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CONTINENTAL MARGIN FROM THE

PORCUPINE SEABIGHT TO THE ARMORICAN BASIN

D.G. Roberts et al

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Abstract

The continental margin between the Porcupine Seabight in the north and the Amorican margin in the south is topographically and geologically complex. The deep trough comprising the Porcupine Seabight is flanked oceanward by the Porcupine Ridge and contrasts with the gentler slopes of the margin near the Goban Spur. Further south, the northern or Armorican margin of the Bay of Biscay is characterised by a steep slope cut by many canyons.

Regional multichannel seismic surveys of the margin extending from the shelf to the deep ocean have been made by the Institute of Oceanographic Sciences and the Institut Francais du Petrole. These surveys aided by the results of dredging and three sites drilled during Leg 48 of the International Phase of Ocean Drilling are used to present the regional structure and stratigraphy of the margin and a tentative evolutionary model.

Between Goban Spur and the Armorican Basin, the structure consists of a series of tilted and rotated fault blocks downthrown consistently toward the ocean and occurring in water depths up to 4500m. Overlying Cretaceous and Tertiary sediments are thin beneath Goban Spur but thicker in the Armorican Basin. The Porcupine Seabight appears to be a deeply subsided basin containing a prominent extrusive (?) body in its northern part and underlain in the south by the tilted blocks of the Goban Spur. The origins of the Seabight are enigmatic but it seems unlikely to be underlain by oceanic crust. The complex structure of the

margin has resulted from major rifting in Mid Jurassic to Early Cretaceous time although there may have been minor earlier phases. Spreading in Biscay began in the Aptian, although rifting was still taking place west of Goban Spur at this time. West of Goban Spur and in the Rockall Trough spreading took place during the post-Albian pre-Campanian interval.

Continental Margin from the Porcupine Seabight to the Armorican Marginal Basin

D.G. Roberts[1], D.G. Masson[1], L. Montadert[2], O. de Charpal[2]

Introduction

Over the last decade, exploration for oil and gas on the western European continental shelf has resulted in a much improved knowledge and better understanding of the regional pattern of tectonics and basin development (see for example Woodland, 1975; Ziegler, 1978; this volume).

There has, however, been relatively little exploration of the deeper waters to the west and southwest of the British Isles, other than the wells recently drilled in the Porcupine Seabight. During the last five years the Institute of Oceanographic Sciences and the Institut Francais du Petrole have made a regional study of the continental margin (fig. 1) in the South Western Approaches as part of the International Phase of Ocean Drilling, with the objective of understanding the structural and stratigraphic evolution of the margin. The study has included the integration of multichannel seismic reflection profiles (figure 2) with deep sea drilling data obtained by D.V. Glomar Challenger.

In this paper, we present an outline of the structural and stratigraphic evolution of the continental margin between the Porcupine Seabight and the Armorican margin. Aspects of the stratigraphy, lithology and palaeontology not included in this paper for reasons of brevity may be found in Montadert, Roberts <u>et al.</u> (1979b).

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Regional Geological Structure and History

Much of western France, the western British Isles and their adjacent continental shelves is comprised of igneous and sedimentary rocks highly deformed and metamorphosed during the Caledonian and Hercynian orogenies. The Celtic Sea is underlain by the Celtic Sea and Western Approaches Basins of Mesozoic and Tertiary age (Kamerling 1979, Robinson et al. this volume).

North of the Hercynian Front the principal structural feature is the northwest-southwest trending Caledonian mobile belt. The tectonics of the belt onshore have been reviewed by Dewey (1974) but the offshore continuation of individual structures within the belt remains unclear. Recent evidence has suggested that the Highland Boundary Fault and important late Caledonian shears such as the Leannan Fault may continue westward beneath the Slyne Ridge, but the westward continuation both on and beyond Porcupine Bank remains largely conjectural.

The Hercynian orogenic belt is exposed in Southern Ireland, Wales, Cornwall and Brittany, but is largely buried offshore beneath the Celtic Sea and Western Approaches Basins. The northern edge of the belt continues through England and Wales into Southern Ireland, curving to the WSW in Ireland. Its continuation beneath the shelf is marked by a prominent WSW-ESE trending magnetic anomaly (figure 3). The Hercynian belt has had a complex history that extends back to the Middle Proterozoic and includes the Cadomian and Caledonian orogenies. The main deformation culminated in Late Carboniferous time and was followed by intrusion of the Cornubian granites at 290 m.y. Late Hercynian (between 310 and 270 m.y.) shear structures involving displacements of tens to hundreds of kms, such as the South Armorican Shear Zone and a major NW-SE dextral shear postulated to extend along Biscay, widely fractured the Hercynian belt, and may have influenced later rift development beneath the margin of north Biscay.

Sibuet (1972) has shown that the Armorican shear zone continued westward beneath the shelf. The southwestward continuation of the Cornubian batholith is marked by two parallel trends of gravity minima corresponding to the Haig Fras and Scilly Isles exposures of the granite (figure 4, 5). Evidence for a further southwestward prolongation may be indicated by granites dredged on the south-eastern Goban Spur (Pautot et al. 1976, Auffret et al. 1979).

The Celtic Sea and Western Approaches sedimentary basins are divided by the Cornubian platform (figure 4). The overall ENE-WSW trend of both basins is perpendicular to the margin.

The Celtic Sea Basin is comprised of a number of sub-basins such as the Bristol Channel and Fastnet Basins (Kamerling, 1979; Robinson et al. this volume) and is bounded in the north by a prominent NE-SW trending fault marking the southern limit of the Palaeozoic massif of Ireland. Thick Permo-Triassic beds that include sands and evaporites were deposited uncomformably on the Caledonian and Hercynian basement in fault controlled basins (Kamerling, 1979). Epicontinental conditions prevailed through the Late Triassic and Early Jurassic. A marked stratigraphic break in the Middle Jurassic associated with contemporaneous volcanism may indicate the onset of the regional epeirogenesis that structured the margin in Late Jurassic-Early Cretaceous time. This latter phase was associated with regressive, contemporaneous "Wealden" deposition and volcanism, and was terminated by the main Late-Berriasian-pre Aptian phase of deformation. Late Lower Cretaceous sandstones and Upper Cretaceous chalks transgress across the deformed early Cretaceous. Shallow water littoral, often swampy, conditions prevailed through Aptian and Albian time. After the Upper Cretaceous transgression renewed movements took place, accompanied by igneous activity in Early Eocene, and Late Eocene-Oligocene time.

Much less published data is available for the Western Approaches Basin.

It is a broad half-graben bounded on its southern side by a series of ENE-WSW trending faults known as the Ushant-Alderney line (Curry and Smith, 1975). Development may have been initiated in fault controlled basins as early as Permo-Triassic time, when thick redbeds and evaporites (?) were laid down. Marine epicontinental conditions prevailed through the Early and Middle Jurassic, but uplift, folding and faulting began towards the end of the Jurassic, and continued into the Lower Cretaceous, which was characterised by marginal conditions (Hallam and Sellwood, 1976; Allen, 1975). These movements terminated by Aptian time. Regional uplift and emergence took place in pre-Eocene time, followed by a second phase of uplift in the Oligocene that led to lacrustine conditions (Curry and Smith, 1975; Roberts, 1974). Marine conditions returned but renewed deformation took place subsequently in response to the Alpine movements.

Bathymetry

The complex bathymetry of the margin between the Porcupine Bank and the Bay of Biscay (figure 1) has resulted from the complex history of rifting and spreading between Europe, North America and Iberia (Roberts et al. 1979). The margin can be divided into several contrasting physiographic provinces comprising the Western Approaches margin, Goban Spur, Porcupine Bank and Seabight, and the Rockall Trough.

The Western Approaches margin is the northernmost part of the Armorican margin that extends from the Aquitaine Basin to the Goban Spur. Much of the shelf is underlain by thin Cretaceous and Tertiary sediments resting on Hercynian basement although north and west of Brittany it is underlain by the deep Western Approaches Basin. The slope is cut by many submarine canyons whose oblique downslope trend may be indicative of underlying structural control. The slope is itself broken by the Meriadzek Terrace, while the Trevelyan Escarpment is a low ridge at the foot of the rise.

The Goban Spur in contrast is generally less than 2000m in depth and consists of a smooth slope that dips gently westward and is cut by few canyons. This slope terminates at the steep NW-SE trending Pendragon Escarpment which has some 2000m relief. The southeast side of Goban Spur consists of prominent NW-SE trending ridges and troughs sub-parallel to the slope of the Western Approaches margin.

North of Goban Spur the anomalous, deep Porcupine Seabight is interposed between the shelf and Porcupine Bank. The Porcupine Seabight is a N-S trending basin closed in the north by the Slyne Ridge and in the south by the Goban Spur; it opens westward through a broad and deep depression between the southern part of Porcupine Bank and the northwest tip of Goban Spur. Few canyons cut the slopes of Porcupine Seabight. The Porcupine Bank is flat topped and bounded by a steep western slope that lies directly on strike with the Pendragon Escarpment to the south. Northwards however, in the mouth of the Rockall Trough, this slope changes trend from NW-SE to NNE-SSW.

The Rockall Trough borders the northern and western edges of Porcupine Bank and separates the Rockall Plateau microcontinent from the shelf west of the British Isles (Roberts, 1974, 1975; Roberts et al. 1979).

Gravity anomalies

The free-air gravity anomaly map of the margin and the adjoining shelf seas (figure 5) has been compiled from data in Day and Williams (1970), Sibuet (1972), Buckley and Bailey (1975), Scrutton (1979), Blundell (1975) and from unpublished charts and traverses of the Hydrographic Department (MOD), and the Institute of Oceanographic Sciences. Bouger anomalies are shown on land after Murphy (1960) and Bott et al. (1958).

Prominent broad NE-SW trending gravity minima oriented perpendicular to the margin in the Celtic Sea define the thick sedimentary basins of the Celtic Sea and Western Approaches. Two parallel NE-SW trending gravity minima superimposed on the high of the Cornubian platform represent the Haig Fras and Cornubian granite ridges which extend close to the shelf edge and possibly to the southeast Goban Spur (Auffret et al. 1979).

In the Celtic Sea, prominent NNE-SSW anomalies cut across the Haig Fras trend as well as the regional trend, and may represent horsts and grabens within the main basin (Robinson et al. this volume). Such trends are not apparent in the Western Approaches Basin. Here, close to the shelf edge, isolated gravity maxima associated with prominent magnetic anomalies may represent buried intrusive bodies of unknown age (Segoufin, 1975).

Beyond the shelf edge, the gravity coverage is much less dense. The most significant anomalies seem to be associated with the continent-ocean transition and large structures within the continental crust.

The continent-ocean boundary or transition has been identified from gravity models, seismic reflection profiles and changes in magnetic anomaly character. Off the Western Approaches margin, a broad negative anomaly is flanked oceanward by a positive NW-SE trending anomaly associated with the Trevelyan Escarpment and sub-surface North Gascony Ridge, considered to lie at the boundary between continental and oceanic crust (Montadert et al. 1979a). West of Goban Spur a linear positive anomaly lying oceanward of a negative anomaly is associated with a basement ridge and distinctive break in magnetic anomaly pattern (Scrutton, 1979; Dingle and Scrutton, 1979). A comparable pattern to the west of Porcupine Bank may also indicate the continent-ocean transition.

In the Western Approaches, between the shelf and the continent-ocean boundary, the free-air anomaly pattern largely reflects the complex bottom topography. On Goban Spur however, linear anomalies probably arise from the underlying NW-SE trending tilted blocks. The Porcupine Seabight is characterised by a broad N-S trending minimum that closes northward near 53°N but also contains an elongate gravity high of +70 mgal. confined to its northern part. Gravity models of the deep structure of Porcupine Seabight have been erected by Buckley and Bailey (1975) and Handley (1971) (in Blundell, 1975). Both gravity models predict sediment thicknesses in excess of 5 km which are confirmed by the reflection data discussed later (figure 10). The elongate gravity high in the Seabight was modelled as thinned 'quasi-oceanic' crust with a high level basic igneous mass included in the sedimentary section. The new reflection data confirm the presence of an extrusive body of presumed pre-Aptian age in the basal part of the sediment section. The body, which closely coincides with the gravity anomaly and a negative magnetic anomaly, measures some 25 by 60 miles but narrows and discontinues to the south near 51°N. Absence of a gravity high south of this latitude cautions against simplistic interpretation of 'quasi-oceanic' crust beneath the Seabight, though substantial thinning of the continental crust is clearly evident.

In the northern part of the Seabight, complex NE-SW trending gravity minima are associated with the Slyne Trough and complex faulting at the head of the Seabight (Buckley and Bailey, 1975). West of Galway Bay an intrusive body of unknown age may be represented by a prominent 90+ mgal anomaly.

Magnetic Anomalies

Magnetic anomalies for the margin and adjoining oceanic areas (figure 3) have been taken from the magnetic anomaly map of the Northeast Atlantic compiled by Roberts and Jones (1975). Major changes in magnetic anomaly character occur close to the base of the slope reflecting the transition between continental and oceanic crust.

West of Goban Spur and Porcupine Bank, strikingly linear NW-SE trending anomalies characterise the oceanic crust and approximately parallel the base of the slope. The oldest clearly recognisable anomaly has been identified as 32 by Pitman *et al.* (1971) and Williams (1975) although anomaly 34 may be an alternative identification (Cande and Kristoffersen, 1977; Kristoffersen, 1978). This anomaly and the younger anomalies to the west terminate near 52°10'N at the prominent east-west trending magnetic lineament associated with the buried eastward extension of the Gibbs Fracture Zone (Vogt and Avery, 1974; Cherkis et al. 1973). The older suite of anomalies present between 32 and the continent-ocean transition may correspond to anomalies 33 and 34 although Kristoffersen (1978) has suggested a slightly earlier age. These anomalies continue northward past the end of the Gibbs Fracture Zone into the Rockall Trough where they comprise a suite of symmetrical NNE-SSW trending anomalies. These are truncated near $53\frac{1}{2}$°N by a linear series of NW-SE trending anomalies which are interpreted as a fracture zone. The NNE-SSW trending anomalies can be satisfactorily modelled by contrasts in direction and magnetization compatible with a zone of oceanic crust some 120 km in width (Roberts et al. in prep.). An age of mid-Late Cretaceous is inferred for this crust based on regional seismic stratigraphy and the continuity of the anomalies to the south.

South of Goban Spur, the WNW-ESE trending anomalies that characterise the central and northern parts of Biscay are interposed between the NW-SE trending anomalies of the Porcupine Abyssal Plain and the continent-ocean boundary. Montadert et al. (1979a) have shown that the oceanic crust of Biscay is overlain by Aptian sediments. These beds are absent on the oceanic crust west of Goban Spur suggesting a younger age for this crust in conformity with the magnetic evidence.

Within the continental domain, there is considerable variation in magnetic character that is beyond the scope of this paper. The Porcupine Bank is characterised by NE-SW trending anomalies that undoubtedly reflect the grain of the underlying Caledonian basement. Complex anomalies on the Slyne Ridge-Slyne Trough area (Vogt and Avery, 1974) reflect the juxtaposition of horsts of Caledonian basement and grabens of presumed Permo-Triassic age (Bailey, 1975; Bailey et al. 1977). Off southwest Ireland, a prominent NE-SW trending steep magnetic gradient coincides with the offshore extension of the Hercynian Front. Prominent magnetic anomalies close to the shelf edge in the vicinity of the Fastnet Basin may represent an igneous centre of Middle Jurassic age (Caston et al. 1979). On Goban Spur, linear NW-SE trending anomalies reflect major fault trends.

Seismic Stratigraphy

Throughout the entire margin area, a relatively undisturbed sequence of Cretaceous and younger sediments is observed to rest on continental or oceanic 'basement'. This broad division forms the basis of the ensuing discussion of the seismic stratigraphy. For the purpose of this paper, the continental basement is defined as the top of the sedimentary sequence deposited prior to the rifting phase; it corresponds to a rifting unconformity rather than to basement in an economic or 'true' sense. Obviously, oceanic basement (i.e. the top of layer 2) is true basement.

Four seismic formations, bounded by unconformities of regional importance and extent, have been recognised above continental basement (figure 5). Age assignments are based principally on the sections penetrated in DSDP sites 400A, 401 and 402 (Montadert et al. 1979) and are as follows:-

Formation 1 (subunits 1a, 1b)	Quaternary to Oligocene	
		unconformity
Formation 2	Eocene to Late Cretaceous	
		unconformity
Formation 3	Albian to Aptian	
		unconformity
Formation 4	Syn-rift sediments	(Middle Jurassic-Early Cretaceous)

'Oceanic' 'Basement' 'Continental'

(Post-Early Aptian only)

It should be noted that minor unconformities occur within each formation.

Basement

Within the continental domain the basement reflection defines a surface of very considerable relief that consists of a series of half grabens situated between tilted blocks (fig. 6, 7, 8). These are bounded by listric normal faults best seen on the Goban Spur, in the Western Approaches and on the margins of the Porcupine Seabight. Dipping reflections within the fault blocks demonstrate that, in general, major tilting and faulting took place immediately prior to deposition of overlying formation 4, although onlap within some fault blocks hints at earlier contemporaneous movement. Sediments underlying the 'basement' reflection locally exceed 2 seconds in thickness and are occasionally seen to rest on opaque, possibly true basement. This unconformity is presumed to correspond to the well known unconformity between the Caledonian-Hercynian basement and the later beds of Permian, Triassic and Jurassic age. Folding observed in several fault blocks west of Ireland and on Goban Spur suggests the presence of Devonian and Carboniferous beds sampled by Scrutton (pers. comm., 1979) and Auffret et al. (1979). Dredgings on fault blocks south of Goban Spur have yielded granodiorites, leucogranites and quartz syenites dated at 275-290 m.y. together with epizonal schists, granulites and charnockites. Caledonian basement is considered to underlie much of Porcupine Bank (Whitmarsh et al. 1974). Evidence for the age of the dipping reflectors between true basement and the overlying syn-rift sediments is lacking at present although a post-Carboniferous to pre-upper Jurassic age can be reasonably inferred on regional geological grounds.

The oceanic basement independently identified from magnetic anomalies and refraction data is defined by a strong irregular reflector associated with numerous diffractions below which there are few coherent reflections. Constraints on the age of the oceanic basement are provided by the magnetic anomaly data discussed earlier and the age of the overlying sediments. In Biscay, the Albian-Aptian black shale interval rests on the basement indicating an Early Aptian age, but it is absent west of Goban Spur indicating a post Albian age. Roberts et al. (in prep.) suggest the crust west of Goban Spur accreted contemporaneously with that in Rockall Trough.

Formation 4 - Syn-rift sediments

The sediments comprising formation 4 rest on the basement and were deposited during rifting. Angular unconformities are locally apparent but the contact more typically appears conformable though a hiatus may well be present. The seismic facies of formation 4 beneath Porcupine Seabight differs from that observed on and to the south of Goban Spur.

Beneath the Goban Spur and Western Approaches margin, contemporaneous deposition during tilting of the fault blocks is indicated by convergence of intra-formation 4 reflections toward the crests of fault blocks. Deposition of the formation was closely controlled by the developing fault blocks, with the result that it is presently thickest beneath the half grabens. Dips within the formation are highly variable, in general decreasing upward, so that a clear distinction from formation 3 is not always possible. Indications of infilling rather than contemporaneous deposition within the upper parts of the formation hint that movements may have ended at different times in different areas.

North of Goban Spur and within the Porcupine Seabight, the seismic facies changes and the well developed reflections present to the south are absent. Individual reflections within the formation are strong but laterally impersistent and indicate minor faulting which terminates at about the top of the formation. Beneath the north flank of Goban Spur, deposition of formation 4 was obviously contemporaneous with rifting but within the deeper parts of the Seabight the formation appears to evenly cover an irregular surface (consisting of tilted blocks?). The apparent lateral passage of formation 4 into the large extrusive body hints that the seismic facies change may be related to volcanogenic sediments. In the south-western Seabight where the overlying cover is thin, a thick formation 4 sequence (up to 3 secs) is seen above a possible basement ridge. Formation 4 thins northward and southward as it onlaps the basement of Porcupine Bank and the Goban Spur.

An upper age limit of Early Aptian is established for formation 4 by the termination of rifting at that time at DSDP sites 402A and 400A. However, evidence for variation in the age of termination of rifting mentioned earlier suggests the possibility of diachronism between formations 3 and 4. Evidence for the age and lithofacies is based primarily on the basal sediment cored at site 401, coupled with evidence from nearby dredgings. At 401, peri-reefal bioclastic limestones of Tithonian to Berriasian age rested on Kimmeridgian to Portlandian limestones. Nearby dredgings have yielded Valanginian-Berriasian peri-reefal limestone and Tithonian Calpionellid limestones. Auffret et al. (1979) also report Early Cretaceous conglomeratic limestones on Goban Spur. In view of recent evidence from the Fastnet Basin, western English Channel and Porcupine Seabight, volcanics of post-Middle Jurassic pre-Aptian age may be anticipated (Robinson et al., this volume; this paper). Precise definition of the basal age must await further drilling although an Oxfordian age for the initiation of rifting is independently suggested by the history of the Parentis Basin and Celtic Sea (BRGM, 1974; Kamerling, 1979; Robinson et al. this volume).

Formation 3

Formation 3 is comprised of the first sediments deposited after rifting and is transparent to slightly layered. An Albian-Aptian age was confirmed by drilling at DSDP sites 400A, 401 and 402A. The top of formation 3 is defined by the prominent Cenomanian-Late Campanian hiatus. Unlike underlying formation 4 which is clearly confined to the continental crust, formation 3 rests on the oceanic crust of the Bay of Biscay which is thus pre-Early Aptian in age. Formation 3 is however absent on the oceanic crust west of Goban Spur which must therefore be post Albian in age.

Within the continental domain, deposition and distribution of formation 3 was closely controlled by the underlying fault block topography (Fig. 9). Formation 3 is thickest in the half graben but infilling and draping had subdued much of the original fault block topography by the end of Albian time. In Porcupine Seabight formation 3 is somewhat thicker and more acoustically transparent, and the underlying fault block topography has had little influence except at the basin margins.

Formation 2

For the most part, formation 2 appears conformable on formation 3 although drilling evidence suggests that a hiatus is often present. Its base is defined by the intra Albian-Campanian hiatus drilled at sites 400A and 401, and its top by the Oligocene-Middle Eocene hiatus known at site 400A. Minor hiatuses of Maastrichtian-Late Palaeocene age and Eocene age occur within this formation. Transcurrent faults and minor overthrusts associated with the Pyrennean deformation do not continue above the top of formation 2.

The seismic facies and thickness of formation 2 is highly variable (fig. 10). Beneath the Western Approaches and Biscay Abyssal Plain, it is typically 500 metres or more in thickness and characterised by numerous reflections. Results from DSDP holes 118, 119 and 400A suggest that it consists of turbidites in the abyssal plains or basinal areas and pelagic limestones on highs. Beneath the slope, it is substantially reduced in thickness. Within the Porucpine Seabight, formation 2 is substantially thicker and is acoustically transparent only in its lower part, well developed reflections appearing toward the top. Seismic tie lines to the IPOD sites shows that the lowermost of these reflections is of probable Late Palaeocene age. Louis and Mermey (1979) have independently confirmed this identification using well data from the northern Seabight. Seismic profiles across the northern Seabight suggest the existence of a prograding limestone shelf in Palaeocene time. In Lower Eocene time, a north to south prograding deltaic system developed, apparently supplied from Porcupine Bank. During Upper Eocene time, the deltaic system was transgressed.

Formation 1

Formation 1 is apparently conformable on formation 2 although an erosional unconformity is present in many places. The base of the formation corresponds to the Oligocene-Eocene hiatus of Biscay and reflector R4 of Roberts (1975), and its top to the present seabed. At site 400A, principal hiatuses lay between the lowermost Pliocene and uppermost Miocene and also within the Lower Miocene. There are substantial variations in both thickness and seismic facies that undoubtedly reflect the delicate balance between the spatially variable sedimentary processes that have controlled sediment distribution, and thus the Neogene stratigraphy. In Biscay, formation 1 is thickest beneath the abyssal plain where its highly layered character suggests deposition by turbidity currents. It is thinnest beneath the slope and on Goban Spur. Montadert et al. (1979a) recognised two subunits, 1a and 1b, divided by a prominent erosion surface which marks the onset of a bottom current regime responsible for erosion and sediment drift formation. This event was apparently associated with canyon cutting and the development of prominent fans. In the Porcupine Seabight where formation 1 exceeds 1.5 seconds in thickness, the erosional event is particularly clear. Formation 1 is characterised by numerous well developed reflections whose geometry suggests fan-levee deposition. West of Porcupine Bank, Formation 1 is much reduced in thickness reflecting isolation from the sediment source.

Geological History and Evolution of the Margin

The geological history of the margin can be conveniently discussed in terms of its development prior to and during rifting and its subsequent development contemporaneous with spreading in the adjacent ocean basin.

Development prior to and during rifting

Regional geological evidence demonstrates that the North Atlantic continents formed a single supercontinent following the Hercynian suturing of Laurasia. Although Late Hercynian shear movements displaced major structures of the Hercynian welt, fragmentation and dispersal of the continents did not take place until after the major rifting and spreading episode (Cimmerian s.l.) in Late Jurassic-Early Cretaceous time. The history of basin development between the Late Carboniferous and the onset of rifting in the Late Jurassic is fragmentary and dependent on the limited data available from dredging and drilling as well as inference based on the geology of the adjacent shelf basins.

Basin development, possibly in response to Late Hercynian orogenic collapse, was initiated in Permo-Stephanian time, but the first episode of regionally important epeirogenesis did not begin until the early Triassic. Available data from the Celtic Sea and Aquitaine Basin demonstrates the existence of both epicontinental and continental conditions in Triassic time with deposition of evaporites and redbeds. By the early Jurassic, tensional movements had apparently ceased and epicontinental conditions prevailed in both the Celtic Sea, English Channel and Aquitaine Basins. Regressive Hettangian and Sinemurian sands have been proven by recent drilling in the Fastnet Basin but non-marine Early Bajocian sands drilled on the formerly contiguous Orphan Knoll hint at a later regression of more regional importance (Robinson et al. this volume; Laughton, Berggren et al. 1972).

The latter regression may indicate the start of rifting previously considered to be of Middle Jurassic age on regional grounds, although there is as yet no direct evidence. Winnock (1971) has shown the Parentis Basin began to subside more rapidly in Oxfordian time. In the Celtic Sea, regional uplift took place in Middle Jurassic time (Kamerling, 1979) (Robinson et al. this vol.) and was accompanied by extrusive and intrusive activity which evidently continued intermittently until the Aptian as is revealed by the bentonitic tuffs of Southern England (Harrison et al. 1977; Hallam and Sellwood, 1976). Results from sites 400A and 402A suggest that rifting ended during the Aptian although there is direct and indirect evidence to show it was not contemporaneous everywhere. Robinson et al. (this vol.) suggest that major rifting ended during the Hauterivian although Kamerling (1979) shows continued faulting up to mid-Aptian time. Evidence from some half graben where the upper part of the syn-rift sequence shows no evidence of contemporaneous movement also suggests that rotation of individual blocks probably ended at different times in different areas. In any event, the presence of Aptian-Albian beds on oceanic crust pinpoints the end of rifting in Biscay, although rifting may have persisted west of Goban Spur until the creation of ocean crust in post Albian-pre Campanian time.

It is clear that faulting was contemporaneous during the deposition of formation 4 because reflectors in general converge towards the crests of the tilted blocks. The distribution of pre-Cenomanian sediments (figure 9) shows that sedimentation was largely controlled by the complex developing pattern of fault blocks at this time. Some half-graben contain as much as two seconds of section but elsewhere the sediments are relatively thin.

Information on the changes in palaeogeography and facies development during the Permian to Late Jurassic is scant because beds encompassing this wide interval have yet to be proven. The oldest Jurassic beds drilled at Site 401 indicate a peri-reefal environment in Kimmeridgian-Portlandian time, in contrast to more open marine conditions indicated by Tithonian Callpionellid limestones dredged nearby (Auffret et al. 1979). If rifting is considered to be an Early Cretaceous phenomenon these data can be interpreted in terms of a pre-rift epicontinental basin fringed by a reefal carbonate platform.

Alternatively, rifting may have been initiated during the mid-Jurassic, continuing until the Aptian. This view is supported by the dredging of outer shelf micritic limestones of Barremian age from Shamrock canyon, and Valanginian-Berriasian chalks from the Meriadzek Terrace (Auffret et al. 1979). These data suggest that in Late Jurassic-Early Cretaceous time the margin differentiated into a series of tilted blocks. The erosion surface shows that many of these were at or close to sea level, allowing truncation, and the development of carbonate banks. Data that would conclusively constrain the evolution of the rift topography will only come from further drilling.

Constraints on the topography at the end of rifting in Aptian time are given by the seismic data and results of drilling at site 400A and 401. The pre Aptian erosion clearly establishes that a large part of the Western Approaches margin and Goban Spur lay at or close to sea level but a depth of 1500-2000m on the outer part of the margin at the end of rifting is indicated by the difference in depths of deposition (Fig. 11) and present difference in altitude of the Aptian at sites 400A and 401 (Montadert, Roberts et al. 1977, 1979; de Charpal et al. 1979). The position of the erosion surface thus provides a crude indication of the palaeobathymetry of the Aptian margin. That much of Goban Spur lay at or close to sea level is indicated by the proximity of the erosion surface to the continent-ocean boundary. In the Western Approaches the erosion surface lay much closer to the present shelf edge suggesting that the margin there formed a deep embayment. This difference in palaeobathymetry may have arisen because of the later onset of spreading to the west of Goban Spur and Porcupine Bank. In addition variations in rifting tectonics related to the different underlying geologies of the two areas may have been important. Inferences on the palaeobathymetry of Porcupine Seabight must be viewed with caution. However, the restriction of the erosion surface to the eastern margins of the Seabight and to Porcupine Bank and its absence beneath the Seabight itself suggests that a basin existed by Aptian time in the Seabight. This is confirmed by onlap of Formation 3 toward the basin margins at least in the southern part of the Seabight.

<u>Tectonics of the Rifted Margins</u>

Between the shelf edge and continent-ocean boundary the structure consists of a series of tilted blocks bounded by faults whose polarity is generally down toward the ocean basin or the axis of Porcupine Seabight. True horsts are rare although Porcupine Bank can be considered as a horst-like feature of very large dimensions. It should be noted that truncation of blocks by the erosion surface can give the misleading appearance of horsts on single-channel seismic profiles.

The principal faults observed beneath the margin are shown in generalised form in Figures 4, 7, 8. It should be stressed that the fault pattern has been mapped from rather widely spaced profiles and the true pattern may be more complex, possibly consisting of a series of anastomosing en-echelon faults whose throw varies along the strike.

In general, the principal fault trend closely parallels the strike of the margin between the Goban Spur and Meriadzek Terrace. In the latter area fault trends range from NNW to 130° (fig. 4, 6, 7). Northward however, the principal faults change trend to 150°E in the Goban Spur area (fig. 8). One particularly large and nearly continuous fault defines the Pendragon Escarpment (fig. 8). Faults trending WNW-ESE observed in both the Goban Spur and near the Meriadzek Terrace have also been reported from the Fastnet Basin and may have been controlled by pre-existing fractures in the Hercynian basement. Within the Porcupine Seabight the boundary faults converge northward and must presumably merge with the fault plexus observed by Bailey (1975) at the foot of the Slyne Ridge. Fault blocks of uncertain trend are also present on Porcupine Bank (Roberts 1975). The southwest part of Porcupine Bank lies directly on strike with the Pendragon escarpment but north of 54°N, the margin changes trend to NNE, parallel to the trend of the magnetic anomalies in the mouth of the Rockall Trough. Structural relationships between the Southern Porcupine Seabight, Porcupine Bank and the northern Goban Spur are enigmatic. The classical fault block structure observed to the south is only weakly developed along the northern edge of Goban Spur with apparent downthrow toward the north. This occurs in conjunction with the unusual seismic facies in formation 4 mentioned earlier, although the seismic data suggests that fault blocks and associated syn-rift sediments can be followed at depth beneath the Seabight. It is tentatively proposed that the Seabight developed as a very large trapdoor structure 'hinged' in the north against the Slyne Ridge so that down faulting was least in the north and greatest in the south.

On Goban Spur and in the Western Approaches, spacing between fault blocks varies from a few to 30 km (fig. 6, 7, 8). Throws vary considerably along strike for individual faults, hinting at an en-echelon pattern, but may be as much as 3-4 km for larger faults. The faults are listric normal faults whose dip flattens with depth in many cases. Rotations are typically 20-30°. Beneath some fault blocks, a very strong prominent group of flat-lying reflectors have been observed that bears no relationship to the tectonised layer above. The reflectors occur beneath faulted Hercynian granites as well as sediments and must therefore correspond to a discontinuity in the mechanical properties of the crust, rather than to a zone of decollement. The reflection corresponds to the top of a 6.3 km sec refractor identified by Avedik et al. (1979). The existence of these reflections and the known geometry of the listric faults impose severe constraints on mechanisms of crustal attenuation during rifting. The listric fault geometry indicate extension of about 10 to 15% of the previous width, but crustal thinning from 30 km to 12 km is required by refraction and gravity data. De Charpal et al. (1978) and Montadert et al. (1979a) propose that rifting was accomplished by a combination of brittle fracture along listric faults in the upper crust with complementary thinning by ductile flow below, so thinning the crust by as much as 18 km. In the Western Approaches, at least, rifting was apparently not preceeded by regional uplift and no erosion occurred prior to or during rifting in the central trough now represented by the asymmetric non-eroded fault blocks close to the continent-ocean boundary. Uplift of the rift margin that post-dates the initiation of the rift is revealed by the Mid-Cretaceous erosion surface, but is not otherwise expressed in the topography because erosion kept pace with uplift. It should be noted however that uplift of the older massifs of Cornubia, Armorica and Ireland may be indicated by the abundant and thick Wealden succession found in the Celtic Sea and Western Approaches Basin (Allen, 1975; Roberts, 1974; Hallam and Sellwood, 1976). Here again however the uplift seems to have followed initiation of the rifting.

Post-Rifting History

Tectonics

In Biscay, the continental lithosphere was completely ruptured by Aptian time and oceanic crust began to accrete along the margin. Rifting ended somewhat later to the west of Goban Spur and in Rockall Trough, spreading in the latter area commencing during the post-Albian pre-Campanian interval. Following the onset of spreading the margin began to subside. The post-rift subsidence is thought to be related to thermal contraction of the lithosphere initiated when the heat source moved away from the margin at the onset of spreading (Sleep, 1971, 1973) although Bott (1971, 1973) has proposed that the subsidence may also occur in response to 'crustal creep' of lower continental crustal material toward the sub-oceanic mantle. In Biscay, Goban Spur and Porcupine Seabight, no significant faulting of the post-rift sequence occurs, with the exception of the Late Eocene or 'Pyrennean' faulting developed in the outer part of the Western Approaches margin. The post-rift subsidence was characterized by a gentle oceanward tilting of the margin of Goban Spur and the Western Approaches and by subsidence of the Porcupine Seabight towards the basin axis. Montadert et al. (1979a) estimated the absolute subsidence of the margin in the Western Approaches from the change in altitude of the Aptian horizon between the end of rifting and the present (Figure 11) using data from drilling and dredging and constraints from seismic reflection profiles. The subsidence curve shows that the present depth attained by a point on the margin depends on its altitude at the end of rifting and on its distance from the continent-ocean boundary, while the absolute value of subsidence seems to depend only on the distance to the continent-ocean boundary. It should be noted that the amount and rate of subsidence is not the same for every point on the margin but that the subsidence has been greatest closest to the continent-ocean boundary. Inflections in the subsidence curve may reflect changes in thickness of the crust suggesting that the subsidence is also dependent on crustal thickness. The subsidence curve can, of course, be used as a means of understanding and predicting depths of deposition and thus facies distribution at particular times. For example, the curve (figure 11) shows that carbonates and carbonaceous limestones of Aptian age originally deposited at shelf depths at sites 401 and 402A now lie in depths ranging 3000-4000m.

It should be stressed that the regional oceanward tilt of the margin due to subsidence was not associated with any rejuvenation of the rift faults, in conformity with plate tectonic models which indicate that major tectonic activity on passive margins ceases at the onset of spreading. There is, however, good evidence of late Eocene deformation on the Biscay Abyssal Plain which increases in intensity towards the north Spanish Trough. In the Western Approaches margin, faulting is most intensive in the vicinity of the Trevelyan Escarpment, which was formed by uplift associated with reverse and transcurrent faults. The tectonized belt passes northwestward into a single group of strike-slip faults that apparently disappear near the southern Goban Spur (fig. 6). East-west folds observed on the Meriadzek Terrace result from the same deformation, which is also marked by renewed movement along NW-SE Hercynian faults in the Bristol Channel area. This was part of a wider compressional event that affected much of western Europe during the Late Eocene and was caused by the Pyrennean deformation.

The shelf was also affected by deformation in Early Tertiary and in Miocene time, but major faulting associated with these events is not evident in the area between the southern Porcupine Seabight and the Armorican margin.

Sedimentary History

Following the rifting, Aptian and Albian beds were laid down in water depths ranging from outer shelf to around 2000m. The topography of the young margin was undoubtedly controlled by the system of tilted blocks developed during the rifting phase. It is clear that these blocks strongly influenced both depositional patterns and facies distribution (figure 9). In the shelf area, the Aptian-Albian carbonaceous shales and limestones comprised a prograding delta-like body deposited on Jurassic carbonates in half-graben. Aptian-Albian sediments that by-passed the natural barriers formed by the fault blocks were transported downslope by turbidity currents to form the deep water shales sampled at site 400A, and seen resting on the ocean crust of Biscay. In the outer fault blocks, isolated from terrigenous sediments, Aptian chalks were laid down. The carbonaceous material, which is thermally immature and largely composed of wood fragments (Deroo et al. 1979; Davey, 1979; Batten, 1979), was probably derived from swamps established in the 'Wealden' deltas (Allen, 1975; Hallam and Sellwood, 1976; Robinson et al. this volume). In contrast, Goban Spur remained a positive feature at, or close to, sea level (Auffret et al. 1979). Within Porcupine Seabight the topographic controls on Aptian-Albian sedimentation appear to have been less important and a thick sequence of unknown facies was laid down as an onlap sequence against the slope. West of Goban Spur and in the western Porcupine Seabight, Aptian-Albian deposition was probably contemporaneous with the continued rifting of the margin in that area.

The geological record for the succeeding Albian-Campanian interval is largely absent because of the important hiatus that encompasses this interval. In Biscay the margin continued to subside and, by Campanian time, depths were abyssal at sites 400A and site 401 (Montadert et al. 1979a). However, Goban Spur may have remained relatively shallow compared to the Western Approaches margin. The mid-Cretaceous transgression began in Albian time and peaked during the Turonian, submerging the outer shelf and much of the adjacent land area, thus cutting off the clastic sediments that characterized the Aptian and Albian on the margin. The apparent absence of much of the Cretaceous during the interval is puzzling in view of the thick chalk sequences laid down in the adjacent epicontinental seas.

To account for the missing interval Roberts and Montadert (1979) have proposed an elevated carbonate compensation depth and increased bottom current activity. The stratigraphic gap may however be exaggerated because key sites were drilled on bathymetric highs. It is therefore possible that a more complete Cretaceous section may be present beneath the Biscay Abyssal Plain, perhaps composed of chalks redeposited by turbidity currents. Within Porcupine Seabight, the greater thickness of formation 2 which onlaps northward suggests the presence of a more complete Cretaceous section (fig. 9, 10). Only the final phases of chalk deposition are recorded in the margin by the thin Campanian-Early Palaeocene chalk section cored at DSDP sites 400A and 401. At sites 400A-402A the Palaeocene was followed by a marked break in lithology, and in the Porcupine Seabight by a sharp change in seismic facies. In the Porcupine Seabight, a deltaic platform prograding from north to south and fed by fans on the western and eastern (?) side of the Seabight was developed by Lower Eocene time with a more distal facies in the southerly parts of the Seabight. These deltaic conditions were succeeded by transgressive facies in Upper Eocene time (Louis and Mermey, 1979). The seismic facies changes are less marked in the more condensed sequence of the Biscay margin but an influx of terrigenous material is clearly apparent in the Eocene section at sites 400A and 402A. In addition, a great increase in both the thickness and layering of the section is seen in the abyssal plain. The change in seismic facies may be related to regional uplift of Ireland in Early Tertiary time (George, 1967). Strikingly, formation 2 is thin to the west of Goban Spur suggesting that the increased influx of sediment was trapped in Porcupine Seabight or bypassed the Goban Spur along canyons in the Western Approaches margin (fig. 10). Although transgression again took place in Late Eocene time, regional uplift possibly associated with the Pyrennean deformation is evident in the Western Approaches Basin and on the margin (Roberts, 1974; Montadert _et al._

1979a, this paper). An unconformity with strong erosion equivalent to R4 of Roberts (1975) occurs between the Eocene and the Oligocene marking a major change in sedimentary regime with resulting erosion and the formation of sediment drifts.

By Oligocene time, the margin had more or less reached its present depth and geography. In the Porcupine Seabight, Goban Spur and Bay of Biscay deep water conditions prevailed. The post-Eocene section is composed of a number of sequences separated by unconformities. One particularly large unconformity of inferred Early Miocene age is associated with deep erosion in the Porcupine Seabight. The unconformities are particularly clear on the upper slope and may be related to eustatic changes in sea level.

Conclusion

In this review, we have attempted to summarise the tectonic and sedimentary history of the margin between the Porcupine Seabight and the Armorican margin (figure 8). Following the Hercynian suturing of Pangaea, the major phase of rifting that ultimately led to the separation of Europe, North America and Iberia took place in Late Jurassic-Early Cretaceous time. The rifted margin is divided into three structural provinces; Porcupine Seabight, Goban Spur and the Western Approaches Margin. The structure of the Goban Spur and Western Approaches is dominated by large normal faults, often listric in type. Large normal faults are also present beneath the margins of Porcupine Seabight but the structural development of the Seabight remains enigmatic. Spreading began in Biscay in Aptian time. At this time a rift may have been present west of Goban Spur and in Rockall Trough. A basin some 2000m in depth existed in the Western Approaches, flanked to the north by the shallower Goban Spur and the Porcupine Seabight.

Following the onset of spreading the margin progressively subsided, tilting oceanward without major faulting. Faulting in the Western Approaches margin in Late Eocene time was apparently related to the Pyrennean deformation.

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References

ALLEN, P. 1975 Wealden of the weald: a new model.
Proc. Geol. Assoc., 86 (4), 389-438.

AUFFRET, G.A., PASTOURET, L., CASSAT, G., CHARPAL, O. de, CRAVATTE, J. and GUENNOC, P. 1979 Dredged rocks from the Armorican and Celtic Margins.
Pp. 995-1008 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48. U.S. Government Printing Office.

AVEDIK, F. and HOWARD, D. 1979 Preliminary results of a seismic refraction study in the Meriadzek - Trevelyan area, Bay of Biscay.
Pp. 1015-1023 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48. U.S. Government Printing Office.

BAILEY, R.J. 1975 Sub-Cenozoic geology of the British Continental Margin (lat. 50 N to 57 N) and the reassembly of the North Atlantic Late Palaeozoic supercontinent.
Geology, 3, p.591-594.

BAILEY, R.J., JACKSON, P.D. and BENNELL, J.D. 1977 Marine geology of Slyne Ridge.
J. Geol. Soc. Lond., 133 (2), 165-172.

BATTEN, D.J. 1979 Miospores and other acid-resistant microfossils from the Aptian/Albian of holes 400A and 402A, DSDP-IPOD leg 48, Bay of Biscay.
Pp. 579-588 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48. U.S. Government Printing Office.

BLUNDELL, D.J. 1975 The geology of the Celtic Sea and Southwestern Approaches.
P.341-362 in: Canada's Continental Margins.
Can. Soc. Pet. Geol. Mem., 4.

BOTT, M.H.P. 1971 Evolution of young continental margins and the formation of shelf basins.
Tectonophysics, 11, p.319-327.

BOTT, M.H.P. 1973 Shelf subsidence in relation to the evolution of young continental margins.
P. 675-683 in: Tarling, D.H. and Runcorn, S.D. (eds); Implications of continental drift on the earth sciences, Vol. 2.
Academic Press, London.

BOTT, M.H.P., DAY, A.A. and MASSON-SMITH, D. 1958 Geological interpretation of gravity and magnetic surveys in Devon and Cornwall.
Phil. Trans. Roy. Soc. Ser. A, 251, (992), 161-191.

BRGM, ELF- Re, ESSO- REP- SNPA 1974 Geologie du Bassin d'Aquitaine.
Paris (BRGM editions).

BUCKLEY, J.S. and BAILEY, R.J. 1975 A free-air gravity anomaly contour map of the Irish continental margin.
Marine Geophys. Rech. Vol. 2, 185-194.

CANDE, S.C. and KRISTOFFERSEN, Y. 1977 Late Cretaceous magnetic anomalies in the North Atlantic.
Earth Planet. Sci. Lett., Vol. 35, 215-224.

CASTON, V.N.D., DEARNLEY, R. and HARRISON, R.K. 1979 Bathonian olivine dolerite intrusions in the Fastnet Basin.
Abstr. Geol. Soc. Newslett, 8 (4),

CHERKIS, N.Z., FLEMMING, H.S., and MASSINGILL, J.V. 1973 Is the Gibbs Fracture Zone a westward projection of the Hercynian Front into North America.
Nature, Phys. Sci., 245, 113-115.

CURRY, D. and SMITH, A.J. 1975 New discoveries concerning the geology of the central and eastern parts of the English Channel.
Phil. Trans. R. Soc. Lond., ser. A, 279, 155-167.

DAVEY, R.J. 1979 Marine apto-Albian polynomorphs from holes 400A and 402A, IPOD leg 48, northern Bay of Biscay.
P. 547-578 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48
U.S. Government Printing Office.

DAY, G.A. and WILLIAMS, C.A. 1970 Gravity compilation in the northeast Atlantic and interpretation of gravity in the Celtic Sea.
Earth Planet. Sci. Lett., 8, 207-213.

DE CHARPAL, O1, GUENNOC, P., MONTADERT, L. and ROBERTS, D.G. 1978
Rifting, crustal attenuation and subsidence in the Bay of Biscay.
Nature, 275, 706-711.

DEROD, G., HERBIN, J.P., ROUCACHE, J. and TISSOT, B. 1979 Organic geochemistry of Cretaceous mudstones and marly limestones from DSDP sites 400 and 402, Leg 48, Eastern North Atlantic.
P. 921-930 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48, U.S. Government Printing Office.

DEWEY, J.F. 1974 The geology of the southern termination of the Caledonides.
P. 205-271 in: The Ocean Basins and Margins, 2, (Nairn A.E.M. and Stehli, F.G. editors).

DINGLE, R.V. and SCRUTTON, R.A. 1977 Continental margin fault pattern mapped south-west of Ireland.
Nature, 268, 720-722.

GEORGE, T.N. 1967 Landform and structure in Ulster.
Scott. J. Geol., 3, 413-448.

HALLAM, A. and SELLWOOD, B.W. 1976 Mesozoic sedimentation in relation to tectonics in the British area.
J. Geol. 84 (3), 301-321.

HARRISON, R.K., SNELLING, N.J., MERRIMAN, R.J., MORGAN, G.E. and GOODE, A.J.J. 1977 The Wolf Rock, Cornwall: new chemical, isotopic age and palaeomagnetic data.
Geol. Mag., 114, 249-328.

KAMERLING, P. 1979 The geology and hydrocarbon habitat of the Bristol Channel Basin.
J. Petrol. Geol., Vol. 2, 75-93.

KRISTOFFERSEN, Y. 1978 Sea-floor spreading and the early opening of the North Atlantic.
Earth Planet. Sci. Lett., 38, 273-290.

LAUGHTON, A.S., BERGGREN, W.A. et al., 1972 Initial Reports of the Deep Sea Drilling Project, Vol. 12, U.S. Government Printing Office, 1243 pages.

LOUIS, P.R. and MERMEY, P. 1979 An example of seismic stratigraphy: The Porcupine Basin - Western Ireland.
(Paper presented at the 49th International Meeting of the Society of Exploration Geophysicists).

MONTADERT, L., ROBERTS, D.G., CHARPAL, O. de and GUENNOC, P. 1979a Rifting and subsidence of the northern continental margin of the Bay of Biscay.
P. 1025-1060 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48, U.S. Government Printing Office.

MONTADERT, L., ROBERTS, D.G., et. al., 1979b Initial Reports of the Deep Sea Drilling Project, Vol. 48, U.S. Government Printing Office.

MURPHY, T. 1960 Gravity anomaly map of Ireland. Sheet 5 - Southwest Dublin Institute for Advances Studies, School of Cosmic Physics Geophysical Bulletin, No. 18.

PAUTOT, G., RENARD, V., De CHARPAL, O., AUFFRET, G.A. and PASTOURET, L. 1976 A granite cliff deep in the North Atlantic.
Nature, 263, 669-672.

PITMAN, W.C., TALWANI, M. and HEIRTZLER, J.R. 1975 Age of the North Atlantic Ocean from magnetic anomalies.
Earth Planet Sci. Lett., Vol. 4, 195-200.

ROBERTS, D.G. 1974 Structural development of the British Isles, the continental margin, and the Rockall Plateau.
P. 343-359 in: The Geology of Continental Margins, Burke C.A. and Drake, C.L. editors.

ROBERTS, D.G. 1975 Marine Geology of the Rockall Plateau and Trough.
Phil. Trans. R. Soc. London, ser. A, Vol. 278, 447-509.

ROBERTS, D.G. and JONES, M.T. 1975 Magnetic anomalies in the north-east Atlantic, sheets 1 and 2.
Abst. Mtg. European Geol. Soc. Reading.

ROBERTS, D.G., MASSON, D.G. and MILES, P.R. (in prep.) Age and structure of the southern Rockall Trough: a new assessment.

ROBERTS, D.G. and MONTADERT, L. 1979 Margin palaeoenvironments of the northeast Atlantic.
P. 1099-1118 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48, U.S. Government Printing Office.

ROBERTS, D.G., MONTADERT, L. and SEARLE, R.C. 1979 The western Rockall Plateau: Stratigraphy and Structural Evolution.
P. 1061-1088 in: Initial Reports of the Deep Sea Drilling Project, Vol. 48, U.S. Government Printing Office.

ROBINSON, K.W., SHANNON, P.M. and YOUNG, D.G.G. This volume (In prep.) The Fastnet Basin, an integrated analysis.

SCRUTTON, R.A. 1979 Structure of the crust and upper mantle at Goban Spur, southwest of the British Isles - some implications for margin studies.
Tectonophysics, 59, 201-215.

SEGOUFIN, J. 1975 Structure du plateau continental armoricain.
P. 109-121 in: A dicussion on the geology of the English Channel.
Phil. Trans. Roy. Soc. Lond., 279.

SIBUET, J.C. 1972 Contribution de la gravimetrie a l'etude de la Bretagne et du plateau continental adjacent.
C.R. Somm. Soc. Geol. France, 24, 124-129.

SLEEP, N.H. 1971 Thermal effects of the formation of Atlantic continental margins by continental break-up.
Geophys. J.R. Astron. Soc. 24, 325-350.

SLEEP, N.H. 1973 Crustal thinning on Atlantic continental margins: evidence from older margins.
In: Tarling, D.H. and Runcorn, S.K. editors; Implications of continental drift on the earth sciences, 2, 685-692.
Academic Press London.

VOGT, P.R. and AVERY, O.E. 1974 Detailed magnetic surveys in the north-east Atlantic.
J. Geophys. Rech., 79 (2), 363-389.

WHITMARSH, R.B., LANGFORD, J.L., BUCKLEY, J.S., BAILEY, R.J. and BLUNDELL, D.J. 1974 The crustal structure beneath Porcupine Ridge as determined by explosion seismology.
Earth Planet. Sci. Lett, 22, 197-204.

WILLIAMS, C.A. 1972 Sea-floor spreading in the Bay of Biscay and its relationship to the North Atlantic.
Earth Planet. Sci. Letts. 24, 440-456.

WINNOCK, E. 1971 Geologie succincte du Bassin d'Aquitaine (contribution a l'historie du Golfe de Gascogne).
P. 1-30 in: Historie Structurale du Golfe du Gascogne, Vol. 4, (1), Paris (Technip).

WOODLAND, A.W. (ed.) 1975 Petroleum and the Continental Shelf of North West Europe: Vol. 1, Geology. 301 pp.
Published for the Institute of Petroleu, G.B., by Applied Scinece Publishers.

ZIEGLER, P.A. 1978 North-western Europe: Tectonics and basin development.
Geologie en Mijnbouw, 57, 589-626.

Figure Captions

Figure 1 Bathymetry of the margin in the South Western Approaches (redrawn from Roberts et al. 1979).

Figure 2 Seismic reflection profiles on the margin in the South Western Approaches. DSDP sites drilled during Leg 48 of Glomar Challenger are also shown.

Figure 3 Magnetic anomaly map of the margin redrawn from Roberts and Jones (1975). Contour interval 100 gammas.

Figure 4 Regional structure map of the margin from the Porcupine Seabight to the Armorican marginal basin. Details of the Celtic Sea and Western Approaches Basin have been omitted for clarity.

Figure 5 Free-air gravity anomaly map of the Celtic Sea and continental margin in the South Western Approaches. Data sources are given in the text.

Figure 6 Schematic structural sections across the margin in the South Western Approaches. Sections are located in Figure 4.

Figure 7 Tectonic pattern of the north Biscay margin. Isopachs drawn on 'basement' in seconds two-way-time.

Figure 8 Tectonic pattern of the Goban Spur. Isopachs drawn on 'basement' in seconds two-way-time.

Figure 9 Distribution of Pre-Cenomanian sediments beneath the margin from Porcupine Seabight to the Armorican Basin.

Figure 10 Total sediment thickness beneath the margin from Porcupine Seabight to the Armorican Basin.

Figure 11 Absolute amount of post-rifting subsidence of the north Biscay margin from the shelf to the oceanic crust. Upper dotted line: simplified topography of the rift at Aptian time. Lower dotted line: present depth of Aptian corrected for loading. Full line: amount of subsidence.

BATHYMETRY

FIG 1


55°
54°
52°
50°
48°
46°
20°
18°
16°
14°
12°
10°
8°
6°
4°
2°
100
0
100
Kilometres
Scale 1:2,000,000
Seismic Reflection Profiles
400 DSDP Site
A
B
C
402
401
400

FIG 2

POSITIVE MAGNETIC ANOMALY
CONTINENT-OCEAN BOUNDARY
100 0 100
Kilometres
Scale 1:2,000,000
GIBBS FRACTURE ZONE
31-32
31-32
54
52
50
48
46
20
18
16
14
12
10
8
6
4
2

FIG 3

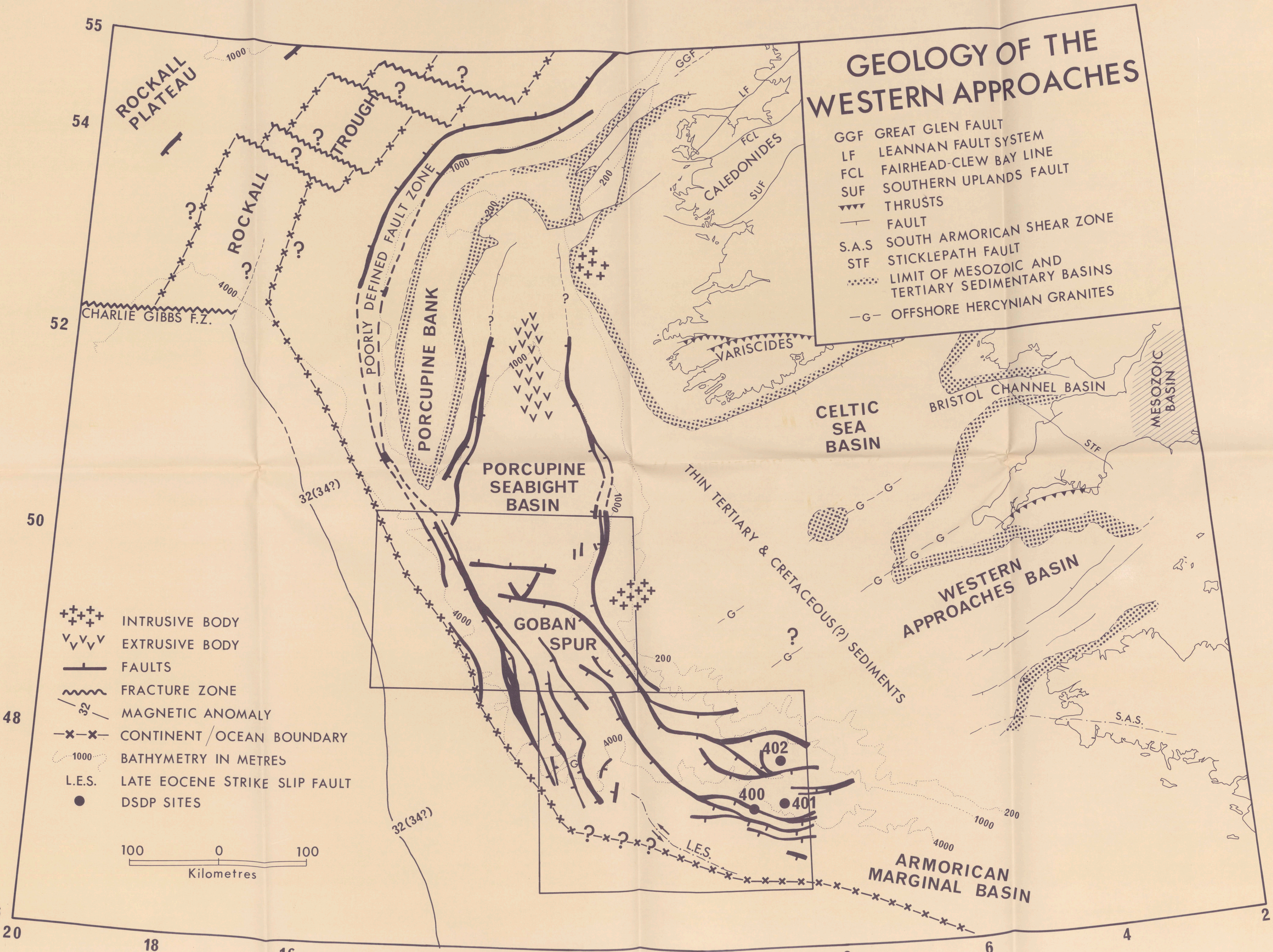
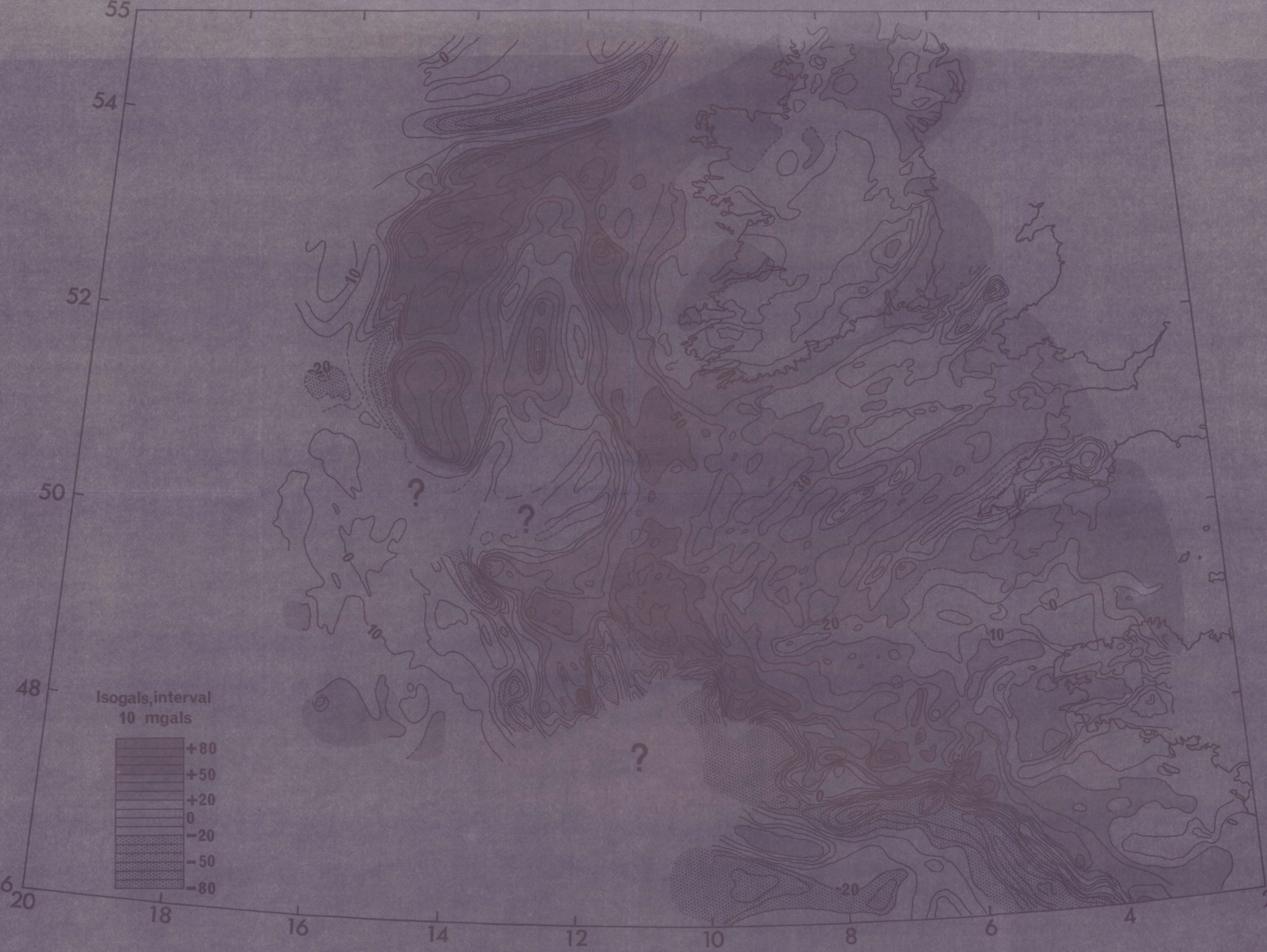
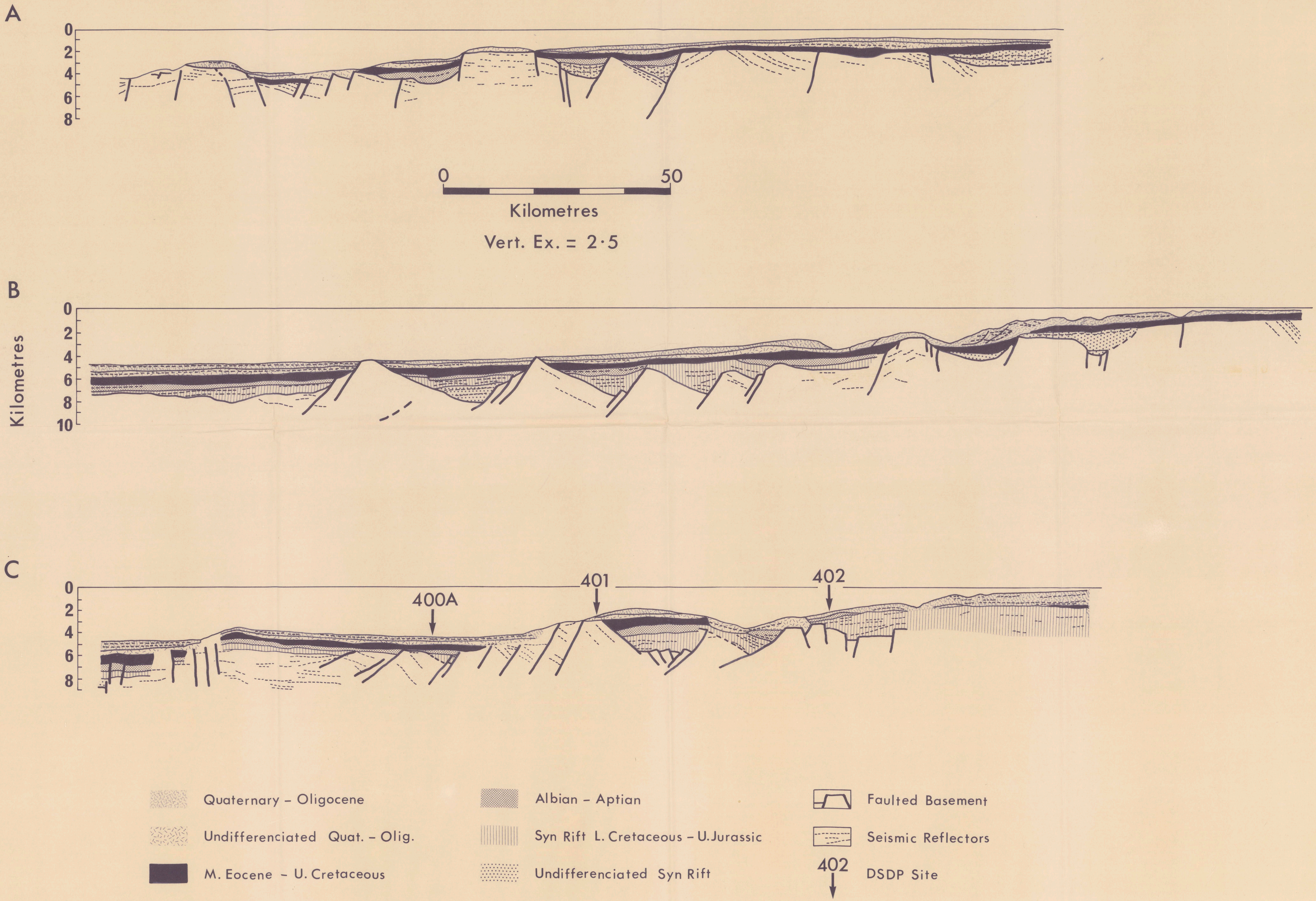

GEOLOGY OF THE WESTERN APPROACHES
GGF GREAT GLEN FAULT
LF LEANNAN FAULT SYSTEM
FCL FAIRHEAD-CLEW BAY LINE
SUF SOUTHERN UPLANDS FAULT
THRUSTS
FAULT
S.A.S SOUTH ARMORICAN SHEAR ZONE
STF STICKLEPATH FAULT
LIMIT OF MESOZOIC AND TERTIARY SEDIMENTARY BASINS
OFFSHORE HERCYNIAN GRANITES
INTRUSIVE BODY
EXTRUSIVE BODY
FAULTS
FRACTURE ZONE
MAGNETIC ANOMALY
CONTINENT / OCEAN BOUNDARY
BATHYMETRY IN METRES
L.E.S. LATE EOCENE STRIKE SLIP FAULT
DSDP SITES
100 0 100
Kilometres
ROCKALL PLATEAU
ROCKALL TROUGH
ROCKALL
CHARLIE GIBBS F.Z.
POORLY DEFINED FAULT ZONE
PORCUPINE BANK
PORCUPINE SEABIGHT BASIN
GOBAN SPUR
CALEDONIDES
VARISCIDES
CELTIC SEA BASIN
BRISTOL CHANNEL BASIN
MESOZOIC BASIN
WESTERN APPROACHES BASIN
THIN TERTIARY & CRETACEOUS(?) SEDIMENTS
ARMORICAN MARGINAL BASIN
32(34?)
402
400
401
55
54
52
50
48
46
20
18
16
14
12
10
8
6
4
2

FIG 4



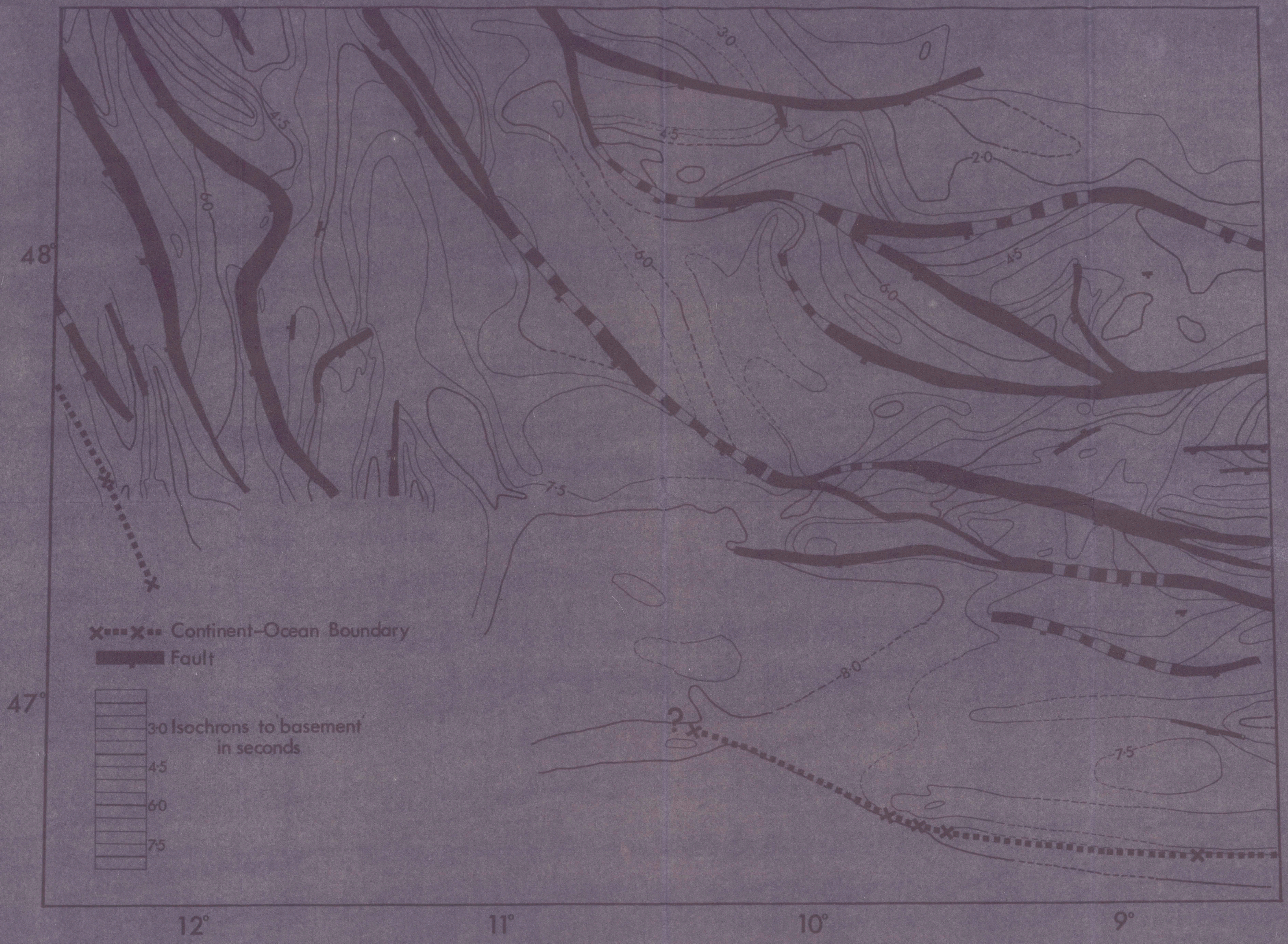
55
54
52
50
48
46
20
18
16
14
12
10
8
6
4
2
Isogals, interval
10 mgals
+80
+50
+20
0
−20
−50
−80
?
?
?
10
−20
50
30
20
10
0
−20

FIG 6



A
0
2
4
6
8
0
50
Kilometres
Vert. Ex. = 2·5
B
Kilometres
0
2
4
6
8
10
C
0
2
4
6
8
400A
401
402
Quaternary – Oligocene
Undifferenciated Quat. – Olig.
M. Eocene – U. Cretaceous
Albian – Aptian
Syn Rift L. Cretaceous – U. Jurassic
Undifferenciated Syn Rift
Faulted Basement
Seismic Reflectors
402
DSDP Site

FIG 6



Continent–Ocean Boundary
Fault
Isochrons to 'basement' in seconds
3·0
4·5
6·0
7·5
2·0
8·0
48°
47°
12°
11°
10°
9°
?

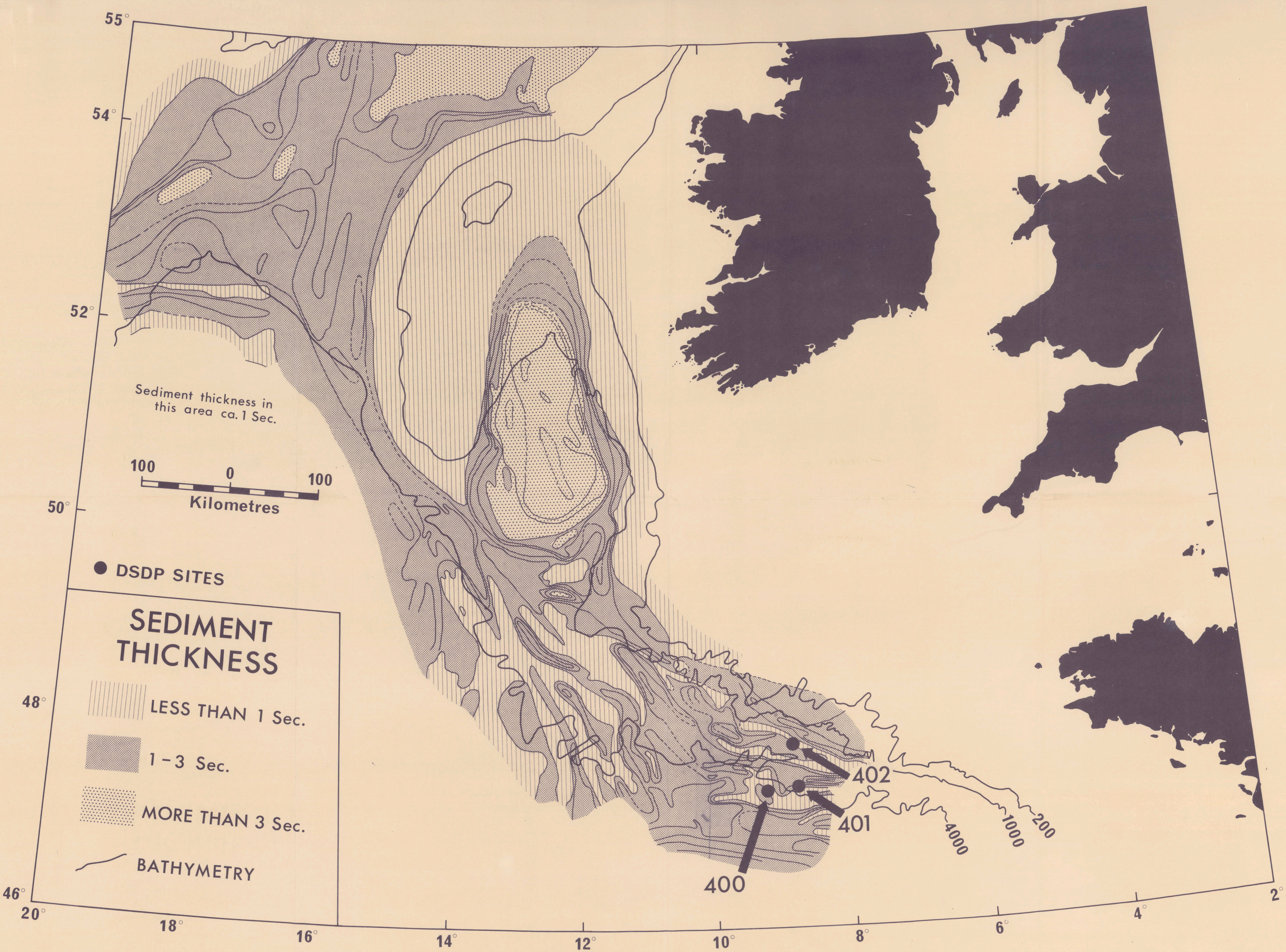
FIG 7


Continent–Ocean Boundary
Fault
3·0
4·5
6·0
7·0
Depth to 'basement' in seconds
50°
49°
15°
14°
13°
12°
11°

FIG 8

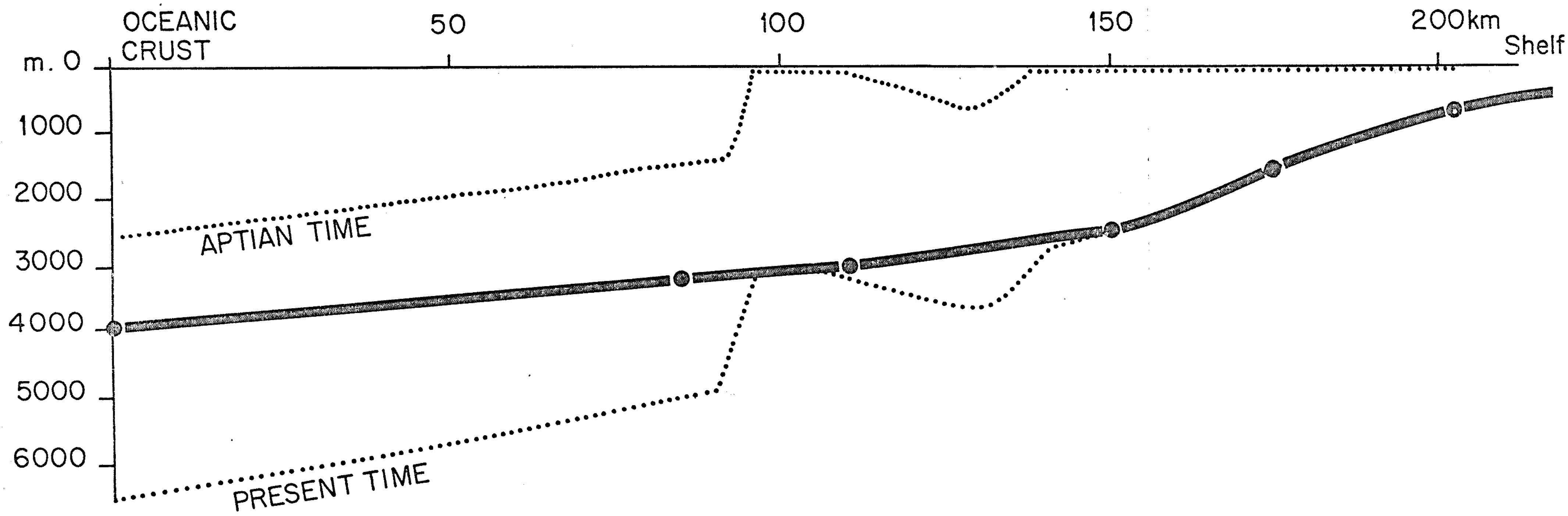
100 0 100
Kilometres
Scale 1:2,000,000
Transverse Mercator Projection
Bathymetry in Metres
DSDP Sites
x–x–x Continent/Ocean Boundary
? Insufficient data
Sediment Thickness
>1 sec.
0–1 sec.
Limit of pre-Aptian erosion surface
402
401
400
54
52
50
48
46
20
18
16
14
12
10
8
6
4
2

FIG 9



SEDIMENT THICKNESS
LESS THAN 1 Sec.
1 – 3 Sec.
MORE THAN 3 Sec.
BATHYMETRY
DSDP SITES
Sediment thickness in this area ca. 1 Sec.
100 0 100
Kilometres
400
401
402
4000
1000
200
55°
54°
52°
50°
48°
46°
20°
18°
16°
14°
12°
10°
8°
6°
4°
2°

FIG 10



OCEANIC
CRUST
50
100
150
200km
Shelf
m. 0
1000
2000
3000
4000
5000
6000
APTIAN TIME
PRESENT TIME

FIG (11)