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The Geology of the Western Approaches of the English Channel. I. Chalky Rocks from the Upper Reaches of the Continental Slope

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THE GEOLOGY OF THE WESTERN APPROACHES OF THE ENGLISH CHANNEL

I. CHALKY ROCKS FROM THE UPPER REACHES OF THE CONTINENTAL SLOPE

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Dredged samples of Tertiary chalks are described from five stations distributed over a distance of about 200 miles along the continental slope. The Foraminifera and nannoplankton indicate a range in age from Middle Eocene to Upper Miocene. The conclusions are reached that (i), the continental slope appears not to have received and retained much clastic sediment of recent geological time, (ii), the facies of the chalks is quite different from that recorded in western Europe, (iii), the chalks crop out at least in the upper reaches of the slope and form terraces, (iv), a structural explanation, probably faulting, is required to account for the conflicting topographical and stratigraphical levels of some samples and (v), there is no support for the existence before Pleistocene times of the continental shelf of the Western Approaches in physiographical form similar to that known today.

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1. Introduction

Aboard the R.V. *Sarsia* in 1958 Dr A. J. Southward of the Marine Biological Association, Plymouth, when dredging for pogonophores about 200 miles west and 120 miles west-south-west of Ushant (Finistère), raised rock-samples from the upper reaches of the continental slope at four stations; in 1961 he worked a fifth station situated about 150 miles west of St Nazaire (Loire Inférieure).

The samples are mixed and include pebbles, cobbles and boulders up to 2 ft. across, and comprise a wide variety of igneous and metamorphic rocks, none of which possesses unique characters indicative of its provenance on land. Their rounded shapes and the polygenic assemblages of rocks suggest a glacial origin. Before a connexion, by way of the gulf of Dover, was effected between the Western Approaches and the North Sea a clockwise current presumably flowed along the front of the Irish and Irish Sea ice and rafted mud, sand, pebbles and boulders on icebergs and ice-floes, which later melted and dumped the glacial detritus approximately at the position on the sea bed that it has been dredged. Subsequently, sometime during the period when the Strait of Dover was opened at the time of the Penultimate or Great Interglacial corresponding to the 32 m Tyrrhenian level (Zeuner 1959, p. 289), about say 300000 years ago,* a strong westerly surge of the dammed meltwater derived from the Great Eastern and Scandinavian ice-sheets also contributed, through the agency of icebergs, to the glacial material on the continental slope and shelf. Whatever their origin these rocks can have no significance with regard to the composition and succession of the solid strata which constitute most of the upper part of the continental slope.

Amidst the rounded samples of glacially derived rocks are pieces of indurated and also soft chalky material. The smallest is an inch long and the largest a block 24 in × 18 in × 8 in; the edges are angular, some of the surfaces are bored by worms, molluscs and perhaps other organisms, and in some examples the chalk appears to be bedrock to which living coral was attached when first collected. The chalks are creamy white, of variable hardness, and closely resemble samples of chalk from Upper Cretaceous rocks. In fact, they were at first thought to be of that geological age but microfossils have shown them to be much younger and to appertain to Tertiary strata (Middle Eocene to Upper Miocene). There are no known occurrences of Tertiary chalks of these ages and of comparable facies either on the mainland or on the sea bed of the Western Approaches as far west and south as at present has been sampled, but the *Globigerina* Silts, to be described later (p. 287), show resemblances. Consequently, the rocks must have been collected, probably *in situ*, at locations on the continental slope itself. The presence of stratified and lithified rocks cropping out on the slope clearly bears on its origin, and does not support the opinion advanced of recent years that the slope is the dumping ground of considerable thicknesses of unconsolidated sediments.

Martini and Curry identified, respectively, the nannoplankton and the Foraminifera, Smith prepared the lithological data and Whittard contributed the stratigraphical analysis and conclusions.

* Zeuner (1958, p. 102) suggests the most recent 'separation of Britain from the Continent occurred in late Boreal times, between 7000 and 6000 B.C.'. The Strait of Dover has thus been opened more than once.

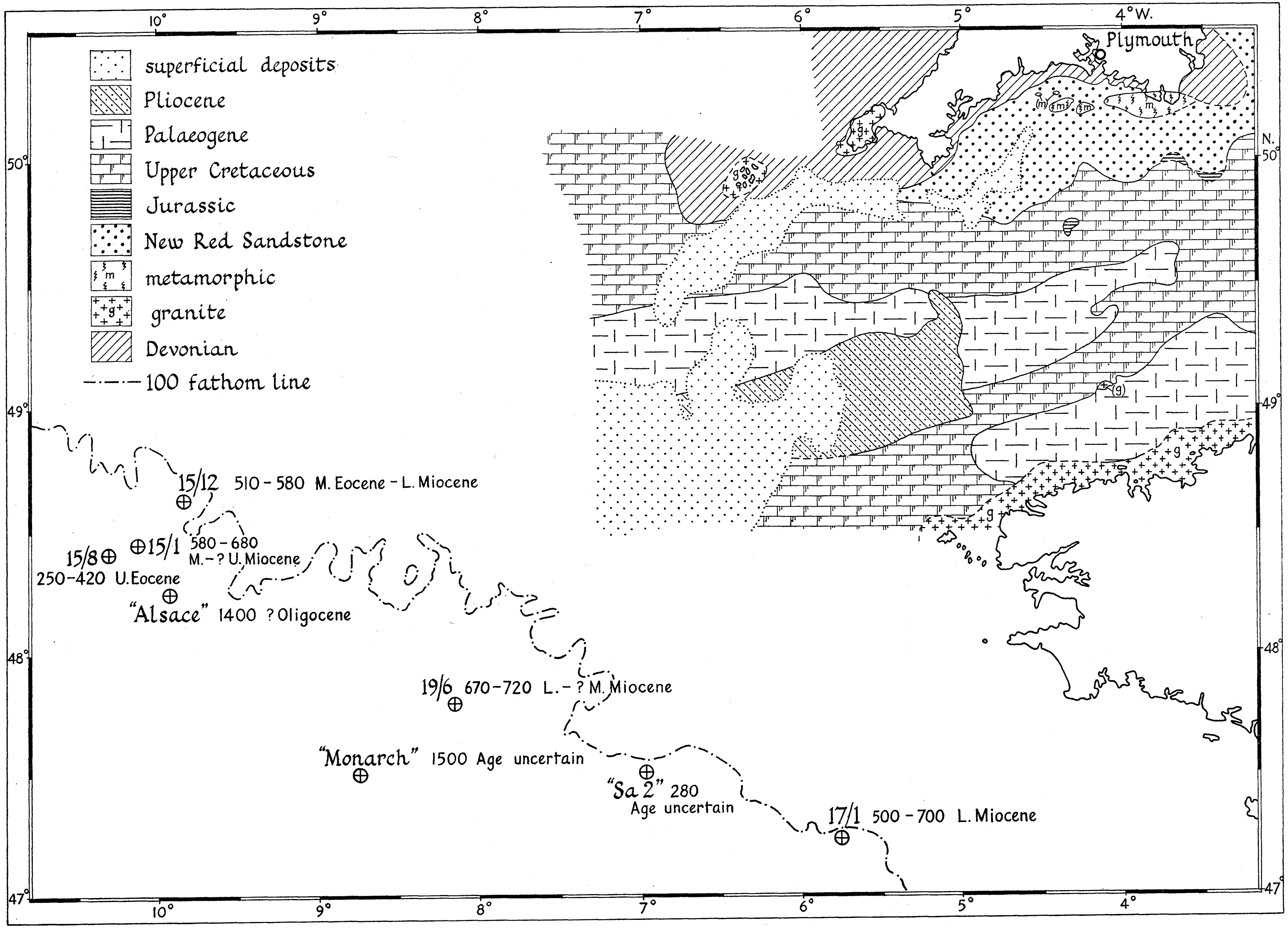

FIGURE 1. Provisional geological map of the continental shelf of the Western Approaches of the English Channel. Depths (fm) and stratigraphical ages are given alongside the locations where chalky samples were dredged from the continental slope. Approximate scale, 35 nautical miles to the inch.

2. The sedimentology of the samples

(a) *Method*

All the samples were sectioned and a point-count analysis was carried out to determine the composition and proportion of the constituents. The study of each sample is based on one thin-section study only; the possibility therefore exists that the composition recorded is not true for the whole sample.

In a preliminary investigation two space intervals of counting across sections were compared, namely 0·33 and 0·1 mm spacings. No appreciable difference in results was noted and subsequently a 0·1 mm space interval across the slide and 2·0 mm spacing at right angles to this were adopted. A closer spacing than 2·0 mm was used in some samples because of the small size of the section.

(b) *Constituents*

The constituents of the samples are as follows.

Calcite has been subdivided according to size. Following Larsen (1961), an arbitrary division at 20μ was chosen and it worked well. Calcite less than 20μ is taken to be autochthonous, while above that size it is invariably allochthonous. Some of the calcite of less than 20μ is also allochthonous, but since this fine calcite gives the chalky appearance to most of the samples the 20μ division was retained.

Glauconite occurs as allochthonous grains in some samples; they have clear boundaries and vary considerably in colour intensity. Autochthonous glauconite is usually pale green and found inside the tests of microfossils. Glauconite was detected in varying amounts in most samples.

Chalcedony is present in minor amounts in some samples (1002, 1009, 1015, 1029, 1030) and as a major constituent in others (1008 and 1012). Where chalcedony occurs as a minor constituent it is often allochthonous, being incorporated as detrital grains.

Dolomite. Rhombs of dolomite form a minor constituent in 1002, 1027, 1030, 1034 and 1038, and their good shape suggests that if they are not autochthonous they have not been carried far. However, in 1037, 14% of the sample is of dolomite rhombs and these appear to be detrital.

Sponge spicules occur in 1008, 1012, 1015, 1029, 1035 and 1038 as a minor accessory and show signs of transport by gentle currents.

Quartz has been identified in some samples, usually as subangular and angular grains.

Felspar. Fresh angular grains of orthoclase felspar occur as a minor constituent (0·7%) in sample 1026.

Zircon was the only heavy mineral recognized and it was found in sample 1026 (0·2%).

Iron minerals are present as a minor constituent in those rocks which contain a fair proportion of detrital material.

Microfossils and shell fragments occur in varying proportions in nearly all the samples but these will be considered later.

(c) *Grouping of the constituents*

The constituents have been grouped in order that the composition of the samples may be presented in a triangular diagram (figure 2). The apices of the triangle are 100% autochthonous material, 100% allochthonous material and 100% organic remains which have not been subjected to any attrition. Autochthonous material includes calcite $< 20\mu$ diameter, autochthonous glauconite, autochthonous chalcedony and dolomite. Allochthonous material includes calcite $> 20\mu$ diameter, quartz, felspar, allochthonous glauconite, dolomite, heavy minerals, iron minerals and shell fragments. Organic remains include complete tests of microfossils.

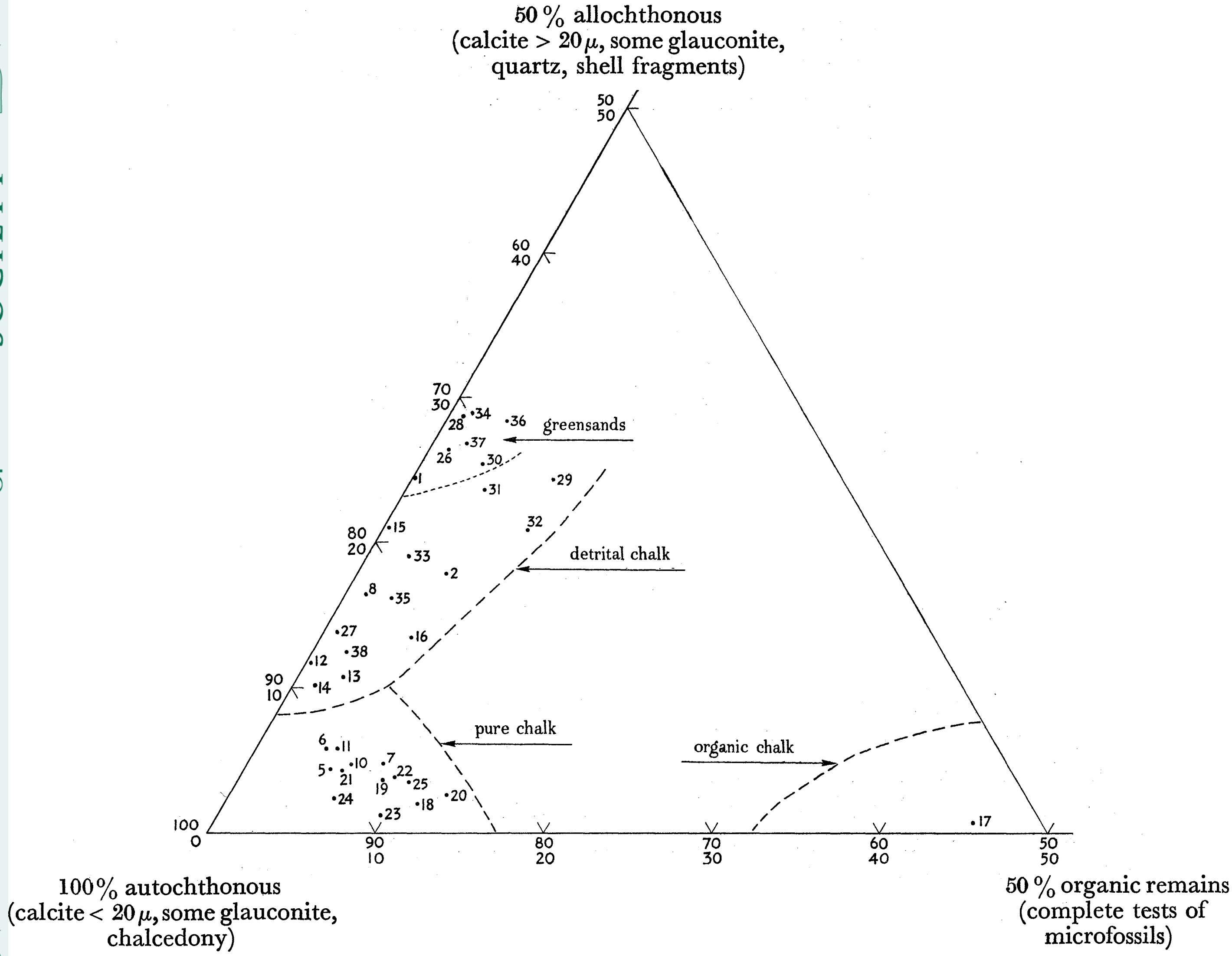

Figure 2. Composition of thirty-five samples of chalky rocks. Sample numbers within the triangle have been abbreviated such that a single number should be prefixed by 100 and a double number by 10.

The composition of all the samples is shown in figure 2, which is that part of the full triangle wherein all the *Sarsia* samples lie. Three main groupings of rock exist in the figure, to which the names pure chalk, organic chalk and detrital chalk have been applied.

Pure chalk. Over 85 % autochthonous material, up to 15 % organic remains and only up to about 5 % allochthonous material.

Organic chalk. Only one example of this variety occurs. It is composed of 55 % autochthonous material and about 45 % organic remains.

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Detrital chalk. 65 % to about 90 % fine calcite (not all of which is autochthonous), 10 % to nearly 30 % allochthonous material and less than 10 % organic remains.

In hand-specimens some of the samples are greensands. They form a distinct group within the detrital chalks and this subdivision is defined on the triangular diagram. The greensands usually contain a higher proportion of quartz-grains than the normal detrital chalks.

In all the detrital samples the coarsest material rarely exceeds the fine-sand grade size, while most of each sample is finer than the 20 μ diameter chosen as the boundary between the two types of calcite. In many of the detrital chalks much of the calcite less than 20 μ diameter seems to be detrital.

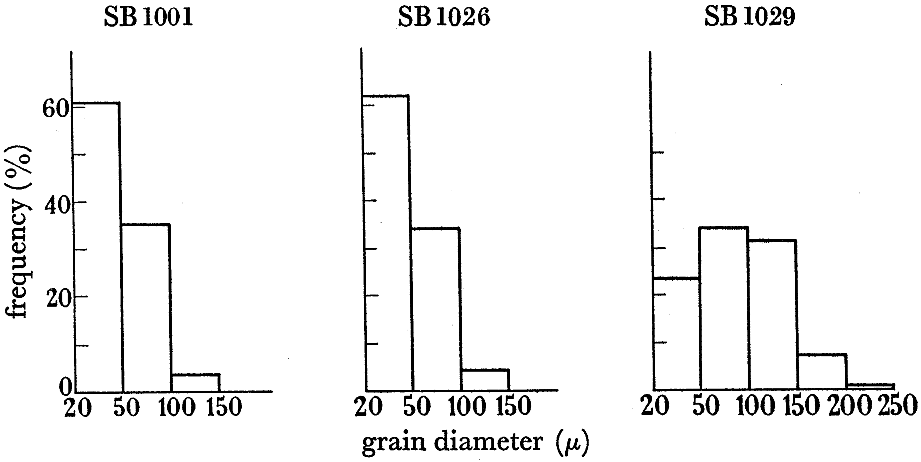

Figure 3. Histograms of the > 20 μ fraction to show the better sorting of the greensands (1001, 1026) as compared with a detrital chalk (1029).

A comparison between two greensand samples (1001 and 1026) and a detrital chalk (1029) was made on the basis of grain-size distribution; the grains were measured using a stage micrometer. The result is shown in figure 3, where the greensands are seen to possess a better degree of sorting than the detrital chalk, due to the increased proportion of shelly fragments in the latter. Such fragments would present a larger surface area to transport and possibly all three samples may have been deposited in similar conditions. All the detrital chalks probably accumulated in shallower water than the pure chalks.

3. The palaeontology of the samples

Microfossils alone occur and attention has been directed to the calcareous nannoplankton* and the Foraminifera, and among the latter particularly to the planktonic forms. The assemblages from four of the five stations show restricted stratigraphical ages; however, from one (15/12) chalks from the Middle Eocene, Upper Eocene and Lower Miocene were mixed in the dredge, which operated over a depth of 70 fm, that is between 510 and 580 fm, and the samples either were broken off successively younger stratigraphical units or, more probably, were detached blocks picked off the sea bed.

* The taxonomic position of the nannoplankton has not been established with certainty but they are usually classified as unicellular algae (Deflandre *in* Grassé 1952; Bramlette & Sullivan 1961).

(*d*) *Station* 15/8

Depth: 250 to 420 fm.
Position: latitude 48° 25′ N, longitude 10° 18′ W.
Samples: numbered SB 1008, 1012–16.
Date: 29 November 1958.

The specimens are richly fossiliferous and contain abundant Foraminifera, Polyzoa and calcareous nannoplankton, and also some echinoderm fragments. SB 1008, 1012, 1015 are white or yellowish detrital chalks with areas of greyish chalcedony and many silicified fossils. SB 1013, 1014, 1016 are soft yellowish detrital chalks with well-preserved but unsilicified fossils.

Table 1. Calcareous nannoplankton from Station 15/8

	1008[1]	1012[2]	1013[4]	1014	1015	1016
Coccolithus pelagicus (Wallich)	*c*	*r*	*a*	*a*	*c*	*c*
sp., 'SM'	*c*	*r*	*f*	*f*	*f*	*f*
Cyclococcolithus cf. *leptoporus* (Murray & Blackman)	*f*	*r*	*a*	*c*	*c*	*c*
Discolithus oamaruensis Deflandre	—	—	—	*r*	*r*	*r*
obliquipons Deflandre	—	—	*r*	—	—	—
sp.	—	*r*	—	—	—	—
Helicosphaera carteri (Wallich)	*r*	*r*	—	—	—	—
cf. *carteri*	—	—	*r*	—	*r*	*r*
[3]*Rhabdosphaera* sp.?	—	—	*c*	—	—	—
Tremalithus oamaruensis Deflandre	*f*	—	*f*	*f*	*f*	*f*
Zygrhablithus bijugatus Deflandre	—	—	*r*	—	—	—
Braarudosphaera bigelowi (Gran & Braarud)	*f*	*r*	*c*	*c*	*f*	*c*
Micrantholithus vesper Deflandre	*f*	—	*f*	*r*	*r*	*r*
Pemma papillatum Martini	*r*	—	—	*r*	—	—
Tetralithus aff. *obscurus* Deflandre	—	—	—	—	*r*	—
Discoaster tani Bramlette & Riedel	*r*	—	*c*	*c*	*c*	*c*
Isthmolithus recurvus Deflandre	*f*	—	*c*	*f*	*f*	*f*
Sphenolithus sp.	*f*	*r*	*f*	*r*	*r*	*r*

a, abundant; *c*, common; *f*, frequent; *r*, rare; *rr*, very rare. This notation will be used in tables 1 to 15.

[1] The prefix SB has been omitted from numbered specimens in tables 1 to 15.

[2] The age of the nannoplankton for 1012 is indeterminable.

[3] In 1013 there are fragments which resemble broken specimens of *Rhabdosphaera tenuis* Bramlette & Sullivan, but because no associated basal plates were recognized they are entered as *Rhabdosphaera* sp.?

[4] Omitted from the list is a nannofossil which was illustrated under the name 'unbestimmtes Skelettelement' (Martini 1958, pl. vi, fig. 31); this fossil is probably restricted to the uppermost Eocene.

The preservation of the nannoplankton varies from good to poor; some specimens show signs of solution and others, especially discoasters, a slight secondary growth of calcite. The assemblage listed in table 1 definitely indicates a correlation with the upper part of the Upper Eocene, particularly as developed in north-west Germany (Martini 1958, 1959).

About fifty species of Foraminifera are present in each of six samples, and the percentage of individuals of planktonic species is in the range 10 to 25 %. Table 2 illustrates the occurrence of planktonic species and of some benthonic ones believed to be significant for purposes of stratigraphical dating. The age-ranges of the planktonic species in the Eocene and Oligocene of Trinidad are included in table 2; *Globigerina* sp. 1 is similar to a species which is known in the Barton Beds of England and the Jackson Formation of the United States, both of Upper Eocene age. Table 2 suggests that the samples are all of about the same geological age, which is Upper Eocene.

Table 2. Foraminifera from Station 15/8

(i) Planktonic forms

							Trinidad				
							Eocene			Oligocene	
	1008	1012	1013	1014	1015	1016	Lower	Middle	Upper	Lower	Upper
Hantkenina cf. *alabamensis* Cushman	—	—	—	*rr*	—	—			—		
Pseudohastigerina micra (Cole)	*r*	—	*r*	*r*	—	*r*		—	—		
cf. *micra* (Cole)	—	—	—	—	*rr*	—					
Globigerina yeguaensis Weinzierl & Applin	*a*	*c*	*a*	*a*	*c*	*a*		—	—		
ampliapertura Bolli	*f*	*f*	*c*	*c*	*c*	*a*			—	—	
cf. *parva* Bolli	*c*	—	*c*	*a*	*f*	*c*		—	*G. parva*	—	
sp. 1	*f*	*r*	—	—	*r*	*rr*					
Globorotalia cocoaensis Cushman	*r*	—	*r*	*f*	—	*f*			—		

(ii) Benthonic forms

Some well-characterized benthonic species found also in the Upper Eocene, Marnes Bleues, Établissement des Bains, Biarritz (B.-Pyr.).

	1008	1012	1013	1014	1015	1016
Gyroidinella magna Le Calvez	*r*	—	*f*	—	—	*r*
Lingulina acutimargo (Halkyard)	—	*rr*	—	—	*rr*	—
Coleites arborescens (Halkyard)	—	—	—	—	*rr*	*rr*
Aragonia sp.	*f*	—	*r*	*r*	*r*	*c*

The nannoplankton and Foraminifera from the chalks of Station 15/8 therefore indicate a stratigraphical correlation within the Upper Eocene, probably restricted to the uppermost Upper Eocene.

(e) *Station* 17/1

Depth: 500 to 700 fm.
Position: latitude 47° 13½′ N, longitude 5° 45½′ W.
Samples: numbered SB 1033–38.
Date: 4 October 1961.

The nannofossils are poorly preserved and show slight to heavy growth of calcite. The assemblages indicate a range in age from Upper Oligocene to the lower part of the Middle Miocene, and there is presumptive evidence that they should be allocated to the Lower Miocene (table 3).

Table 3. Calcareous nannoplankton from Station 17/1

	1033	1034	1035	1036	1037	1038
Coccolithus pelagicus (Wallich)	*a*	*c*	*c*	*a*	*f*	*c*
sp. A	*c*	*f*	*c*	*c*	*f*	*f*
Cyclococcolithus leptoporus (Murray & Blackman)	—	*r*	—	—	—	—
Discolithus multiporus Kamptner	*r*	*r*	*r*	*r*	—	*f*
Helicosphaera carteri (Wallich)	*r*	*r*	—	*r*	*r*	*f*
Rhabdosphaera claviger Murray & Blackman	—	—	—	—	*r*[1]	*r*[1]
hirsuta Deflandre	—	—	—	—	*r*	—
Scyphosphaera sp.	*r*	—	—	*r*	—	*r*
Braarudosphaera bigelowi (Gran & Braarud)	*r*	*r*	—	*r*	*r*	*f*
Discoaster cf. *variabilis* Martini & Bramlette	—	—	—	—	*r*	*r*
sp. D	*r*	*r*	*f*	*r*	*r*	*f*
Sphenolithus heteromorphus Deflandre	—	*r*	—	—	—	*r*
sp.	*r*	—	*f*	*f*	*r*	*f*
Lithostromation perdurum Deflandre	—	—	—	—	—	*r*

[1] Rare specimens of *Rhabdosphaera claviger*, a widespread form in Recent deep-sea sediments, probably occur as a contamination from infilled animal burrows.

Table 4. Planktonic Foraminifera from Station 17/1

	1033	1034	1035	1036	1037	1038
Globigerina ciperoensis Bolli	*a*	*f*	*c*	*c*	—	*a*
praebulloides Blow	*c*	*a*	*a*	*a*	*c*	*c*
Globigerinita naparimaensis Bronnimann	*f*	*f*	*f*	*rr*	—	—
Globoquadrina altispira (Cushman & Jarvis)	*r*	*f*	*r*	*r*	—	*a*
dehiscens (Chapman, Parr & Collins)	—	*rr*	—	—	—	—
Globigerinoides cf. *bisphericus* Todd	—	—	—	—	—	*rr*
ruber (d'Orbigny)	*r*	*r*	*r*	*f*	—	*a*
trilobus (Reuss)	*f*	*c*	*f*	*f*	—	*a*
Globorotalia cf. *archeomenardii* Bolli	*f*	*f*	*f*	*f*	—	*f*
mayeri (Cushman & Ellisor)	*c*	*c*	*f*	*c*	—	*f*

The soft chalky limestones contain abundant organic debris. Foraminifera are common and about 50% are planktonic forms, except in 1037 where planktonics are rare. Sample 1034 includes a few larger benthonic foraminifers, which appear to belong to a species of *Nephrolepidina*; there is also one specimen each of *Globotruncana* cf. *arca* Cushman and

Racemiguembelina fructicosa (Egger) which are derived from the Maestrichtian. The planktonic specimens indicate a Lower Miocene, Lower Aquitanian age (table 4).

(*f*) *Station* 19/6

Depth: 670 to 720 fm.
Position: latitude 47° 48′ N, longitude 8° 09½′ W.
Samples: numbered SB 1010, 1011, 1017, 1018.
Date: 17 May 1958.

The preservation of the nannoplankton is not good, especially the discoasters, because of secondary growth of calcite. Samples 1010, 1011, 1018 are similar and are placed better in the lower part of the Middle Miocene than in the Lower Miocene, but because of the poor preservation of all discoasters a more precise age is difficult to determine. In 1017, the rare specimens of *Coccolithus solitus*, *C.* sp. cf. 'SM' (see p. 281), *Micrantholithus* cf. *fornicatus*, *Discoaster barbadiensis* and *D.* aff. *tani* could be attributed to reworked material derived from the Eocene. The assemblages are given in table 5.

Table 5. Calcareous nannoplankton from Station 19/6

	1010	1011	1017	1018
Calcidiscus cf. *medusoides* Kamptner	*r*	*r*	—	*r*
Coccolithus pelagicus (Wallich)	*a*	*a*	*a*	*a*
solitus Bramlette & Sullivan	—	—	*r*	—
sp. A	*c*	*a*	—	*a*
sp., cf. 'SM'	—	—	*r*	—
Cyclococcolithus cf. *leptoporus* (Murray & Blackman)	*r*	—	—	—
sp. A	*f*	*c*	—	*f*
Discolithus multiporus Kamptner	*f*	*f*	*r*	*f*
Helicosphaera carteri (Wallich)	*c*	*c*	*f*	*c*
Rhabdosphaera stylifer Lohmann	—	*r*	—	*r*
Scyphosphaera apsteini Lohmann	*f*	*r*	—	*r*
Braarudosphaera bigelowi (Gran & Braarud)	—	—	*f*	*r*
Micrantholithus cf. *fornicatus* Martini	—	—	*r*	—
Discoaster barbadiensis Tan Sin Hok	—	—	*r*	—
aff. *tani* Bramlette & Riedel	—	—	*r*	—
cf. *variabilis* Martini & Bramlette	—	—	*r*	—
sp. B	*c*	*c*	—	*c*
sp. D	*f*	*f*	—	*f*
sp.	—	—	*c*	—
Thoracosphaera sp.	—	—	*r*	*r*
Sphenolithus sp.	*f*	*c*	*f*	*c*

The soft, white, pure chalks contain between 5 and 20% of bulk of fossils, and the remainder constitutes the matrix. Among the Foraminifera 90 to 95% are planktonic. The assemblage listed in table 6 is believed to be not earlier than Miocene in age; it contains frequent *Globigerinoides bisphericus*, which is stated to be confined to the Upper Aquitanian, and also the Middle Miocene *Sphaeroidinella rutschi*; *Globorotalia* cf. *archeomenardii* may indicate Aquitanian or Burdigalian. Table 7 gives the time-ranges, so far as they have been ascertained, of various foraminiferal species recorded from Miocene deposits. The foraminiferal evidence is conflicting but is suggestive of a tentative correlation with the Lower Miocene.

The nannofossils and foraminifers from 16/9 thus point to a Lower to Middle Miocene age for the chalky rocks dredged at this station.

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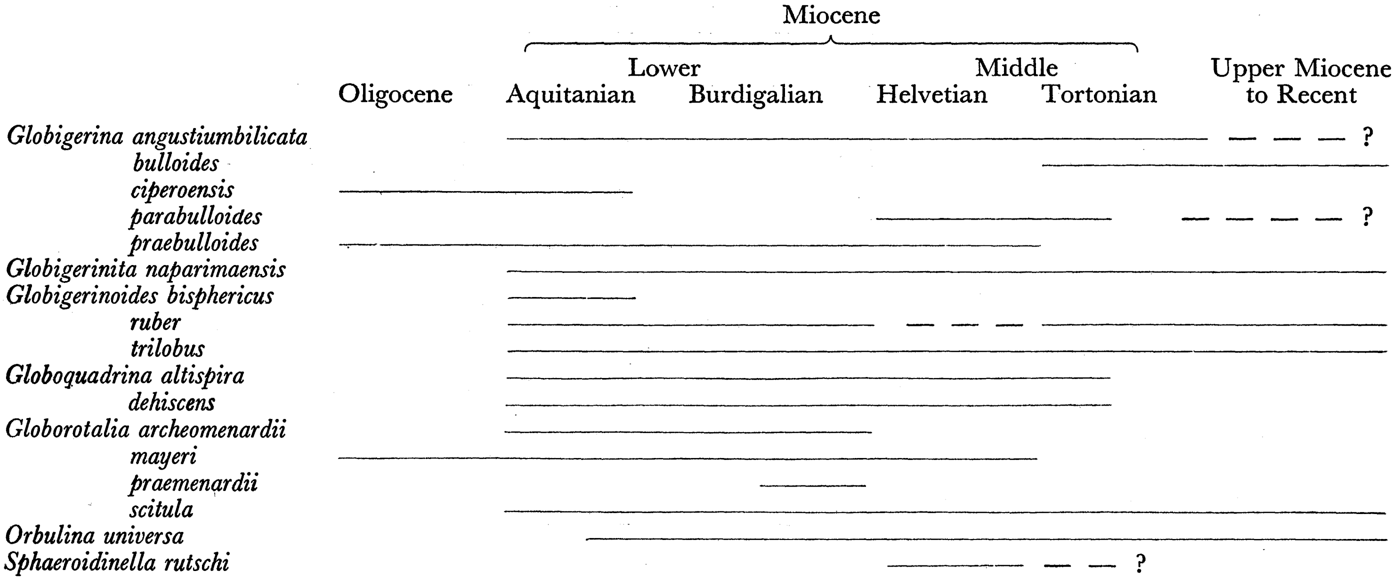
TABLE 6. PLANKTONIC FORAMINIFERA FROM STATION 19/6

	1010	1011	1017	1018
Globigerina angustiumbilicata (Bolli)	*f*	*f*	*c*	*c*
parabulloides Blow	—	*rr*	—	—
praebulloides Blow	*c*	*c*	*c*	*c*
Globigerinita naparimaensis Bronnimann	*a*	*a*	*r*	*c*
Globigerinoides bisphericus Todd	*f*	*f*	*f*	*rr*
ruber (d'Orbigny)	—	*rr*	*r*	—
trilobus (Reuss)	*a*	*c*	*a*	*f*
Globoquadrina altispira (Cushman & Jarvis)	—	*c*	*c*	*c*
cf. *altispair*	*c*	—	—	—
dehiscens (Chapman, Parr & Collins)	*f*	*f*	*c*	*f*
Globorotalia cf. *archeomenardii* Bolli	*f*	*r*	*f*	*rr*
mayeri (Cushman & Ellisor)	*f*	*r*	*a*	*f*
Sphaeroidinella rutschi (Cushman & Renz)	*c*	*f*	—	*f*

TABLE 7. OBSERVED RANGES OF SOME NEOGENE PLANKTONIC FORAMINIFERA



Tabulation founded mainly on Blow (1959), Bolli (1957), Cita & Silva (1960).

(*g*) *Station* 15/1

Depth: 580 to 680 fm.
Position: latitude 48° 27′ N, longitude 10° 07′ W.
Samples: SB 1005–7, 1019–25.
Date: 28 November 1958.

The preservation of the nannoplankton is again not good, because most of the specimens show secondary growth of calcite, especially the discoasters. The stratigraphical range of the assemblages (table 8) is from the upper part of the Middle Miocene to the Upper Miocene.

Like the rocks from Station 19/6 these are pure chalks but with a slightly lower content at 80 to 90% of planktonic Foraminifera (table 9). The abundance of *Globigerina parabulloides* and the absence of typical *G. bulloides* places the fauna in the Middle Miocene, which is confirmed by the occurrence of *Sphaeroidinella rutschi* and *Orbulina universa*, although *Globorotalia praemenardii* suggests an earlier age (table 7).

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The fossil evidence accords with a Middle Miocene (also possibly Upper Miocene) age and the samples from Station 15/1 are the youngest obtained by Dr Southward from the continental slope.

TABLE 8. CALCAREOUS NANNOPLANKTON FROM STATION 15/1

	1005	1006	1007	1019	1020	1021	1022	1023	1024	1025
Calcidiscus medusoides Kamptner	*f*	*f*	*f*	*f*	*f*	*f*	*f*	*f*	*f*	*f*
Coccolithus pelagicus (Wallich)	*c*	*c*	*c*	*c*	*c*	*a*	*c*	*a*	*c*	*c*
sp. A	*a*	*a*	*a*	*c*	*c*	*a*	*c*	*c*	*c*	*c*
Cyclococcolithus leptoporus (Murray & Blackman)	—	—	*r*	—	*r*	—	—	—	—	—
Discolithus multiporus Kamptner	*r*	*f*	*r*	*r*	*f*	*r*	*f*	*r*	*f*	*r*
Helicosphaera carteri (Wallich)	*f*	*c*	*c*	*f*	*c*	*f*	*c*	*f*	*f*	*c*
Rhabdosphaera hirsuta Deflandre	*f*	*f*	*f*	*f*	*c*	*f*	*r*	*f*	*f*	*f*
Scyphosphaera amphora Deflandre	*r*	—	*r*	*r*	—	—	*r*	—	—	—
campanula Deflandre	—	*r*	*r*	*r*	*f*	*r*	—	*r*	*r*	*r*
aff. *halldali* Deflandre	—	—	—	—	—	*r*	—	—	—	—
Discoaster brouweri Tan Sin Hok	—	—	—	—	*r*	—	—	—	—	*r*
aff. *challengeri* Bramlette & Riedel	—	—	—	—	—	—	*r*	—	—	—
variabilis Martini & Bramlette	—	—	—	*r*	*f*	—	*r*	—	*r*	*f*
sp. B	*f*	*f*	*f*	*f*	*f*	*r*	*f*	*f*	*f*	*f*
Thoracosphaera sp.	—	—	—	—	*r*	—	—	—	—	—
Sphenolithus sp.	*a*	*f*	*c*	*c*	*a*	*f*	*f*	*c*	*c*	*c*
Lithostromation perdurum Deflandre	—	*r*	—	—	*f*	*f*	—	*r*	*r*	*r*

TABLE 9. PLANKTONIC FORAMINIFERA FROM STATION 15/1

	1005[1]	1006[1]	1007[1]	1019	1020	1021	1022	1023	1024	1025
Globigerina angustiumbilicata (Bolli)	—	*r*	*f*	—	*c*	*r*	*r*	*r*	*c*	*c*
parabulloides Blow	*a*	*r*	*r*	*r*	*f*	—	*r*	*f*	*f*	*f*
praebulloides Blow	*a*	*a*	*c*	*c*	*c*	*f*	*a*	*a*	*c*	*a*
Globigerinita naparimaensis Bronnimann	*c*	*c*	*f*	*c*	*c*	*f*	*c*	*c*	*f*	*c*
Globigerinoides trilobus (Reuss)	*f*	*f*	*f*	*f*	*f*	*a*	*a*	*f*	*r*	*a*
Globoquadrina altispira (Cushman & Jarvis)	—	—	—	—	—	*c*	—	—	—	*c*
cf. *altispira*	*f*	*c*	*c*	*c*	*c*	—	*f*	*c*	*c*	—
dehiscens (Chapman, Parr & Collins)	*c*	*c*	*c*	*c*	*f*	*c*	*f*	*f*	*f*	*f*
Globorotalia mayeri Cushman & Ellisor	*c*	*f*	*c*	*f*	*f*	*a*	*f*	*c*	*c*	*c*
praemenardii Cushman & Stainforth	*c*	*c*	*a*	*c*	*a*	*a*	*r*	*f*	*c*	*c*
cf. *scitula* (Brady)	*r*	—	*r*	—	—	*r*	*r*	—	—	—
Orbulina universa d'Orbigny	*f*	*r*	*f*	*r*	*c*	*c*	*f*	*r*	*f*	*c*
Sphaeroidinella rutschi Cushman & Renz	—	*f*	*r*	*r*	—	—	—	*r*	—	—

[1] The list given for these three samples is different from the provisional assemblages published in Whittard (1962, p. 401). This is due in part (i) to changes of nomenclature, as *G. sacculifera* is a junior synonym of *G. trilobus*; (ii) to misidentification, *G. eggeri* is now recorded as *G. mayeri*, *G. hirsuta* as *G. praemenardii*, and *G. conglobata* as *G. dehiscens*; (iii) to contamination, because *G. ruber* and *G. truncatulinoides* have been found in Recent sands recovered from crevices in SB 1031.

(*h*) *Station* 15/12

Depth: 510 to 580 fm.

Position: approximately latitude 48° 38′ N, longitude 9° 50′ W.

Samples: numbered SB 1001–2, 1026–32.

Date: 30 November 1958.

Apparently, three distinct geological horizons are suggested by the microfossils, viz. (i), Middle Eocene—lower Upper Eocene, (ii), upper Upper Eocene and (iii), Lower Miocene.

(i) *Middle Eocene—lower Upper Eocene* (1001, 1026, 1029). Samples 1001 and 1026 are soft pale-buff greensands (figures 2, 3) lying within the lithological group of detrital chalk. They are rich in Foraminifera, which are infilled with calcite and poorly preserved, and about 25 % are planktonic forms. The faunas listed in table 10 are closely similar, clearly of Eocene age and probably appertain to the Middle Eocene. 1029 is a hard detrital chalk which provided no Foraminifera.

The preservation of the nannoplankton is generally good in 1001 and 1026, but sometimes discoasters and *Braarudosphaera bigelowi* show slight to heavy secondary growth of calcite. The two assemblages listed in table 11 exhibit much more definite differences than do the Foraminifera; 1026 is to be attributed to the Middle Eocene (unteres Ober-Eozän of

Table 10. Planktonic Foraminifera from two samples from Station 15/12

	1001	1026	Eocene of Trinidad: Lower	Middle	Upper
Pseudohastigerina micra (Cole)	*c*	*c*		——	——
Globigerina cf. *yeguaensis* (Weinzierl & Applin)	*f*	*f*		——	——
cf. *soldadoensis* Bronnimann	*f*	*f*	——		
cf. *turgida* Finlay	*c*	*f*	——		
Globorotalia cf. *spinuloinflata* (Bandy)	*f*	*f*		——	
sp.	—	*r*			

The identifications of the species of *Globigerina* and *Globorotalia* are not definite, but the stratigraphical ranges are given for the actual species.

north-west Germany (Martini 1959, p. 138) and the Lutétien Supérieur of south-west France), and 1001 to the lower part of the Upper Eocene (mittleres Ober-Eozän of north-west Germany and Bartonien of south-west France). In 1029 the nannoplankton shows heavy secondary growth of calcite and the chalky sample probably originated from the Middle Eocene or lower part of Upper Eocene because of the presence of *Discoaster barbadiensis* and *Coccolithus solitus*.

(ii) *Upper Upper Eocene* (1002, 1027, 1031). Hard, white or pale-buff, detrital chalks with echinoderm remains. The Foraminifera are benthonic, ill preserved, and no serious attempt was made to name them. Several species are the same as those observed in the group of samples 1008, 1010–18, from Stations 15/8 and 19/6, and may therefore point to an Upper Eocene age.

The nannoplankton is generally poorly preserved. Table 12 leaves no alternative but to correlate with the upper Upper Eocene particularly of north-west Germany.

(iii) *Lower Miocene* (1028, 1030, 1032). The preservation of the nannoplankton is poor and the assemblages listed in table 13 are not particularly distinctive stratigraphically. Nothing more precise than possibly Upper Oligocene—Lower Miocene for 1028, possibly Miocene for 1030, and younger than Lower Oligocene for 1032 is permissible.

The proportion of planktonic to total Foraminifera is high at about 80 %. The absence of *Globorotalia praemenardii*, *Sphaeroidinella rutschi*, and the extreme rarity in one sample only of *Globoquadrina dehiscens*, coupled with the frequency of *Globigerinoides ruber* (table 14), which

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according to Bolli (1957) occurs in the lower part of the Miocene of Trinidad and then disappears only to reappear in the highest Miocene, assigns the rocks to the Aquitanian, and they are slightly older therefore than the assemblages recorded from Station 19/6.

TABLE 11. CALCAREOUS NANNOPLANKTON FROM THREE SAMPLES FROM STATION 15/12

	1001	1026[1]	1029
Coccolithus grandis Bramlette & Riedel	—	*f*	—
pelagicus (Wallich)	*c*	*c*	*f*
solitus Bramlette & Sullivan	*f*	—	*r*
sp., cf. 'SM'	—	*r*	*r*
Cyclococcolithus cf. *leptoporus* (Murray & Blackman)	*c*	*f*	*f*
Rhabdosphaera tenuis Bramlette & Sullivan	—	*r*	—
Zygolithus dubius Deflandre	*r*	*r*	—
Zygrhablithus bijugatus Deflandre	—	*r*	—
Braarudosphaera bigelowi (Gran & Braarud)	*f*	*c*	*f*
Micrantholithus vesper Deflandre	*r*	—	—
Discoaster barbadiensis Tan Sin Hok	*f*	*c*	*r*
aff. *crassus* Martini	*r*	—	—
cf. *distinctus* Martini	—	*f*	—
kuepperi Stradner	—	*r*	—
lodoensis Bramlette & Riedel	—	*r*	—
saipanensis Bramlette & Riedel	—	*r*	—
sublodoensis Bramlette & Sullivan	*r*	—	—
tribrachiatus Bramlette & Riedel	—	*r*	—
sp.	*f*	—	—
Nannotetraster aff. *mexicanus* (Stradner)	—	*r*	—
swasticoides (Martini)	—	*r*	—

[1] Rare specimens of *Discoaster tribrachiatus* and a single *Zygolithus protenus* could be assigned to reworked material from the Lower Eocene.

TABLE 12. CALCAREOUS NANNOPLANKTON FROM THREE SAMPLES FROM STATION 15/12

	1002	1027	1031[1]
Coccolithus pelagicus (Wallich)	*c*	*c*	*f*
sp. 'SM'	—	*r*	*r*
Cyclococcolithus cf. *leptoporus* (Murray & Blackman)	*f*	*c*	*f*
Tremalithus oamaruensis Deflandre	*f*	*f*	*f*
Braarudosphaera bigelowi (Gran & Braarud)	*r*	*r*	*r*
Micrantholithus vesper Deflandre	*r*	—	—
Discoaster aff. *tani* Bramlette & Riedel	—	*f*	—
sp.	*r*	—	—
Isthmolithus recurvus Deflandre	*r*	*r*	*r*
Sphenolithus sp.	—	*f*	—

[1] A single specimen of *Archangelskiella* sp., omitted from the list, is a form which commonly occurs in the Maestrichtian and probably represents reworked material from the Upper Cretaceous.

TABLE 13. CALCAREOUS NANNOPLANKTON FROM THREE ADDITIONAL SAMPLES FROM STATION 15/12

	1028	1030	1032
Coccolithus pelagicus (Wallich)	*c*	*c*	*c*
sp. A	*c*	—	—
Discolithus multiporus Kamptner	*r*	—	—
cf. *multiporus*	—	*r*	—
Helicosphaera carteri (Wallich)	*f*	—	—
Braarudosphaera bigelowi (Gran & Braarud)	*r*	—	*r*
Discoaster sp. D	*f*	—	—
sp.	—	*r*	*r*
Sphenolithus sp.	*r*	*r*	*r*

Table 14. Planktonic Foraminifera from three additional samples from Station 15/12

	1028	1030	1032
Globigerina cf. *angustiumbilicata* (Bolli)	—	*c*	—
cf. *ciperoensis* Bolli	*c*	—	—
praebulloides Blow	*c*	*f*	*f*
Globigerinita naparimaensis Bronnimann	*c*	*c*	*f*
Globigerinoides trilobus (Reuss)	*a*	*a*	*c*
ruber (d'Orbigny)	*f*	*f*	*f*
Globoquadrina altispira (Cushman & Jarvis)	*a*	*a*	*f*
cf. *dehiscens* (Chapman, Parr & Collins)	—	*rr*	—
Globorotalia mayeri (Cushman & Ellisor)	*c*	*c*	*c*
cf. *archeomenardii* Bolli	*r*	*r*	—

(*i*) *Remarks on the nannoplankton and some undescribed species*

Though most of the Eocene samples could be identified without difficulties, the Miocene samples caused some problems. This can be attributed, first, to the lack of well-preserved guide-fossils, especially discoasters, because of solution or secondary growth of calcite and, secondly, to the lack of described nannoplankton from the younger Tertiary. Some of the more important nannoplankton with well-known stratigraphical ranges could not be identified with certainly but, nevertheless, two main groups within the Miocene samples were distinguished. First, a group of seven samples (table 5 and 1034, 1037–8, table 3) which are placed in the Lower Miocene to lower part of the Middle Miocene and, secondly, a group of ten samples (table 8) placed in the upper part of the Middle Miocene to Upper Miocene. Comparison with the Mohole material and samples from well-known Mediterranean and central-American Miocene localities indicates that some nondescript forms and even calcified discoasters can give evidence as to the stratigraphical position.

Coccolithus sp. 'SM'

A large oval coccolith composed of two moderately curved plates, of which the lower one is slightly smaller, and a short connecting tube. The central opening is relatively large. In polarized light this species shows four distinctive dark bars on the plate, and the central opening looks more rectangular than oval. Length, 13·5 to 21·0μ; width, 10·5 to 19·0μ.

Distribution: common in the Upper Eocene of many regions, for example, north-west Germany (oberes Ober-Eozän), Denmark (Sövind marl), Mississippi (Yazoo clay).

This new species will be described elsewhere; the letters 'SM' indicate the Sövind marl as *stratum typicum*.

Coccolithus sp. A

A small oval coccolith composed of two plates and a short connecting tube. The central opening is smaller at the bottom than at the top of the tube. In polarized light this species shows a swastika-like cross in the centre, the crooked ends of which pass over into dark bars at the outer rim. Length, 6 to 9μ.

Distribution: common in the Oligocene and Miocene of many regions. The upper limit seems to be within the uppermost Miocene.

Cyclococcolithus sp. A

A nondescript circular coccolith composed of two plates which are connected by a short tube. The plates show delicate striae. The central opening is smaller at the bottom than at the top of the tube. In polarized light the central part shows a swastika-like cross which becomes enlarged to form dark bars at the crooked ends. Diameter, 6 to 10μ.

Distribution: common in the Lower and Middle Miocene of many regions. The upper limit seems to be at the top of the lower part of the Middle Miocene (comparable with the Helvetian).

Sphenolithus sp.

A nannofossil composed of small calcite elements. One side looks like a concave basal plate. Only easily identified by means of polarized light when the fossil shows a distinctive structure of four units. The specimens found in the Miocene samples are identical with the specimen figured in Martini & Bramlette (1963, pl. i, figs. 6–7). Perhaps they are closely related to *Sphenolithus abies* Deflandre. Diameter, 2 to 5μ.

Distribution: common in the Miocene of many regions. The upper limit seems to be at the top of the Miocene. No specimens have been found in Pliocene materials.

Discoaster sp. B and *Discoaster* sp. D

The discoasters from the Miocene show in most cases moderate to heavy secondary growth of calcite, and therefore it is impossible to allocate names to such specimens. Nevertheless, two main groups can be distinguished; discoasters (i), with enlarged ends to the rays and (ii), with rays of nearly equal width. These two groups, though they are heavily calcified, resemble the two main groups of well-preserved discoasters from the Oligocene, Miocene and Pliocene. One group includes such species as *Discoaster deflandrei* Bramlette & Riedel, with a flat centre and enlarged ends to the rays, which occurs throughout the Oligocene up to the Lower Miocene. The other includes such species as *Discoaster challengeri* Bramlette & Riedel or, as an extreme, *D. brouweri* Tan Sin Hok with small and long rays, common in the Miocene and Pliocene. Calcified discoasters which are similar to the first group are listed as *Discoaster* sp. D (pointing to *deflandrei*), and those similar to the second group are recorded as *Discoaster* sp. B (pointing to *brouweri*).

(*j*) *Notes on the Foraminifera*

All the samples of chalky rock were deposited in clear water in the open sea. In marine beds ranging in age from Middle Eocene to Upper Miocene large Foraminifera such as *Nummulites*, *Discocyclina* and *Miogypsina* might be expected but, with the exception of a few small orbitoids in 1034, none was discovered. For this and other reasons probably none of the chalks was laid down in shallow water.

Chalks from Stations 15/1 and 19/6 contain unusually high proportions of planktonic forms. Similar proportions are known from the white marls of the Langhian of Italy, the Miocene of Cyprus and the modern *Globigerina* ooze, but in Tertiary rocks of western Europe generally such high proportions are exceptional. Samples from Stations 15/8 and 15/12 (numbers 1028, 1030, 1032) also have many planktonics seldom matched in European Tertiary beds such as in the middle London Clay, the Marnes Bleues of Biarritz, and some Tethyan Miocene and Pliocene blue clays usually regarded as of relatively deep-water origin. On the other hand, high concentrations of planktonics have occasionally been found in Recent sediments from shallow seas facing deep water where, however, the content of clastic material is much higher.

4. The stratigraphy of part of the upper reaches of the continental slope

Previous records of chalky, or other, material of Tertiary age from the south Celtic Sea are scanty. Wiseman & Ovey (1950, p. 42) stated that 'the Eocene planktonic genus *Hantkenina* has been identified...from the continental slope west of Finistère (unfortunately the exact locality cannot be traced but it approximates to $47\frac{1}{2}°$ N, $08\frac{3}{4}°$ W) at a depth of 2743 m (1500 fm) in a sample of anchor-mud collected by H.M.T.S. *Monarch*...Upper Cretaceous foraminifera are also found in the same sample including ?*Reussella* [*Bulimina*] *limbata* (White)..., *Stensiöina pommerana* Brotzen (Maestrichtian) and *Pseudotextularia fruticosa* (Egger) (Senonian)'. The sample of mud was undoubtedly contaminated with microfossils reworked from Cretaceous and possibly Eocene deposits. Bourcart & Marie (1951) referred to samples, obtained by the cable-ship *Alsace*, which they correlated with the Oligocene on the evidence of such foraminifers as *Globigerina mexicana* Cushman, *Angulogerina angulosa* Williams, *Cassidulina globosa* Hantken, *Nonion umbilicatulum* Montagu and *N. hantkeni* Cushman. Day (1959) recorded at 47° 31′ N, 6° 58′ W, from a depth of 280 fm, 'clean, white, hard, chalk-fragments and chalky sand' which he identified as possibly Cretaceous or Tertiary in age. In none of the three cases cited above is the palaeontological evidence unequivocal. Chalky material, one piece of which was Upper Cretaceous in age because it contained *Exogyra*, and some flints were described by Peach (1912) as part of a dredged collection from 50° 22′ N, 11° 44′ W. Some of these chalks, obtained from a depth of 981 fm, might have been Tertiary in age but they could only have been distinguished on their Foraminifera and nannoplankton which remained unidentified.*

The thirty-five samples we have examined from the continental slope can be grouped into five moderately well-defined stratigraphical divisions on the evidence of the microfossils. The horizons are: (i) Middle Eocene to lower Upper Eocene, (ii) upper Upper Eocene, (iii) Lower Miocene (Aquitanian and Burdigalian), (iv) Middle Miocene (Helvetian) and (v) possibly Upper Miocene.

Allowance was made for the angle of the cable which hauled the dredge, yet there is a lack of agreement between the depths read on the echo-sounders and the depths on bathymetric charts (Hill 1956; Day 1959) when the positions are plotted according to Decca navigation. The fixes on the bathymetric charts fall in deeper or shallower water than was registered by the echo-sounders, and there is no recognizable pattern of disagreement. The discordance in readings can possibly be attributed to lack of precision in the MS 26E echo-sounder working over the irregular topography of the steep continental slope, but although they were not corrected for temperature the depths should be reasonably accurate; more probably it is due to the inaccuracy in Decca navigation west of 7° W, and the longitude and latitude positions in that part of the south Celtic Sea where the dredges operated are only approximations because of the acute intersections of the lattice lines. No useful purpose is therefore served by superimposing the plotted positions of the several stations over the bathymetric chart, nor by drawing profiles of the continental slope from this chart in order to compare the geological section for each location. Alongside the stations marked on figure 1 is added the geological age of the rocks determined at each, and thus direct

* Mr M. Black (1962) has recently described the new species *Coccolithus sarsiae* and *C. celticus* from chalks dredged from a depth of 450 fm from another locality on the continental slope situated between 47° 36′ N and 47° 37′ N, and 7° 26′ W and 7° 27′ W; a late Tertiary age was deduced.

comparison can be made with the outcrops which are shown on the provisional geological map of the continental shelf.

Station 15/1 lies to the north-east of 15/8 at about 9 miles distace; the presence of Palaeogene beds of the upper part of the Upper Eocene farther from the shelf-break* and recovered from the topographically shallower depth of 250 to 420 fm (15/8) appears to be anachronistic when compared with the Middle Miocene found at the greater depth of 580 to 680 fm (15/1) and nearer to the shelf-break. The samples from each station are consistent in their geological characters and indicate they were taken *in situ*; there is no evidence that the dredge picked up loose pieces of chalky material which were far travelled. This stratigraphical anomaly in terms of topographical position implies that relative to 15/8 the strata at 15/1 have been lowered by a few hundred fathoms; faulting, between extreme positions approximately at right angles to the continental slope and approximately parallel with it, is one reasonable explanation; folding is an alternative but is less probable. On the other hand, 15/8 may have been *in situ* and material at 15/1 moved down slope through superficial instability of the sea bed; this is an unlikely explanation because the samples from 15/1 show no admixture, and being all of the same kind there are strong presumptive reasons that only chalks from the same outcrop were dredged.

Station 15/12, about 23 miles north-east of 15/8, produced rocks ranging in age from Middle Eocene to Lower Miocene, all collected from a topographical interval of only 70 fm on the slope. The meagre data that exists elsewhere suggests the total thickness of the Tertiary chalks is to be measured in many hundreds of feet, but at 15/12 a wide stratigraphical range has been identified over a maximum thickness of not more than 400 ft. Either the succession is greatly condensed or rocks from several stratigraphical horizons have been transported down the slope to their present position to produce the mixed sample. In this probable event, the most important information is therefore the presence of the oldest recognizable horizon, because these beds will generally occupy the deepest topographical place and will not have travelled up slope. The oldest beds are Middle Eocene—lower Upper Eocene in age and a reasonable assumption is that somewhere between a depth of 510 to 580 fm these beds are *in situ*. The admixture of chalks of several ages could also be attributed to complex faulting, bringing all types into juxtaposition within the range of depth indicated, but such an explanation does not alter the assumption that Eocene rocks are probably in place. If this interpretation is viable then Eocene rocks of approximately comparable ages occur at 15/8 and 15/12, but again there is an apparent incompatibility between their geological age and topographical level; furthermore, in line between these stations are the supposedly downfaulted Miocene deposits of 15/1.

Station 19/6, about 90 miles east-south-east of the three locations already mentioned, provided a stratigraphically pure sample of Lower to Middle Miocene age, but it was recovered from the deepest part of the slope of all samples, that is, between 670 and 720 fm. This, with the exception of Station 15/1, is the youngest deposit so far recorded from the slope. Again the anomaly between the depth of the sea bed and the stratigraphical age exists here as in most other samples.

* Name defined by Heezen *et al.* (1959, pp. 18, 51) for the abrupt transition from the continental shelf to the continental slope, and 'may locally be a Pliocene or Miocene structural bench, but elsewhere late Pleistocene or Recent'.

Station 17/1 lies about 105 miles east-south-east of 19/6 and yielded Lower Miocene (Lower Aquitanian) chalks slightly older than those taken from 19/6 and from the mixed haul from 15/12.

Of the three examples referred to on figure 1 as *Alsace* (Bourcart & Marie 1951), *Monarch* (Wiseman & Ovey 1950) and *Sa* 2 (Day 1959) only the palaeontological information from *Alsace* can be utilized and even this is doubtful because it is impossible to state if the sample was obtained from in place or was derived. At about 1400 fm a grapnel collected a small piece, 25 cm by 10 cm, of greyish-blue silicified chalk which yielded silicified and pyritized Foraminifera similar to those present in the Oligocene. There is reasonable certainty that the small piece of rock represents a series of beds which appear in, and help to form, the continental slope, and being of Oligocene age it establishes the occurrence of these rocks.

The concept that the continental slope of the south Celtic Sea has been, and is, a dumping ground for considerable thicknesses of unconsolidated sedimentary material is no longer acceptable. The continental shelf hereabouts is unusual, because, generally considered, there is much less sedimentary deposition than might reasonably be anticipated; it is for this reason that the region lends itself particularly well to a geological survey of the underlying hard rocks by means of the free fall corer. Our experience has been that, apart from a few large areas lying to the south-west of Wolf Rock, south-east of The Lizard and north-west of Ushant (figure 1), the sedimentation of sand and/or gravel is commonly only from a few inches to about 30 in. thick. Underwater photography on the shelf hardly ever provides a clear picture and, evidently, there is much sediment in suspension near the sea bed—it is in the zone of flotation. But such a zone apparently is not confined only to the lower depths of water, because the ebb and flood of the complex system of tides, the ever-changing currents and the relatively shallow water combine to move the sediment to and fro particularly in the Channel; much of it is moved in suspension. The water turbulence allows no time and little opportunity for deposition on the sea bed, which is here unique inasmuch as it generally can be described as a nearly plane surface tilted westwards on a slope which falls 84 fm in 420 miles, or 1 in 4400, and transversely is an exceedingly shallow concavity; within this there is the narrow channel of Hurd Deep and an unrecorded pit to the south-west, and sharp peaks of igneous rocks which are mainly distributed towards the periphery. Nevertheless, the loose sedimentary cover deepens towards the edge of the continental shelf where sand-waves up to 40 ft. high with wave crests as much as 2800 ft. apart, have been detected with oblique asdic (Cartwright & Stride 1958).

The slope is cut into by many valleys of complex pattern (Hill 1956; Day 1959). Dark-blue clays overlain by brown silty clays are known to form a veneer at least on the upper part of the slope and in some of the canyon-like valleys which fret the slope (Whittard 1962, p. 402). Apart from these clays and glacially derived material, other unconsolidated and uncompacted sediments are the grey and brown, foraminiferal muds and oozes, and fine-grained sands which Day (1959) recorded, but these are not known to attain any thickness much greater than several feet.

The recent discovery of stratified rocks at several localities distributed along the slope over a minimum distance of 200 miles is a definite indication that the valleys were excavated from rock cropping out on the slope. Additional data is now available from Dr J. B. Hersey (personal communication) who has obtained thumper records which show a series of terraces or benches in the sea bed extending down to at least a depth of 270 fm, and these correspond with strata of exceedingly low axial dip intersecting the more steeply inclined slope. Similar relationships between stratigraphy and topography have been described from near Cape Hatteras, Virginia (Heezen, Tharp & Ewing 1959, p. 46), where 'resistant formations form prominent structural benches' on the continental slope. Here, in two land-based boreholes a succession from Recent deposits through the Tertiary, underlain by the Upper Cretaceous and finally the Lower Cretaceous, was founded upon a crystalline basement; on the slope itself Tertiary and Upper Cretaceous elements reaching down to a depth of about 1500 fm were identified as benches by projecting the O.D. levels out to sea, the assumption being made that there was no change in inclination of the several divisions over a distance of about 40 nautical miles. Accepting this assumption, similar breaks in the topography were recognized in profiles of the slope along its length towards Cape May over a distance of 30 nautical miles. The model that Heezen and his co-authors have built of this part of the eastern American continental slope does not correspond with that which is emerging from the western European slope, where already the disagreement between topography and the level of stratigraphical horizons at comparable stations is known to be sufficiently pronounced to require some structural control, such as folding, faulting or unconformity.

5. Stratigraphical comparison with the continental shelf

The 'scarp facies' of the samples retrieved from solid rock *in situ* on the continental slope comprises mainly pure and detrital chalks, sometimes glauconitic, rich in planktonic foraminifers and nannofossils but without macrofossils; it is in marked contrast with the 'shelf facies' which exhibits a wide variety of shallow water sediments ranging from organic limestones to coarse sandstones, sometimes charged with molluscs and predominantly benthonic foraminifers. Some major stratigraphical divisions are known from the slope that have not been recognized on the shelf, and even where rocks deposited during about the same geological time-span have been correlated they are essentially dissimilar in their lithology and palaeontology.

(k) *Eocene*

No chalks have been described from the shelf nor from the mainland of Britain or France. Milioline limestones of Lutetian age, in many ways comparable with deposits in the Paris Basin and the Cotentin Peninsula, have been cored or dredged in innumerable places in the English Channel (Dangeard 1928; King 1954; Curry 1960; Boillot & Le Calvez 1961). The most south-westerly occurrence we have found is at 49° 10′ N, 6° 10′ W, some 150 miles east-north-east of station 15/12 where Middle Eocene of the scarp facies has been located.* Glauconitic Tertiary strata indicative of shallow water conditions extend as far west as 49° 20′ N, 7° 10′ W, and these are associated with beds containing abundant *Nummulites*. King (1954, p. 80) observed that Palaeogene limestones in the west of the English Channel are rich in milioline foraminifers and there are but few records of *Nummulites*, whereas to the east the converse applies. He noted that both faunal types exist in the Paris Basin and suggested that the distribution in the English Channel may be due to sparse sampling. The

* Much farther north are the records of Cole & Crook (1910) of milioline limestones at 51° 37½′ N, 12° 0′ W, which is their most westerly known occurrence.

cores that we have taken in the Western Approaches west of the longitude of Plymouth show no such apparently anomalous distribution of the Foraminifera because milioline and nummulitic strata certainly crop out on the sea bed in many places.

Ypresian deposits remain undetected in the Western Approaches, as does the Palaeocene, and the Palaeogene outcrop suggests unconformity (figure 1). Records of a thumper traverse, carried out in collaboration with Dr J. B. Hersey in 1960 aboard *Chain*, have now been interpreted and a clear discordance in dip exists on the shelf between the Cretaceous and Tertiary rocks.

The highest Eocene, of Auversian or Bartonian age, may be represented by some of the milioline limestones but no significantly distinctive data on this subject are as yet available, whereas chalks of corresponding age have been recognized in the scarp facies on their content of nannofossils.

(*l*) *Oligocene*

There is as yet no evidence of the existence of rocks of Oligocene age in the western part of the English Channel though such may be proved among the samples of limestones collected at about longitude 4° W.

(*m*) *Miocene*

No Miocene is known from the English Channel or the Western Approaches as far as 7° 10′ W and it seems that Miocene seas did not invade these regions which presumably existed as land. Nevertheless, 80 miles away the continental slope has yielded Miocene chalky samples of the scarp facies.

(*n*) *Pliocene*

No Neogene deposits younger than possibly the Upper Miocene have been recovered from the continental slope but commencing at 5° W and occupying an axial and central position on the floor of the Western Approaches is an unconformable tongue-shaped outcrop of yellowish-grey and light-buff, more or less indurated, sandy silts containing innumerable small foraminifers, particularly *Globigerina* and related genera, and nannofossils (figure 1); the silts are here named the *Globigerina* Silts. Mr C. D. Ovey commented on our earlier cored samples, and reported that the planktonic Foraminifera indicate clear water and a good outlet to the ocean, while *Globigerina eggeri* Rhumbler and *Globigerinoides trilobus* (Reuss) point to much warmer conditions than exist today in this region. Among the benthonic forms *Cibicides lobatulus* (Walker & Jacobs) is abundant, as in the Coralline Crag, and in addition at least six other species are common to the *Globigerina* Silts and Coralline Crag. On the other hand, *Reussella* sp. and all the pelagic species have not been recorded from the Coralline Crag. *Entosolenia* sp., a St Erth occurrence, was noted. Mr Ovey's verdict was that the *Globigerina* Silts are of Coralline Crag age, being earlier than the St Erth's assemblage. Samples SB 144/4 and 140/3 were then passed to Dr B. M. Funnell who recognized some small immature examples of *Elphidiella hannai* (Cushman & Grant) which is common in the early Pleistocene of the North Sea Basin, but occurs rarely in the upper horizons of the Pliocene in the same region; on the west coast of North America it ranges from Pliocene to Recent. Dr Funnell reported that the dominance of planktonic forms in 140/3 and their abundance in 144/4 cannot be matched in the Pliocene of north-west Europe, although they are approached by samples from the Dutch boring at Zaandam, and concluded that the presence of *E. hannai* indicates a post-Miocene age, whereas its scarcity shows pre-Pleistocene affinity; the Foraminifera of the *Globigerina* Silts 'show similarities to, and differences from, Coralline Crag assemblages, and the differences may be a reflexion of a difference of facies'.

The nannoplankton is poor and no index-species of stratigraphical importance have been seen. The assemblages from SB 409 and 410/3 resemble those from the Sands of Diest (Diestian) of Antwerp and in table 15 the nannofossils are included for comparison. There is an obvious resemblance between the Diestian list and that for SB 409 and 410/3. A sample of the Lenham Beds has been examined for nannofossils but it has proved to be decalcified; the Coralline Crag has provided well-preserved specimens of common *Coccolithus pelagicus* and rare *Braarudosphaera bigelowi*. The stratigraphical correlations founded on first the Foraminifera and secondly the nannoplankton agree closely.

TABLE 15. CALCAREOUS NANNOPLANKTON FROM THE *GLOBIGERINA* SILTS

	144/4[1]	408[1]	409	410/3	Diest
Coccolithus pelagicus (Wallich)	*c*	*r*	*c*	*c*	*c*
sp. A	*f*	*f*	*f*	*f*	*r*
Discolithus multiporus Kamptner	*r*	—	—	—	—
Helicosphaera carteri (Wallich)	—	*r*	*f*	*f*	*r*
Scyphosphaera sp.	—	—	*r*	—	—
Braarudosphaera bigelowi (Gran & Braarud)	—	—	*r*	*r*	*f*
Discoaster sp. B	—	—	*f*	—	*r*
sp. D	—	—	*r*	*r*	—
Thoracosphaera sp.	—	—	*f*	—	—
Sphenolithus sp.	*r*	—	*r*	*r*	—
Lithostromation perdurum Deflandre	—	—	—	*r*	—
Trochoaster deflandrei (Stradner)	—	—	—	—	*r*

[1] Stratigraphical age not determinable more precisely than younger than Lower Miocene.

The outcrop of the *Globigerina* Silts becomes broader, and presumably the thickness greater, as followed westwards and it is reasonable to predict that sedimentary rocks of comparable age, possibly chalks, will eventually be recovered from the top regions of the continental slope.

(*o*) *Environmental conditions and physiography*

The English Channel and the Western Approaches in outline may be likened to a triangle with the apex at the Strait of Dover. Here the sea bed is the continental shelf, and the shelf-break lies about 120 miles to the south-west of the Scilly Isles.

One of the major unanswered geological questions is for how long has the shelf existed? Much new information has come to hand of recent years, and the admittedly sparse evidence needs to be examined, if only at the present time superficially, to ascertain whether there is any argument of substance in favour of the shelf as it is known today in the south Celtic Sea having been in existence during all, or part of, Tertiary times.

Lying within the Upper Cretaceous and occupying the central region of the western and mid-Channel is a subtriangular outcrop of shallow water and coastal Eocene deposits which, subsequent warping notwithstanding, were laid down on a sea bed which relative to present-day sea level stood 70 fm lower. Later, definitely during Miocene times, the sea receded, and when the marine incursion of the Pliocene followed, the *Globigerina* Silts were deposited in a gulf-like depression; their richness in pelagic Foraminifera and the faunal evidence of clean warm seas with good oceanic connexion suggest much deeper water

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conditions than those in which the coastal Eocene sediments accumulated. However, farther south-west on the slope there existed the contrasting conditions which favoured the formation of foraminiferal and coccolithophorid calcareous muds with only a very small content of clastic matter; here almost certainly existed open sea conditions removed from the land, and deep water which continued at least from Middle Eocene to Middle or possibly Upper Miocene times; if the tongue-shaped and easterly wedging *Globigerina* Silts are included there seem good reasons to advocate that all these sediments, flanked to north and south by strata of shallow water origin, moved eastwards as infillings of a gulf and did not serve to increase the thickness of an existing continental shelf by adding superimposed sedimentary layers. This implies that the continental shelf of Eocene-Pliocene times, if it existed, was deeply cut into by the south Celtic Sea and that a large gulf, tapering north-eastwards, extended into the western English Channel for varying distances at differing geological times, but at the end of the Pliocene it appears to have reached at least to the longitude of Falmouth-Ushant. Much additional sampling on the slope and the shelf south-west of 7° 40′ W is needed to show whether this physiographical explanation is tenable.

6. General conclusions

The tentative model that is gradually being built of the continental slope off western Europe possesses the following characteristics; (i), the slope appears not to have retained much clastic sediment of recent geological time, and some no doubt has been transported to deeper water by one or other agency; (ii), the slope is cut into by canyon-like valleys particularly between longitudes 7 and 12° W; (iii), although several of the dredged hauls contain rock samples hard enough to have travelled from afar others are so soft that their source must be near at hand and in many cases they were *in situ*; (iv), indurated and lithified rocks ranging at least from the Middle Eocene to Middle or Upper Miocene which, by reason of low south-westerly axial inclination, intersect and crop out on the slope; (v), the chalky deposits of the scarp facies are quite different from anything known in western Europe; (vi), a record taken by Dr J. B. Hersey across the shelf and slope (private communication) has detected terraces or benches no doubt caused by the outcrops of differing strata which show a gentle axial inclination; (vii), there is sometimes a lack of agreement between depth on slope of the scarp facies and increasing stratigraphical age even when allowance is made for the inclination of strata and their different levels on the walls of the deeply cut canyons, and (ix), presumptive evidence is lacking to support the theory that the shelf of the Western Approaches and south Celtic Sea as known today existed in a similar physiographical form before Pleistocene times.

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