedtke 1978; 1979; Julig *et al.* 1991; Hoard *et al.* 1993; Cackler *et al.* 1999). These methods have often been successful in discriminating between chert or flint sources when the materials have no differentiating macroscopic traits. However, attribution of an artefact to a source (as opposed to elimination of some possible sources) presupposes complete knowledge of the characteristics of all potential source outcrops and secondary deposits, and this is rarely the case (Shackley 1998).

Sourcing by analysis of mineralized microfossil inclusions within flints has included studies of foraminifera (e.g. Reid 1984) and of radiolarians (e.g. Pollock *et al*. 1999). Palynological sourcing has also been used successfully in flint and chert sourcing studies in the past, although the results have often been preliminary and subject to further refinement of knowledge of the biostratigraphy of potential source exposures (e.g. Valensi 1955; 1960; Deflandre 1966; Mauger 1984; Brooks

Era	*Period*	*Epoch*	*Age*	*Duration (millions of years)*	*Commenced (Ma)*
Cenozoic	Paleogene	Paleocene	Danian	4.5	65.0
Mesozoic	Cretaceous	Late	Maastrichtian	6.3	71.3
			Campanian	12.2	83.5
			Santonian	2.3	85.8
			Coniacian	3.2	89.0
			Turonian	4.5	93.5
			Cenomanian	5.4	98.9
		Early	Albian	13.3	112.2
			Aptian	8.8	121.0
			Barremian	6.0	127.0
			Hauterivian	5.0	132.0
			Valanginian	5.0	137.0
			Berriasian	7.2	144.2

Table 9.1 Geological timescale for the latest Mesozoic and Early Cenozoic (dates from Gradstein et al. *1995).*

1989a; 1989b). Most of the previous studies investigated either thin flakes, chips or polished thin sections of flint, and were thus severely limited by the often low abundance of microfossils in the flints being investigated; this method can also be very time consuming as it requires lengthy microscopical examination of several duplicate thin sections to isolate sufficient specimens for a meaningful interpretation of the microfossil assemblages. More recently, palynological sourcing of flint artefacts has employed acid digestion techniques, whereby dissolution of the siliceous matrix of the flints releases a concentrated residue of microfossils, enabling more efficient collection of more robust datasets (e.g. Glover *et al*. 1993; Wrenn and Heinrich 1996). The widespread application of micropalaeontological techniques has, perhaps, been inhibited by the belief that (as was suggested for the English Chalk flints) 'the method would not seem to be generally suitable for this purpose. The fossil content is likely to be fairly uniform in a single stratigraphic division of the chalk, which may cover a wide geographical area' (Sieveking *et al*. 1972, 152). Another inhibiting factor may be the belief that different sources cannot be discriminated in space, if each source location has a long vertical (i.e. temporal) rock sequence with internal variability.

Flint: its nature and occurrence in the Upper Cretaceous of north-west Europe

The present study is a preliminary exploration of the potential for sourcing British Chalk flint primarily by analysis of its dinoflagellate cyst components. Whilst flint and other types of siliceous nodules have formed in many different lithologies throughout geological history, in north-west Europe flint is usually associated with the areally extensive outcrops of the Upper Cretaceous Chalk. The chalk deposits of the Anglo-Paris Basin were deposited during the Late Cretaceous (Table 9.1), in unusual depositional conditions that promoted rapid accumulations of calcareous deposits (rates perhaps as high as 15cm/1000 years, and with a total chalk accumulation of ≥500m, Luedtke 1992, 28). Chalk originated as a biogenic ooze consisting of the skeletal remains of many billions of single-celled calcareous planktonic organisms (e.g. coccoliths, foraminifera, etc.), but which also incorporated organic-walled microplankton (OWM). Over time the carbonate-rich oozes became lithified into the great thicknesses of chalk we see today. However, certain horizons of the Upper Chalk sequence are characterized by a preponderance of flint nodules. Flint is a term used to describe a particular form of chalcedonic silica, which is cryptocrystalline and porous in structure. Compositionally flints are comprised of minute plates and rods of alpha quartz (SiO_2), which range from 0.2–30.0μm in length and around 0.6μm thick. The misorientation of the crystallites results in interstitial pore spaces filled with fluid. Theories of syngenetic and epigenetic nodule formation have now given way to the accepted tenet that the flint nodules in the Upper Cretaceous Chalk formed by diagenetic precipitation of silica within the carbonate ooze (e.g. Anderton *et al.* 1979), although the process of precipitation of the nodules is still incompletely understood. Some flints demonstrate an internal continuity of sedimentary structures from the surrounding chalk, thus confirming the diagenetic theory. It is believed that remobilized opaline silica (resulting from the dissolution of siliceous microplankton – e.g. diatoms and radiolaria – and sponge spicules) nucleated in sites rich in decaying organic matter due to modifications of the local geochemistry. Nodules probably precipitated as early diagenetic opaline silica, which, through later solution and reprecipitation, transformed firstly into cristobalite and then into chalcedonic silica.

The non-carbonate component of the calcareous oozes (such as clays, phosphates and organic matter) varied both laterally and vertically, and these materials are often preserved within the fabric of the flint nodules. The lateral variation in the composition and abundance of these components in flints is less pronounced than the vertical variation throughout the chalk sequence, and it is this phenomenon that has been utilized in the sourcing investigations undertaken to date (Sieveking *et al.* 1972). Previous palynological investigations have demonstrated that in many instances the OWM deposited along with the calcareous oozes have also been preserved within the fabric of the siliceous flints as they grew within the sediments.

The Chalk lithofacies of north-west Europe was deposited over a period of >30 million years, and the species composition of OWM assemblages changed markedly over geological time. The most common flints from the Upper Chalks occur parallel to bedding, although some exhibit cross-cutting relationships. Laterally equivalent flints from a particular horizon may therefore contain dateable assemblages of OWM. Species level identification of the fossil OWM macerated from the flints should therefore enable comparison of the assemblages with established biostratigraphical zonation schemes, thus determining the relative age of the flint material. It should therefore prove possible to date a given flint nodule/artefact, and to compare this date with the ages of known outcrop sources for local flint. Since its deposition, the north-west European Chalk has been folded, which has resulted in the bedding now being slightly inclined, resulting in exposures of different stratigraphic levels in different local geographical areas. This means that biostratigraphic markers can be used as geographical markers today.

In a similar manner to the ecological controls on the distribution of living microplankton, fossil OWM show particular palaeobiogeographical distributions. Therefore, flints of comparable ages taken from different outcrops deposited below the north-west European Chalk Sea should be characterised by OWM assemblages displaying particular species compositions. Thus, comparison of species assemblages between different biogeographic realms might also allow the determination of provenance of a particular flint nodule/artefact.

Regrettably, although there have been several recent publications detailing the temporal distribution of dinocysts within Cretaceous Chalk sequences of the United Kingdom and north-west Europe (e.g. Slimani 1994; Fitzpatrick 1995; Louwye 1995; Prince *et al.* 1999) there is as yet an insufficiently comprehensive database of the biogeographic distribution of these fossil taxa on both regional and temporal scales to allow such provenancing to be undertaken. Relative dating of flint nodules/artefacts and comparison with known local sources of flints is currently the only really achievable goal of such investigations.

Organic-walled microfossils: an introduction

Clastic and chemically-precipitated sedimentary rock units are comprised of not only a mineralic (inorganic) component, but most usually a biogenic component in addition. This biogenic component can consist of macroscopic remains (often mineralized) and microscopic remains. The microscopic remains may be of either mineralized skeletal remains (such as coccoliths, foraminifera, diatoms, radiolaria, etc.) or of organic nature. It is the latter group that is of interest in the context of this submission. This organic material is deposited contemporaneously with the mineralic component, and may consist of both marine and non-marine moeties. Lithification of the sediment into a rock (diagenesis), burial or thermal maturation can modify the organic component in several ways, but many types of the organic material are extremely resistant to such external factors and can be found even in rocks of low metamorphic grade.

Whereas the mineralic component of the sediment, and any associated sedimentary structures (e.g. lamination, bioturbation, ripples, etc.), are referred to as the sedimentary 'facies' of the rock unit, the organic component is known as the 'palynofacies', and may be comprised of various types of organic debris. This organic debris can be divided into three categories, the first being unstructured material (so called amorphous organic matter or AOM, representing partially degraded marine or non-marine phytodetritus); the second comprising fragments of structured material (including such things as plant cuticle or wood fragments). The final group are the 'palynomorphs' which represent either complete single-celled organisms (including dinoflagellate cysts, foraminiferal test linings, prasinophyte phycomata, etc.) or isolated organs of multicellular organisms (e.g. fungal hyphae/fruiting bodies, pteridophytic spores, gymnosperm and angiosperm pollen). Although the composition of palynofacies from individual samples can be very characteristic, the total assemblage of palynofacies components is rarely diagnostic for a particular sample, a much more distinctive signature can be obtained by the examination of the structured palynomorphs extracted from a given sample.

Although spores and pollen can be found in sediments deposited in the marine realm due to their being transported to the site of deposition by terrestrial run-off, water currents and wind, the dominant component of marine sediments is composed of various types of organic-walled microplankton. In sediments of Mesozoic to recent age (<200 Ma) organic-walled microplankton are largely represented by the protistan Division Dinophyceae (Fensome *et al.* 1996), the dinoflagellates, and it is this group which is important in the context of the present study.

Dinoflagellates are single-celled organisms generally between 20 and 150μm in size, which move helically through the water column propelled by two dissimilar flagella lying in grooves on the surface of the cell. This motile (swimming) stage often takes the form of an 'armoured' theca, which possesses interlocking cellulosic plates deposited inside vesicles in the cell wall. These organisms usually reproduce vegetatively by binary fission, with the cellulosic theca being rapidly attacked and destroyed by bacterial action following the death of the organism. However, at certain periods (often related to nutrient depletion), the cells act as gametes and undergo a phase of sexual reproduction. As a part of this process, a non-motile resting cyst or dinocyst is produced, which has an obligate period of dormancy before excysting to form a new vegetatively-reproducing generation. Made of a complex organic polymer known as dinosporin (Fensome *et al.* 1996, a sort of 'biological plastic'), the cyst is geologically preservable, in marked contrast to the cellulosic theca.

The non-motile cysts act as sedimentary particles, drifting through the water column towards the sediment/water interface, where they can become incorporated in bottom sediments (where they may remain viable for decades), and eventually become fossilized. Organic-walled dinocysts are abundant in most fine-grained sediments, such as muds and silts, from the continental shelf to the slope, but are less common in oceanic settings. These microfossils are identified to species level on the basis of certain morphological features such as the number, construction and relationships of cyst wall layers, and more particularly on the type of excystment opening (the archeopyle), process form and distribution, and signs of paratabulation (the arrangement of the original cellulosic thecal plates as reflected on the cyst).

Both before and after the advent of acid-digestion techniques in the 1930s, many palynological investigations relied on the examination of the microfossil content of flint flakes, chips or thin sections (e.g. Ehrenberg 1838; O. Wetzel 1933; Deflandre 1936; Lejeune-Carpentier 1938; Foucher 1976; 1981). However, although microfossils were proven to occur in many flint nodules, sourcing of artefacts made from such nodules using microfossil inclusions has never become an established technique.

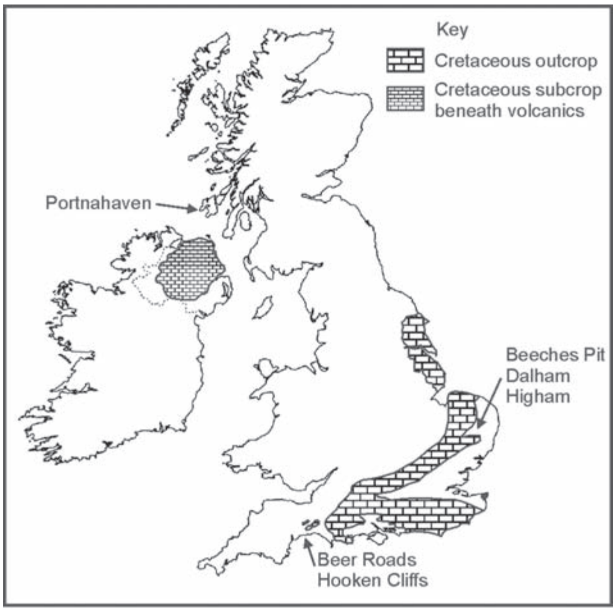

Figure 9.1 Locations sampled for this study.

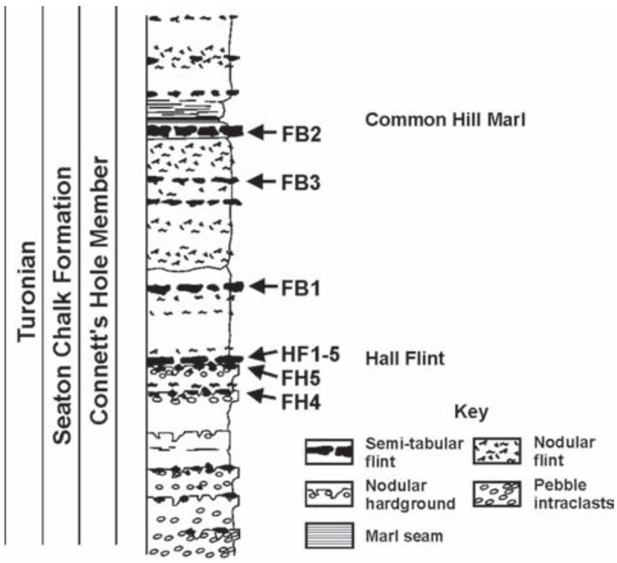

Figure 9.2 Lithological log of the Beer Roads succession showing sampled horizons (modified from Tocher and Jarvis 1987).

Materials and methodology

Samples of flint nodules were recovered from exposures and secondary deposits at three British locations (Beer Head, Devon; Beeches Pit, Dalton and Higham, all in the vicinity of Bury St Edmunds, East Anglia; and Portnahaven, Islay, Scotland; see Figure 9.1). The English locations are within the area of modern Cretaceous Chalk outcrop. The chalk strata that formerly extended from Northern Ireland to Scotland (and formerly overlay the modern Islay bedrock) have been eroded away, except where they are protected by overlying Tertiary volcanic strata in Northern Ireland (Figure 9.1).

In Devon a sampling strategy was devised in order to be able to answer two particular questions. Firstly a series of samples was collected along a lateral traverse of a single bedding-parallel band of flint nodules to assess the lateral consistency of dinocyst assemblages extracted from a single flint nodule horizon. Secondly a series of samples perpendicular to bedding was collected to determine the degree of biostratigraphic discrimination possible over short vertical sequences of flint nodules (Figure 9.2). Beer Head in south Devon represents the south-westernmost limit of the exposed English Chalk and samples were taken from the Beer Roads (NGR: SY 232891) and Hooken Cliffs (NGR: SY 220879) exposures (see Jarvis and Tocher 1986; 1987 for the stratigraphy and Tingle 1998 for the archaeological context). At Beer Roads, a bedding-parallel series of five flint samples was taken at intervals of two metres from the Hall Flint band (samples HF1–

HF5) over a transect of some ten metres to address the consistency of assemblages in a single stratigraphic horizon. In addition, a bedding-perpendicular series of six samples were taken from the flinty hardgrounds (FH4 and FH5) underlying the Hall Flint through the Hall Flint to the flint bands below the Common Hill Marl (samples FB1–FB3). At Hooken Cliffs samples (prefixed HC) were also collected, although the precise stratigraphic position could not be determined because the section did not possess any of the distinctive marker beds found at Beer Roads.

In East Anglia, samples were taken from a geological trench dug at Beeches Pit (NGR: TL 798719), and from chalk exposures at Dalton Quarry (NGR: TL 725624) and Higham Railway Cutting (NGR: TL 749661). At Dalton Quarry, samples were taken from the flint band immediately overlying the Top Rock at the base of the sequence. At Higham Railway Cutting samples were taken from a flint band accessible above the plant overgrowth, but its stratigraphic position is uncertain due to the lack of marker beds (see Bristow 1990 for the stratigraphy and Gowlett *et al*. 2000 for the Beeches Pit archaeological context). The sampled exposures span the boundary between the Middle and Upper Chalk and it was hoped that the fossil content of the flint nodules would therefore differ between exposures – providing a reference base for inferring the lithic procurement behaviour of the Beeches Pit hominids.

From Islay, flint samples were in the form of beach cobbles recovered from Portnahaven Beach (NGR: NR 166522) by Dr G. Marshall as part of the Southern Hebrides Mesolithic Project (Mithen 2001). These cobbles were of unknown geological provenance, and palynological processing was undertaken in order to try to establish their provenance given that no chalk exposures occur on Islay. Marshall (2001a; 2001b) has proposed that beach cobbles on the west-facing beaches of Islay, Colonsay and Iona are the only significant sources of flint in the southern Hebridean region, on the basis of a survey of the mainland west coast and of the islands of the Inner Hebrides between the Mull of Kintyre and the Isle of Skye (Marshall pers. comm.). It was hoped that the microfossil content of Islay beach cobbles would enable identification of the biostratigraphic zone of the (now entirely eroded) Upper Cretaceous Chalk from which they derive, and provide a reference against which flint cobbles from Colonsay and Iona could be compared in future analyses.

Sample processing

The resistant organic component of a sediment can be extracted by employing acid maceration techniques that have been developed in industrial and academic palynological laboratories for the past 70+ years. Such techniques involve dissolving the mineralic component of the rock to liberate the organic material contained within, and require specialist laboratory facilities to safely handle the chemicals involved.

Standard palynological methodology usually involves preparation of the sample material such as cleaning to remove any adherent contaminants, drying and crushing the portion of the sample to be processed. The crushed sample is weighed, placed into a labelled polypropylene beaker in a fume cupboard. The amount of sample required to produce a viable residue is variable and sometimes difficult to quantify macroscopically, but a good rule of thumb is one gramme for very organic-rich clastic sediments, approximately 20g for most clays and silts, and a greater amount for coarser-grained and chemical sediments. The samples are pre-treated with dilute (32%) hydrochloric acid to remove any carbonate minerals (calcite, aragonite, etc.). The sample is left at least overnight to react, and the supernatant is decanted. The remaining sediment/residue is washed several times and the supernatant decanted until neutrality is reached. Then the siliceous component of the sample (quartz, clays, feldspars, micas, etc.) is removed by maceration in 62% hydrofluoric acid. This compound is extremely dangerous and should only be utilized in laboratories expressly equipped for the purpose, furthermore, the reaction can be exothermic requiring extra care. Digestion is aided by the regular stirring of the contents of the beaker. Again, when the silicates have been dissolved, the sample is again washed and decanted to neutrality. At this stage in processing, an exotic 'spike' may be added to the residue if quantitative results are required from the sample (this usually takes the form of a modern palynomorph which is easily distinguished from the fossil material, such as *Lycopodium* spores). At this stage the residue is sieved through nylon mesh (generally of 20μm mesh size, although the mesh size must be appropriate to the types of palynomorph to be examined). The remaining residue is then boiled in a glass beaker with 10% hydrochloric acid to remove any neo-formed fluorides, and again washed to neutrality and sieved. At this stage assessment of the acid-resistant residues strewed in aqueous suspension on microscope slides is conducted, to assess what further processing may be required. If there are large amounts of amorphous organic matter (AOM) present, then the sample can be subjected to ultrasonication to fragment the AOM, in order that it can be sieved out of the residue. If the sample is 'dirty' or contains a lot of iron pyrites, it can be cleaned up by oxidizing using a variety of reagents, e.g. nitric acid, fuming nitric acid, Schultz Solution, etc., and again washed to neutrality/sieved. The sample is then generally ready for mounting.

Again a variety of techniques and mounting media can be used for making temporary or, more usually in the study of pre-Quaternary sediment, permanent mounts. Glycerine jelly, Elvacite or Aquamount are some of the substances that are regularly employed in British laboratories, the important factor being a suitable refractive index of the mounting medium for light microscopic investigation of the sample contents. In our laboratory, permanent mounts are made by air-drying an aqueous strew mount on a cover slip, and when dry the cover slip is glued onto a microscope slide by inverting it into a small amount of Elvacite. The samples in this study were examined using an Olympus BH–2 microscope equipped with Nomarski differential interference contrast (DIC). Counting procedure employed here involved the identification of a standard 300 individual dinocyst specimens to generic or specific level per sample investigated.

For the palynological processing of the material examined in this project, the 'standard' chemical treatment was modified to take into account the nature of the lithologies being processed. Due to the indurated nature of the flint nodules, they were first crushed in a mechanical press into pieces approximately 0.5cm in size. Generally palynomorph yield from flints is low, so approximately 100g of crushed material was processed for each sample. The samples were then processed as above, up to test slide stage. Reconnaissance microscopy revealed that there was no need for further treatment of the residues as they were already relatively clean, and generally free of obscuring AOM or pyrite.

Results

Macroscopic characteristics

The beach pebble samples from Islay were weathered, were either lacking in or possessed a very thin cortex, and varied in colour from light grey to buff or olive-green/brown. One pebble (sample Islay 11) was a dark grey-black colour. In contrast, the nodule samples from Beer Roads and from East Anglia were indistinguishable from each other macroscopically, being fairly homogeneous, fine-grained, black, lacking in visible fossil inclusions and with a thin (0.5–1mm) cortex.

Palynofacies

Although the description of the palynofacies of the samples examined in this study was a major goal of the initial project, palynofacies results will not be considered at length in this publication. The Beer samples (where they contained sufficient material for palynofacies analysis) contained dinocysts, wood fragments, and fewer instances of pollen, foraminiferal test linings and acritarchs. The East Anglian material failed to yield sufficient material for palynofacies analysis; what assemblages were recovered consisted of a few poorly preserved dinocysts, some amorphous organic matter (AOM), very rarely pollen, and a little membranous tissue. The Islay samples generally yielded sparse assemblages and were not investigated for their palynofacies composition. One flint pebble from Islay yielded an exceptionally rich dinocyst assemblage (60+ species) which was examined from a biostratigraphical point of view.

Dinoflagellate cyst assemblages: Devon

Eleven samples contained sufficient material for palynofacies analysis, yielding over 46 species of dinocyst and other forms of microplankton. The list provided in Table 9.2 catalogues the dinocyst species identified in the Beer Head and Hooken Cliffs residues and their respective abundances. Details of species authors can be found in Williams *et al.* (1998).

The samples from Devon were studied to investigate lateral and vertical variation in dinocyst assemblages extracted from flint bands, although the taxonomic resolution was on a coarser scale than that for the Scottish samples studied herein. However, the dinocyst species composition determined in this project is similar to that recorded from the host chalks from the same Devon locations by Tocher and Jarvis (1987). The species diversity is relatively low, although by comparison with the work of the latter authors, yield from the flints is better than that from the host chalks, possibly due to post-depositional destruction of the OWM in the chalks by oxidation. Given that the great majority of the speciated dinocyst taxa identified from the Beer samples are long-ranging forms, the biostratigraphic resolution that can be achieved is limited (dating of the samples was not specifically the aim of this part of the project). However, comparison with the work of Tocher and Jarvis (1987), and using the zonation schemes of Foucher (1981) and Fitzpatrick (1995), the occurrence of *Senoniasphaera rotundata* indicates that the samples studied are of Early Turonian age or younger. Furthermore, the presence of *Endoscrinium campanulum* indicates that the samples are of Mid-Turonian age or older, thus confining the samples to the Early to Mid-Turonian (Fitzpatrick 1995).

Although the degree of taxonomic resolution of dinocyst species was not high, discriminant function analysis was undertaken to determine whether it was possible to separate out the samples from the three successive levels of the Beer Roads exposure, and from the Hooken Cliffs exposure (Figure 9.2). The samples from Beer Roads derive from some 10m of vertical succession. For the purposes of this analysis, these samples were treated simply as coming from one of four groups (HF, FH, FB, HC). The first and second discriminant functions are derived from the following standardized coefficients, which quantify the influence (positive, negative and in terms of magnitude) of the counts of six common taxa on the function scores (Table 9.3).

The first discriminant function accounts for 71.9% of the variation accounted for by the model, and is statistically significant ($p = 0.009$). The second discriminant function accounts for 25.7% of the variation accounted for by the model, and nearly attains conventional statistical significance ($p = 0.07$). Group centroids ('+' in Figure 9.3) for these two discriminant functions can be seen on Table 9.4.

It is noticeable that the stratigraphic order within the Beer Roads exposure is reproduced in the rank order for

Sample ***Species name***	***HF1***	***HF2***	***HF3***	***HF4***	***HF5***	***FB1***	***FB2***	***FB3***	***FH4***	***FH5***	***HC2F***	***HC3F***
Alterbidinium sp.										1		
Batiacasphaera spp.	2		1	1	1			2		1	2	
Callaiosphaeridium asymmetricum	2	1			2			1				
Canningia colliveri	2	5	4	3		4	10	4	1	9	3	2
Canningia sp. 1	3			1								
Cribroperidinium spp.												1
Cleistosphaeridium spp.	6	2	5	1	2		1			57		1
Cometodinium sp.							1			1		
Cyclonophelium distinctum	17	14	31	17	20	5	16	19	17	30	8	25
Cyclonophelium sp. 1		1		1		7	1					1
Dapsilidinium spp.			1				1			2		
Endoscrinium campanulum	4		2			1			2			
Eschariasphaeridia sp.						1						
Exochosphaeridium spp.	10	1	5	8	17	1	3	6	7	7	12	3
Florentinia laciniata		1								1		
Floreninia mantelli										1		
Florentinia sp. 1							1			1		
Gonyaulacysta spp.				1		1	1				2	
Hystrichodinium pulcrum	10	7	13	4	11	4	4	26		18	1	4
Hystrichosphaeridium sp. 1				1			5	1				
Hystrichosphaeridium spp.			1	3	2	1		4				
Isabellidinium magnum	1	1	1				1		2	3	2	1
Kiokansia sp.						1						
Leptodinium spp.						1						
Meirogonyaulax spp.							1			8		
Membranilarcia liradiscoides		1	1	1	2	1		3		3		
Microdinium ornatum	1	1	1	2	2							1
Microdinium spp.	7	1	6	8	7	21	20	11	6	14	5	7
Odontichitina spp.	5		2		2	1	4	2	5	7	4	1
Ovoidinium spp.												1
Palaeohystrichophera infusioroides	143	163	118	159	117	201	165	124	41	6	215	72
Palaeoperidinium pyrophorum											1	
Pervospheridium spp.				1	2					1		
Prolixosphaeridium sp.												1
Pterodinium cingulatum	24	7	8	9	5				3	20		
Pterodinium cornutum				1						1		
Rhyptocorys veligera								1				
Senoniasphaera perforata							1					
Sentusidinium sp. A						1				1		
Spiniferites spp.	58	59	75	59	79	53	52	58	62	99	33	29
Surculosphaeridium longifurcatum	4	4	6	3	10			1	1		1	4
Tanyosphaeridium spp.	1	5	4	3	3			5	2	3	3	
Trichodinium castanea	11	2	1	4		2	1	12	6	7	2	13
Veryhachium rhomboidicum							1					
(acritarch)												
Indeterminate dinocysts	8	8	4	9	17		8	9	10	13	20	15
Total numbers counted	**311**	**276**	**286**	**291**	**284**	**307**	**290**	**280**	**155**	**302**	**314**	**182**

Table 9.2 Dinocyst species counts from the flint samples collected at Beer Roads and Hooken Cliffs, Devon.

values on the second discriminant function (starting with the lowest sample, from the hardgrounds (FH), and moving up through the Hall Flint (HF) to the flint bands (FB) above the Hall Flint). This reflects the preponderance of *Spiniferites* spp. dinocysts in the hardgrounds sample, and the increasing preponderance of the peridinioids (especially *Palaeohystrichophora infusiorioides*) in samples from further up the column.

Dinoflagellate cyst assemblages: East Anglia

The nine macerated samples from these exposures were

Taxon:	***First D.F.***	***Second D.F.***
Cyclonephelium distinctum	-1.37	0.77
Exochosphaeridium sp.	-1.33	0.3
Hystrichodinium pulcrum	2.44	1.1
Microdinium sp.	1.98	0.76
Palaeohystrichophora infusioroides	0.20	1.03
Spiniferites spp.	0.57	-1.32

Table 9.3 Weights for the first two discriminant functions plotted in Figure 9.3.

Locality:	***First D.F.***	***Second D.F.***
Lower flint hardgrounds (FH)	5.38	-6.09
Hall Flint (HF)	-2.37	-1.61
Upper flint bands (FB)	6.27	2.70
Hooken Cliff (HC)	-6.17	3.01

Table 9.4 Group centroids for the first two discriminant functions plotted in Figure 9.3.

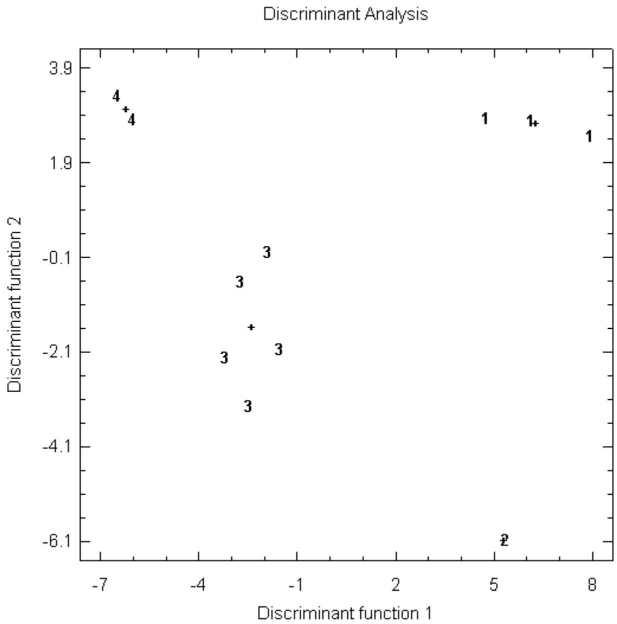

Figure 9.3 Values for samples plotted in relation to the two discriminant functions. 1) = FB (flints above Hall Flint band); 2) = FH (flint hardgrounds below Hall Flint band); 3) = HF (Hall Flint band); 4) = HC (Hooken Cliffs samples).

all either barren of dinoflagellate cysts, or contained only very rare and poorly preserved dinocyst material.

Dinoflagellate cyst assemblages: Islay

Twelve rolled flint nodules (beach pebbles) from Islay (each approximately five centimetres in diameter) were macerated. Although many of the flint nodules processed provided sparse residues and few specimens, all of the species identified in separate residues appear compatible in age. In particular, one flint nodule (Islay 11) proved to yield an extremely rich assemblage and yielded over 60 species of dinocyst and other types of microplankton. A species list is provided here, cataloguing the species identified in the Islay 11 residue (Table 9.5).

The geological ranges of the species encountered in this Islay sample have been determined by comparison with the ranges published in monographic works on Late Cretaceous dinocysts from north-west Europe, notably Yun (1981) and Kirsch (1991) who both worked on material from Germany; Slimani's (1994) study of Belgian and Dutch outcrop samples and that of Louwye (1995) on Belgian borehole cores. In addition, use has been made of two compilations of geological ranges for the dinocyst species from the Cretaceous of north-west Europe (Foucher 1979) and onshore and offshore Great Britain (Costa and Davey 1992). By examining the recorded ranges of the taxa identified it is possible to determine the age of the sample by defining the concurrent ranges of the taxa involved. The term LAD refers to the Last Appearance Datum as reported by Costa and Davey (1992).

Many of the species identified in the samples are of little use as accurate age constraints as they have very long geological ranges, in some instances ranging into the Tertiary System (e.g. *Palaeoperidinium pyrophorum*, *Spiniferites* spp.), or being present in samples from throughout virtually the whole of the Mid and Late Cretaceous (e.g. *Hystrichodinium pulchrum*, LAD: latest Maastrichtian; *Odontochitina operculata*, LAD: earliest Maastrichtian) (see also Foucher 1979). Other components of the assemblages are taxa restricted to the Late Cretaceous part of the geological timescale, for example the genus *Dinogymnium* becomes extinct at the end of the Maastrichtian (Costa and Davey 1992).

The age of the sample material can be more closely constrained as being no younger than Campanian due to the presence of several species which are not present in sediments of a younger age: *Palaeohystrichophora infusiorioides* (LAD: end Campanian), *Invertocysta flandriensis* (Turonian to Campanian: Louwye 1995). These range tops are almost coincident with those of *Odontochitina costata* and *Trithyrodinium suspectum*. The total range zone of *Senoniasphaera protrusa* spans the latest Santonian to the very end of the Campanian (Costa and Davey 1992). Yet greater accuracy is achievable by reference to *Eisenackia knokkensis* and *Rhynchodiniopsis saliorum* which have only ever been recorded by Louwye (1995) in rocks of Early Campanian age, corroborated by the recorded range of *Pervosphaeridium intervelum* (Early to Mid Campanian, Kirsch 1991).

Thus with some confidence the flint nodules from Islay provided for this study can be determined palynologically as being of Early Campanian age. However, there are no

Dinoflagellate cysts:
Achomosphaera ramulifera (Deflandre) Evitt 1963
Apteodinium deflandrei (Clarke & Verdier) Lucas-Clark 1987
Batioladinium sp.
Canningia reticulata Cookson & Eisenack 1960b
Cannosphaeropsis utinensis (O. Wetzel) Sarjeant 1985b
Chatangiella sp.
Cleistosphaeridium armatum (Deflandre) Davey 1969a
Dinogymnium acuminatum Evitt *et al.* 1967
D. denticulatum (Alberti) Evitt *et al.* 1967
D. spp.
Eisenackia knokkensis Louwye 1995
Exochosphaeridium bifidum (Clarke & Verdier) Clarke *et al.* 1968
Florentinia spp.
Hystrichodinium pulchrum Deflandre 1935a
H. cf. ramoides Alberti 1961
Hystrichosphaeridium ?duplum Lentin & Williams 1989
H. spp.
Hystrichosphaeropsis ovum Deflandre 1935
H. quasicribrata (O. Wetzel) Gocht 1976
Invertocysta flandriensis Louwye 1995
Leberidocysta sp.
Lingulodinium varispinosum Slimani 1994
Membranilarnacia liradiscoides (O. Wetzel) Downie & Sarjeant 1965
Microdinium angulatum Below 1987b
M. densigranulatum Below 1987b
M. minutum Louwye 1995
Odontochitina costata Alberti 1961
O. operculata (O. Wetzel) Deflandre & Cookson 1955
O. porifera Cookson 1956
Oligosphaeridium pulcherrimum (Deflandre & Cookson) Davey & Williams 1966b
Palaeohystrichophora infusioroides Deflandre 1935a
Palaeoperidinium pyrophorum (Ehrenberg) Sarjeant 1967b
Pervosphaeridium intervelum Kirsch 1991
P. pseudohystrichodinium (Deflandre) Yun 1981
Protoellipsodinium spinocristatum Davey & Verdier 1971
Psaligonyaulax deflandrei Sarjeant 1966
Pterodinium cingulatum (O. Wetzel) Below 1981a
P. comutum Cookson & Eisenack 1962b
Raetidinium truncigerum (Deflandre) Kirsch 1991
Rhynchodiniopsis saliorum Louwye 1995
Riculacysta sp.
Senoniasphaera protrusa Clarke & Verdier 1967
Spinidinium echinoideum (Cookson & Eisenack) Lentin & Williams 1976
S. sp.
Spiniferites spp.
Surculosphaeridium ?cassospinum Yun 1981
S. longifurcatum (Firtion) Davey *et al.* 1966
Tanyosphaeridium xanthiopyxides (O. Wetzel) Stover & Evitt 1978
T. boletum Davey 1974
Trichodinium castanea (Deflandre) Clarke & Verdier 1967
Trigonopyxidia ginella (Cookson & Eisenack) Downie & Sarjeant 1965
Trithyrodinium evittii Drugg 1967
T. suspectum (Manum & Cookson) Davey 1969b
Valensiella foucherii Slimani 1994
Wallodinium lunum (Cookson & Eisenack) Lentin & Williams 1973
Xenascus esbeckianum Yun 1981
X. gochtii Corradini 1972
X. sarjeantii Corradini 1972
Xiphophoridium alatum (Cookson & Eisenack) Sarjeant 1966

Others:
Palambages morulosa O. Wetzel 1961
Pterospermella sp.
Veryhachium sp.
Foraminiferal test linings (uniserial, biserial, planispiral)

Table 9.5 The species identified in the Islay 11 residue.

deposits of Cretaceous age on Islay itself. The Early Campanian age defined for the Islay flints is compatible with the known outcrops of Upper Cretaceous flints in the Chalk of the White Limestone of Antrim (Wilson 1981), which has a recorded age of Santonian to Campanian (the Creggan and Boheeshane Chalks being deposited in Early Campanian times – *Offaster pilula* and *Gonioteuthis quadrata* macrofossil zones). The age of the few chalk deposits in the Hebrides has been recorded as Senonian and is thus also compatible with the age of the flint material analysed for this study. Thus, the nodules which are now found as beach cobbles on Islay either represent a *remainé* assemblage of flints eroded from a former chalk outcrop which extended from Northern Ireland to Scotland, or possibly originated as glacially transported 'erratics'.

Discussion

Flint is notoriously difficult to source; the very factors that make it so useful in the production of sharp cutting edges (its homogeneous, fine-grained microcrystalline structure) are also the factors that prevent easy discrimination of different source outcrops. However, this study has demonstrated the potential of palynological analyses to resolve the geological age of the deposit in which certain flint nodules were formed, and thus to determine provenance for archaeological flint artefacts in regions where biostratigraphic zones outcrop at different levels across a transect in space (due to deformation of the host strata). As previously noted, attribution of an artefact to a source (as opposed to elimination of some possible sources) presupposes complete knowledge of the characteristics of all potential source outcrops and secondary deposits, and this is rarely the case (Shackley 1998). If the potential of this technique is to be realized in the future, a systematic sampling programme is required to describe variability within and between flint bands and exposures across the whole extent of the north-west European Chalk. There have been few published archaeological results so far for material from this region: a good instance is Mauger's (1984) demonstration of the presence in flint artefacts at the Magdalenian site of Étiolles (Ile-de-France) of dinocysts of *Palaeohystrichophora infusiorioides* (LAD: end Campanian), which enabled him to conclude that the source must lie at least 50km to the south-east of the site. Our own preliminary findings suggest that renewed attention to this sourcing methodology will yield useful new results.

There are several important conclusions that can already be drawn from this study. Firstly, the most obvious observation is that not all flint nodules (notably the East Anglian samples) yielded viable palynological assemblages, and indeed, palynological yield varies even amongst those that do contain palynomorphs. The reasons for this are unclear, although microfossil preservation in flint nodules may possibly be related to the timing and geochemical conditions under which the nodules formed. Given the excellent three-dimensional preservation of dinocysts in some samples from Devon and Islay, nodule formation was clearly a very early diagenetic phenomenon, prior to the compaction of the oozes in which they were deposited. This can be corroborated by reference to the work of Carson (1987) which demonstrated that the flints from Devon exhibit petrological and isotopic characteristics indicative of just such early diagenetic formation. There may be two reasons to explain the nodules that did not yield palynomorphs. Either these nodules were formed at a slightly later diagenetic stage, which allowed partial or complete destruction of the palynomorphs in the sediment by prolonged exposure to oxidizing porewaters prior to nodule precipitation. Alternatively, it may be that the palynological content of some derived flints have been modified by post-depositional weathering: this may be indicated by the samples from Islay, as the one flint from this location which yielded an abundant dinocyst assemblage was also the one which was darkest in colour, and appeared least affected by its residence time on Portnahaven beach.

Secondly, examination of the samples from the traverse of the Hall Flint band has demonstrated that dinocyst assemblages from a single bedding-parallel flint horizon vary very little over tens of metres of exposure. This is the first time that such lateral consistency of assemblage composition has been documented from flint horizons. Although only one flint band has been investigated in this study, this observation illustrates that dinocyst assemblages display a consistent signature over a single bedding-parallel flint nodule horizon, thus providing a 'finger-print' for a particular nodule band which might be identifiable in artefacts made from that horizon. In addition, it would appear that in certain geological circumstances, such as those pertaining in the Beer succession, flint nodules preserve a more complete and representative assemblage of organic-walled microplankton than do the surrounding host chalks.

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