PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Geology of the Bristol Channel Floor

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THE GEOLOGY OF THE BRISTOL CHANNEL FLOOR

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[Plates 5–7; maps on two pullouts]

CONTENTS

A reconnaissance survey has been made with side-scan sonar, Boomer and gravity corer of a sea-floor area extending from the mouth of the River Severn to the longitude of Hartland Point, and from the North Devon coast to the latitude of Porthcawl. The results include the recognition of two major WNW–ESE trending synclines arranged *en échelon* with a minor intervening pericline. The eastern syncline, traceable to the longitude of Watchet and preserving Upper Pliensbachian (Lower Jurassic) rocks in its core, is the seaward extension of the Glastonbury Syncline. The western syncline, of which little more than the eastern half could be investigated, includes a sequence of Jurassic rocks up to high Kimeridge Clay. This Bristol Channel Syncline is cut by a series of NW–SE trending tear-faults analogous to those in southwest England and has its southern margin truncated by a strike fault with northerly transport.

The Jurassic sequence is unusual in its abnormal thickness (in excess of 1600 m) and its predominantly argillaceous nature. Thick limestones are unknown, although cementstone bands occur, mainly in the Lower Lias. Sands and sandstones were found only in beds of Upper Oxfordian and, dubiously, of Portlandian (Middle Volgian) age. Elsewhere in the succession, and notably for the Aalenian–Lower Callovian interval, the correlatives of thick carbonate sequences of mainland successions are thin sands and sandy clays or non-sequences. The Bristol Channel region may therefore have supported a lesser depth of water than other basins in southern England. Facies changes within the area are small. They offer no support to the hypothesis of a Welsh island, but suggest the possibility of a Cornubian source area for clastic sediments in early Upper Jurassic times.

1. Introduction

The Bristol Channel is one of the most striking indentations of the British coastline. Its western portion forms abrupt limit to the hills of north Devon and west Somerset and yet gives the sea access to the low-lying flats of south Somerset farther east. In spite of this, the uppermost part of the estuary turns boldly northeast and passes between the hills of Gloucestershire and Monmouthshire. Although rocks on the sea floor had not been sampled previously there had been much discussion about the geological history of the surrounding land area and a number of different suggestions have been made about the possible origin of the Channel itself. In brief, the westerly trending portion of the Bristol Channel lies almost parallel with facies boundaries and isopachs of Upper Palaeozoic rocks and also with end-Palaeozoic and Mid-Tertiary-fold directions and so may indicate some deep-seated structural control. Although the structural form of the Channel may have been initiated at about Permo-Trias times and developed during the Mesozoic as evidenced by the presence of shoreline deposits of Glamorgan (Kent 1949; Wobber 1966), it has been suggested that it only became clearly defined as a result of thrusting (Falcon, in Cook & Thirlaway 1952; Bott, Day & Masson-Smith 1958), Tertiary folding (Jones 1931), or because of massive erosion (North 1955) of down-faulted Mesozoic rocks (Simpson 1953, 1961). The considerable amount of post-Eocene erosion experienced by this region is suggested by the uncovering of the Lundy granites. The whole of the floor was probably exposed to subaerial weathering during the Pleistocene glacial episodes.

The recognition of a trough of Mesozoic rocks beneath the Bristol Channel has already been reported briefly (Donovan, Savage, Stride & Stubbs 1961), the strata ranging from Trias to near the top of the Kimeridgian (Lloyd 1963): the only detailed study refers to a small area off Barry (Banner, Brooks & Williams 1971). The ground as a whole was found to be particularly suitable for geological exploration because large areas had been almost stripped of superficial cover by the strong tidal currents and because the harder beds had been etched out, partly by the passage of the sand (Donovan & Stride 1961 *a*) for deposition elsewhere (Belderson & Stride 1966). The purpose of the present paper is to provide a reconnaissance geological map of the floor of the Bristol Channel and, as a result, to provide evidence for its origin and geological history.

2. The reconnaissance survey

Shipboard exploration of the floor of the Bristol Channel was carried out acoustically by means of echo-sounder, side-scan sonar (figure 2), a Boomer continuous reflexion profiler (Bowers 1963) and by means of physical sampling with a 500 kg gravity corer and a dredge (figure 1). Some of the samples near to shore were taken by divers. The total number of rock samples collected was 158. Although the work at sea lasted for less than a month, in total, it was found necessary to make eight visits to the area during a period of 4 years (see table 1). The most convenient courses for the side-scan sonar survey lay parallel with the shipping lanes and tidal currents although some attempt was made to run parallel with the regional strike. Outcrops of individual beds could then be followed for up to 3 n mile (5.5 km),† until they were lost because of local deviations in strike, displacement by faults or a cover of superficial material. The preferred courses with the Boomer lay normal to the strike revealed by the side-scan sonar, although because of instrumental difficulties this was not always possible.

Table 1. Geological exploration of the Bristol Channel

ship	survey dates	acoustic surveys: side-scan sonar	acoustic surveys: Boomer	sampling: corer	sampling: dredge	sampling: divers
R.R.S. *Discovery II*	22.iv–2.v.60	X	—	X	X	—
	19–20.ii.61	X	X	—	—	—
	6–9.v.62	X	X	X	—	—
H.M.S. *Shackleton*	6.iii.61	—	—	X	—	—
	24–26.viii.61	X	—	X	—	—
Porlock Weir motor-boats	20–26.vi.61	—	—	—	—	X
Ilfracombe and Combe Martin motor-boats	20–24.iv.62	—	—	—	—	X
R.V. *Sarsia*	21–29.xi.63	—	—	X	—	—

The location of the ships, both at sampling stations and at quarter hourly intervals while underway, was determined for the most part by means of Mark V Decca Navigator equipment. Occasional fixes by means of radar or compass bearings on the shore revealed discrepancies attributable largely to the fixed and variable errors of the Decca system. In plotting the courses it has been assumed that the ships proceeded at constant or at progressively varying speeds between points where a change of course was made. In spite of this, it was necessary to make some corrections amounting to about 200 m to obtain coincidence between the same feature recognized on some of the survey lines which cross one another a few kilometres north of Foreland Point.

In addition to work from aboard ship, use was made of aqualung divers (working from motor-boats) to determine the location of the Palaeozoic–Mesozoic boundary. The divers were not completely successful, owing to the problem of diving in fast flowing muddy water and because of the blanket of pebbles. They found it impossible to sample Horseshoe Rocks because of the tide race occurring there. At each diving station the location of the motor boat was determined, with reference to the coast, by means of a sextant; depth was determined by portable echo-sounder.

† 1 n mile ≈ 1.85 km.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

3. Geological map of the Bristol Channel

All available geological and geophysical data (figure 1) have been combined in the simplest possible way to construct the geological map of the Bristol Channel (figure 3) and the three structural cross-sections (figure 4). One hundred and fourteen samples of determinable age (21 Palaeozoic, 21 Triassic and 72 Jurassic) form its basis, together with some guidance from the lithology of samples devoid of fauna and the rock notations on navigational charts. Strike lines, some broad differences in lithology and minor faults were particularly well shown by the extensive side-scan sonar coverage of ground rich in stone bands. Dip directions, both real and apparent, the continuity of beds in depth, as well as the main fold axes and indications of minor folds were revealed by the Boomer. However, on the geological map it has not been possible to show the minor faults; geological boundaries have been omitted where control is poor. Uncertainty is most apparent in three regions: (1) on the northern flank of the Bristol Channel Syncline, where there may be extensive strike faulting; (2) south of Glamorgan, between Nash Point and Barry; (3) east of a line from Barry to Watchet, where data are scarce. Although the geological map is inevitably somewhat speculative, its internal consistency is such that the structural data provided by side-scan sonar and Boomer is in keeping with the stratigraphic control, so that the map cannot be too far from the truth.

Much of the northern and western limits of the geological map have been set by the presence of loose superficial sands, too thick to be penetrated by our corers and seemingly unbroken by outcrops, despite an extensive search for them with side-scan sonar and some use of the Boomer. Similarly, gravels near the southern shore presented an impenetrable barrier. Between these areas the sands and gravels were thin and discontinuous.

4. Palaeozoic rocks

Information about the Palaeozoic rocks is less abundant than for Mesozoic strata. Only 21 cores were obtained (partly due to the difficulty of sampling hard rocks), although some additional material was obtained by divers and by dredging. No fossils were seen in any Palaeozoic sample, so that identification has depended entirely on sedimentary features, cleavage character and lithological matching with rocks on the adjacent land. While these criteria, taken together, were sometimes determinative, there are other cases where doubt may still persist. Some strikes were provided by side-scan sonar, although these were less useful than for the Mesozoic strata, owing to unsuitable rock types, a pebble cover, and in the west, in particular, because of the numerous faults and minor folds.

On the south side of the Bristol Channel there is a belt of Palaeozoic rocks (figures 1, 3 and appendix I) which is narrowest at about Foreland Point (03° 47′ W), but broadens progressively in a westerly to northwesterly direction. Sonographs show that these rocks strike in a similar direction, in keeping with their strike in north Devon and west Somerset. The same strike was observed on the sea floor between west Devon and Lundy (figure 5, plate 5), although details are rather difficult to work out because of fracturing and the presence of numerous minor folds. These old rocks follow a gentle arch north of Lundy and appear to be more intensely broken (Belderson, Kenyon, Stride & Stubbs 1972, figure 16) than is observed elsewhere in the area. Although there are too few samples to allow geological boundaries to be drawn, it is clear that the broad anticlinal structure of the Devonian rocks of west Somerset (Webby &

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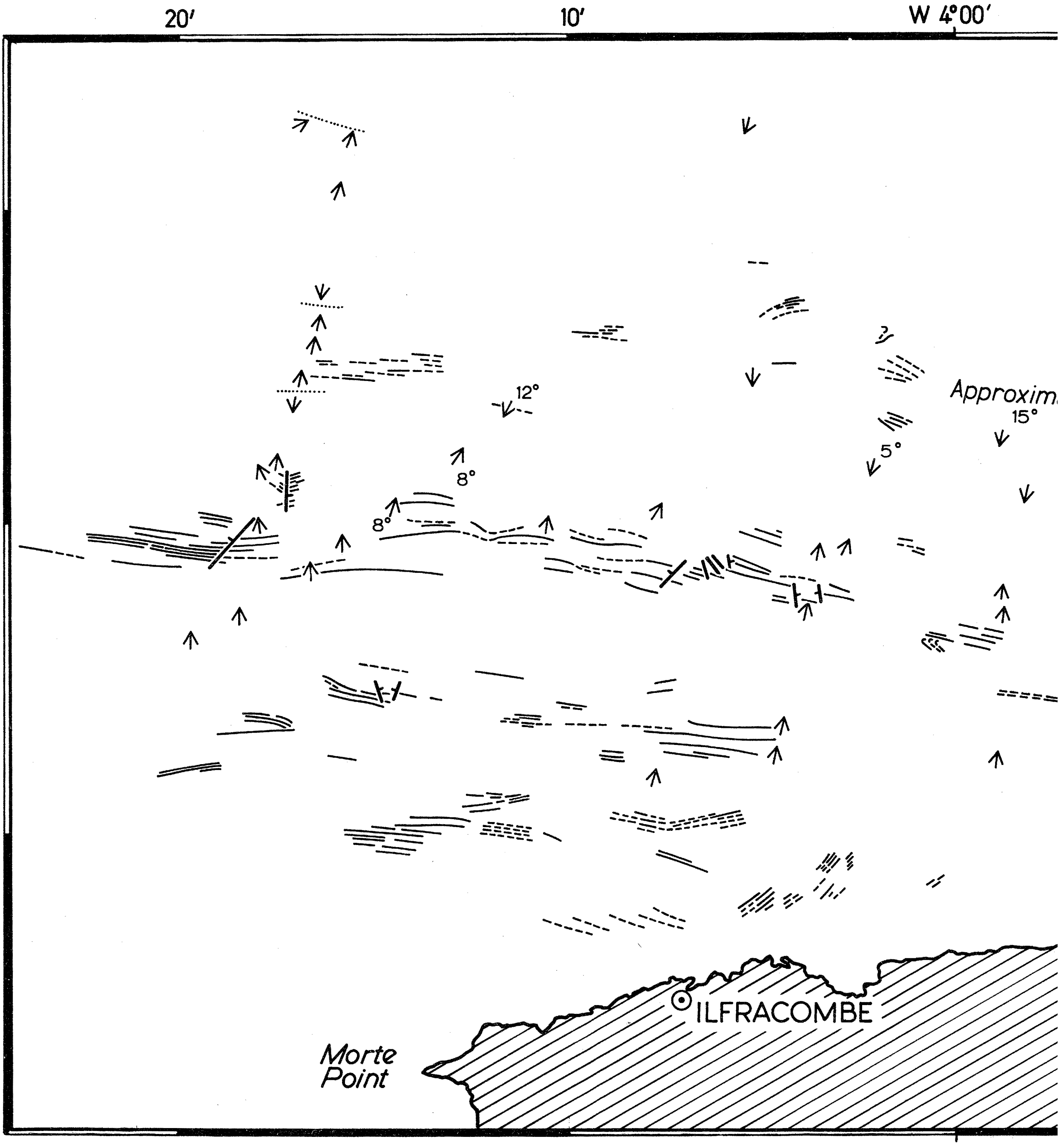
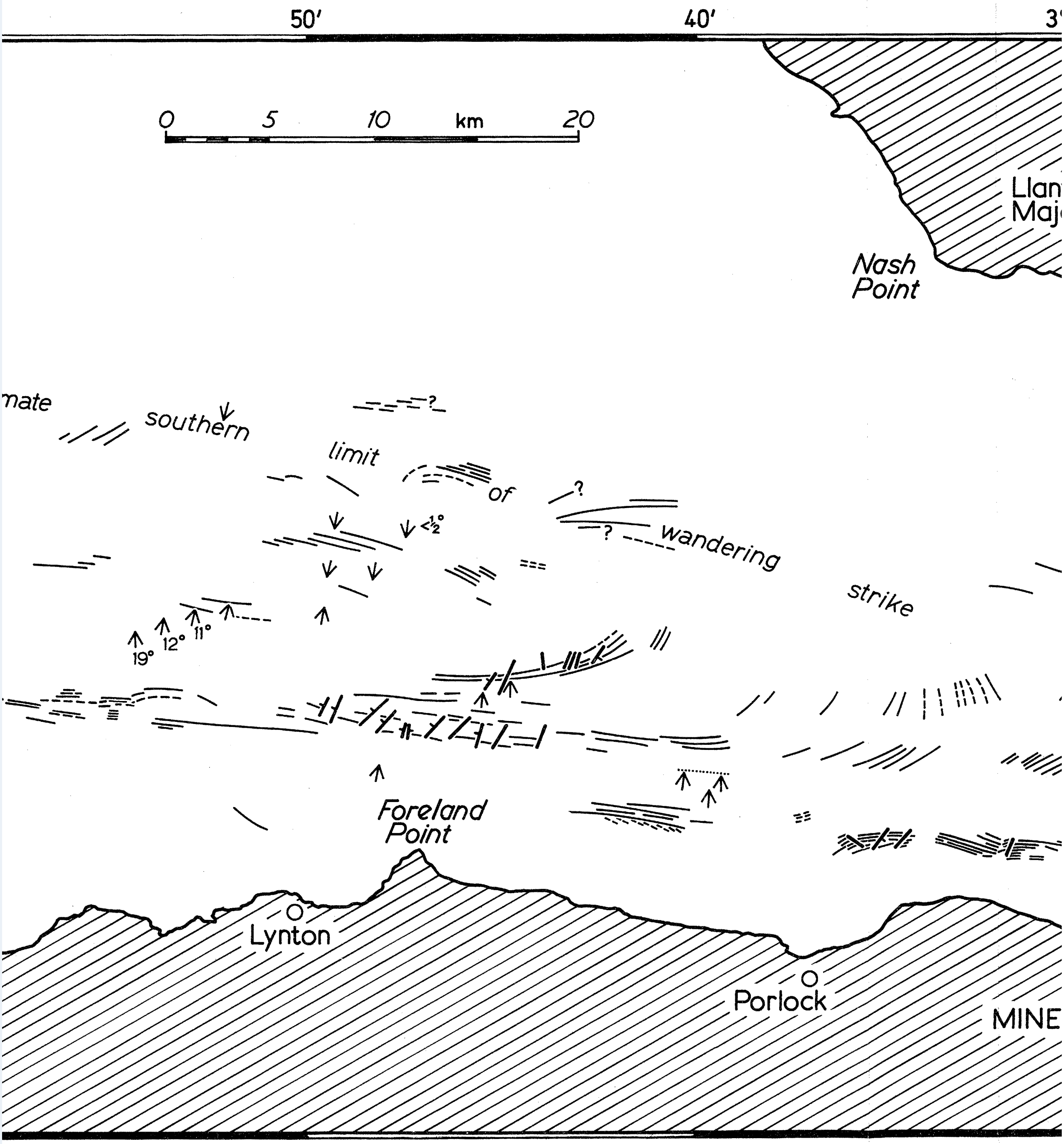
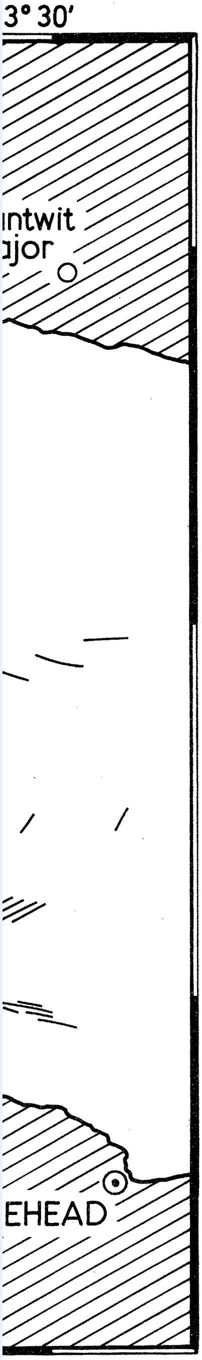


FIGURE 1. The location of 'strike' lines a



and dips used in the present study of the Bristol Channel.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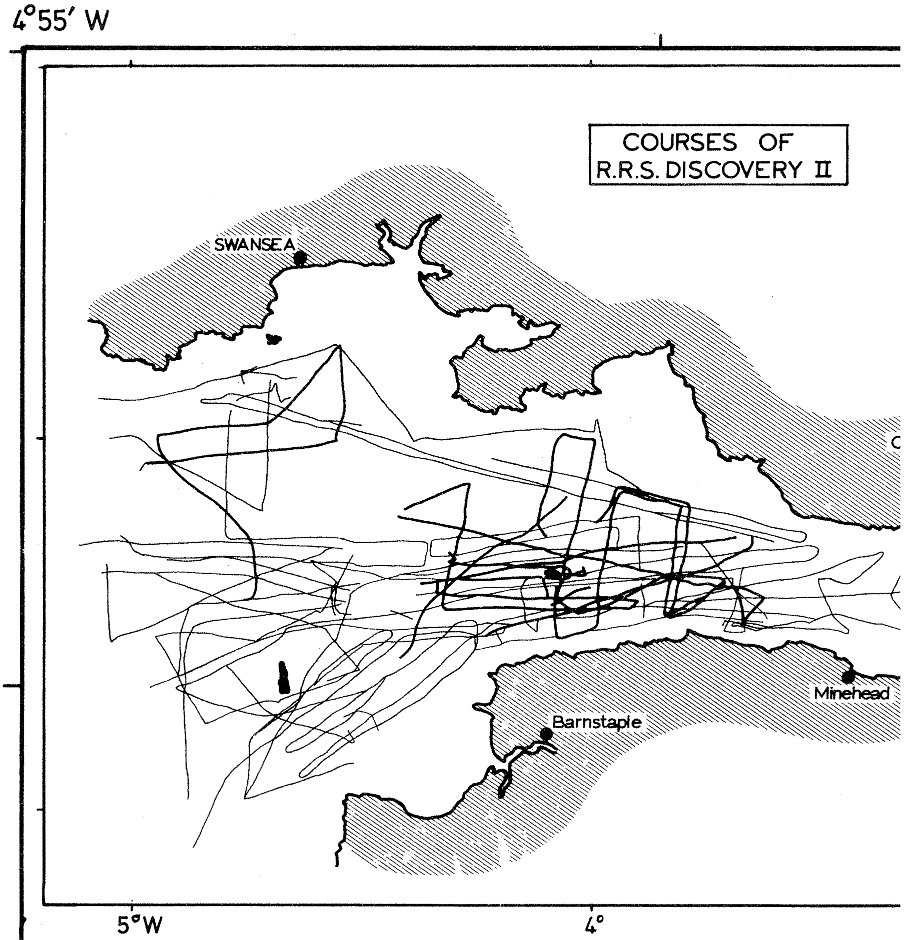
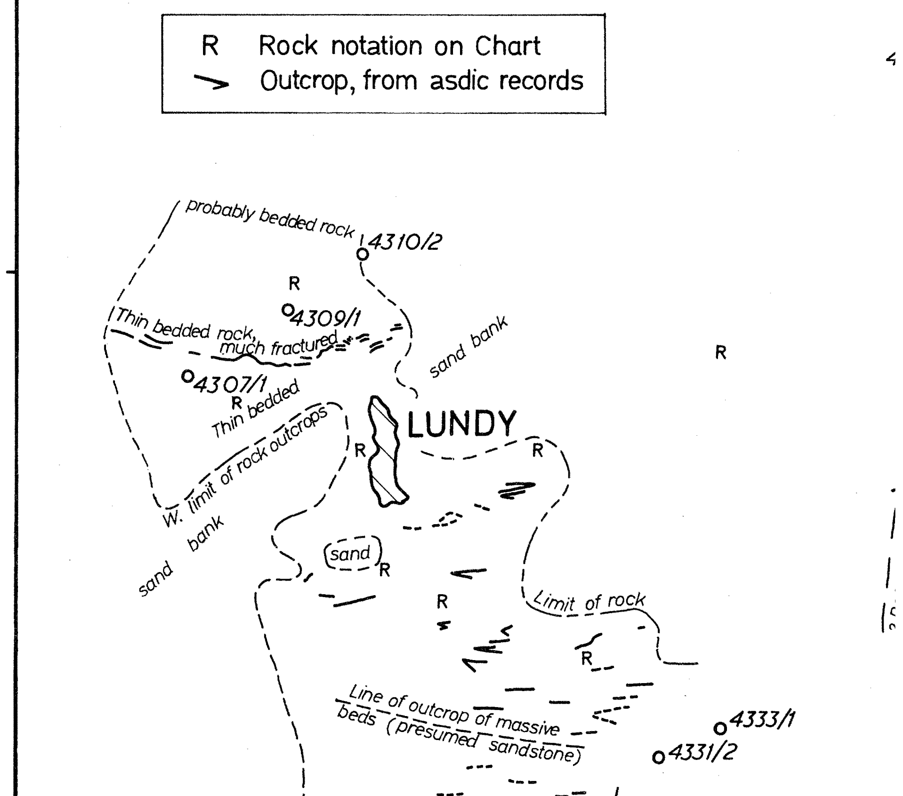
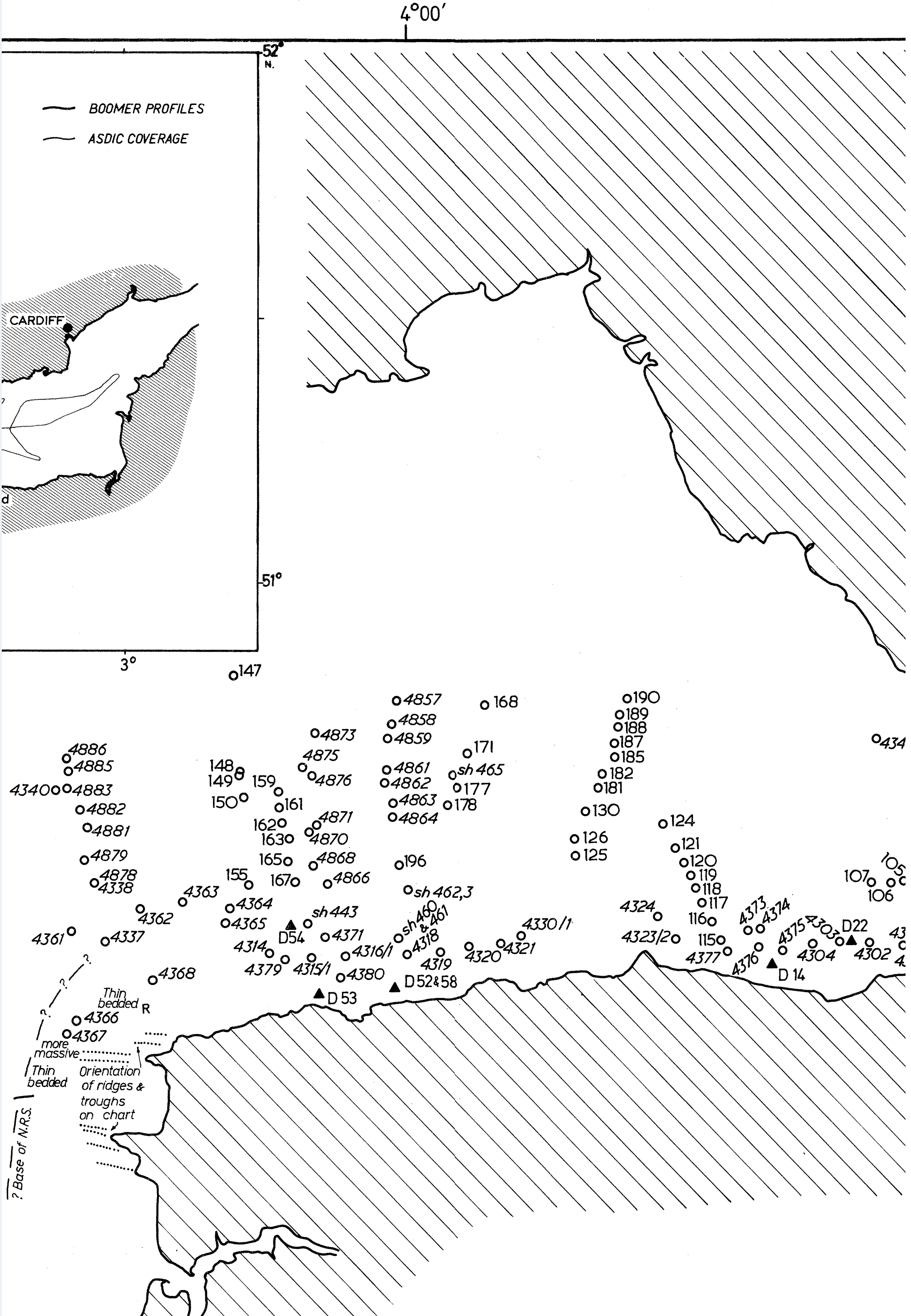
ntwit
ajor
EHEAD


4°55′ W
COURSES OF
R.R.S. DISCOVERY II
SWANSEA
Barnstaple
Minehead
5°W
4°


R Rock notation on Chart
Outcrop, from asdic records
probably bedded rock
4310/2
4309/1
Thin bedded rock, much fractured
4307/1
Thin bedded
W. limit of rock outcrops
sand bank
sand bank
LUNDY
sand
Limit of rock
Line of outcrop of massive beds (presumed sandstone)
4333/1
4331/2


4°00′
52° N.
BOOMER PROFILES
ASDIC COVERAGE
CARDIFF
51°
3°
147
4857
168
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189
188
187
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4379
4315/1
4316/1
4380
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4320
4321
4330/1
D 53
D 52 & 58
4368
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4373
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D22
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4376
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Thin bedded
R
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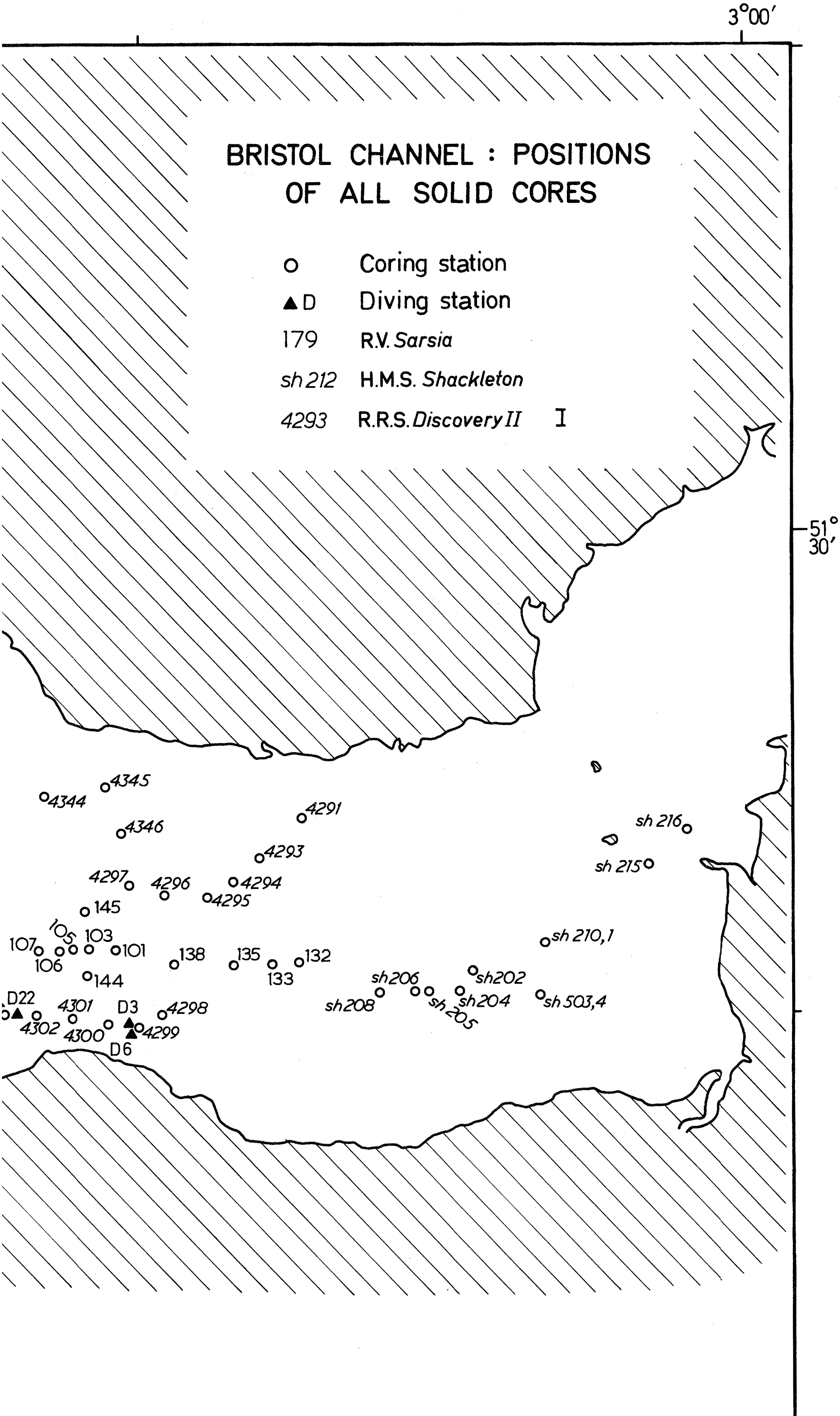
4367
more massive
Thin bedded
Orientation of ridges & troughs on chart
? Base of N.R.S.


3°00′
51° 30′
BRISTOL CHANNEL : POSITIONS OF ALL SOLID CORES
o Coring station
▲D Diving station
179 R.V. Sarsia
sh 212 H.M.S. Shackleton
4293 R.R.S. Discovery II
I
4345
4344
4346
4291
4293
4297
4296
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145
105
103
107
101
106
138
135
132
133
144
D22
4301
D3
4298
4302
4300
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D6
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sh 215
sh 210,1
sh 206
sh 202
sh 208
sh 204
sh 205
sh 503,4

FIGURE 1. The location of 'strike' lines ar

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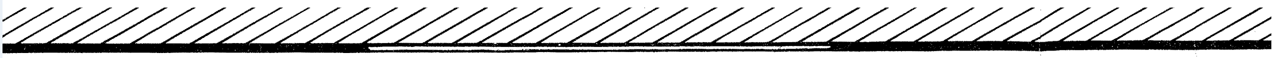
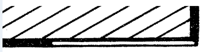


and dips used in the present study of the Bristol Channel.



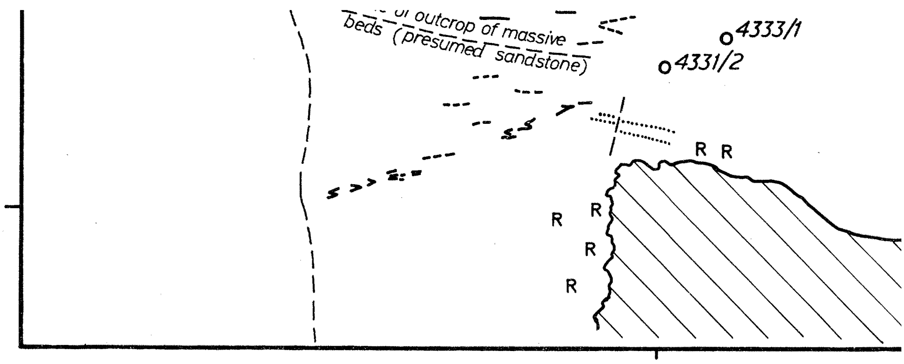


FIGURE 2. The location of coring stations on the floor of the Bristol Channel, t

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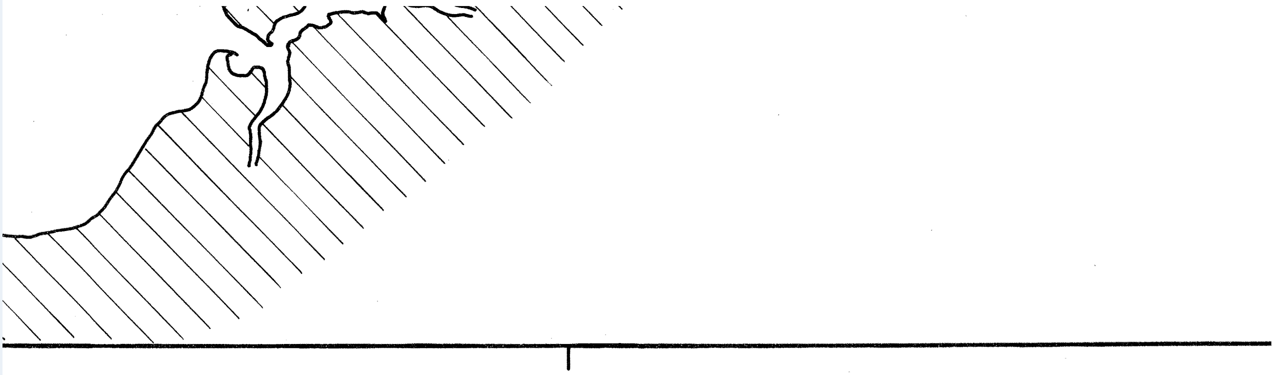
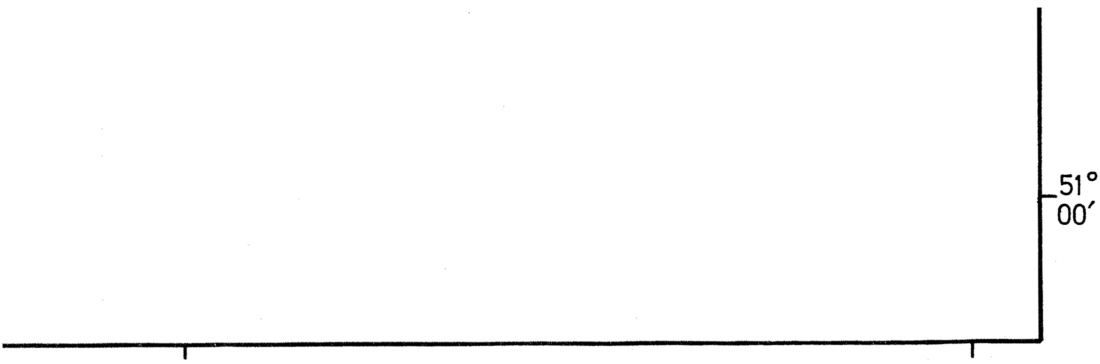


, together with strike lines and the approximate limit of outcrops of Palaeozoic rocks in the vicinity of Lundy. The inset fi



ıe inset figure shows the side-scan sonar (asdic) coverage and the location of Boomer profiles.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

SOLID GEOLOGY OF THE BRISTOL CHANNEL

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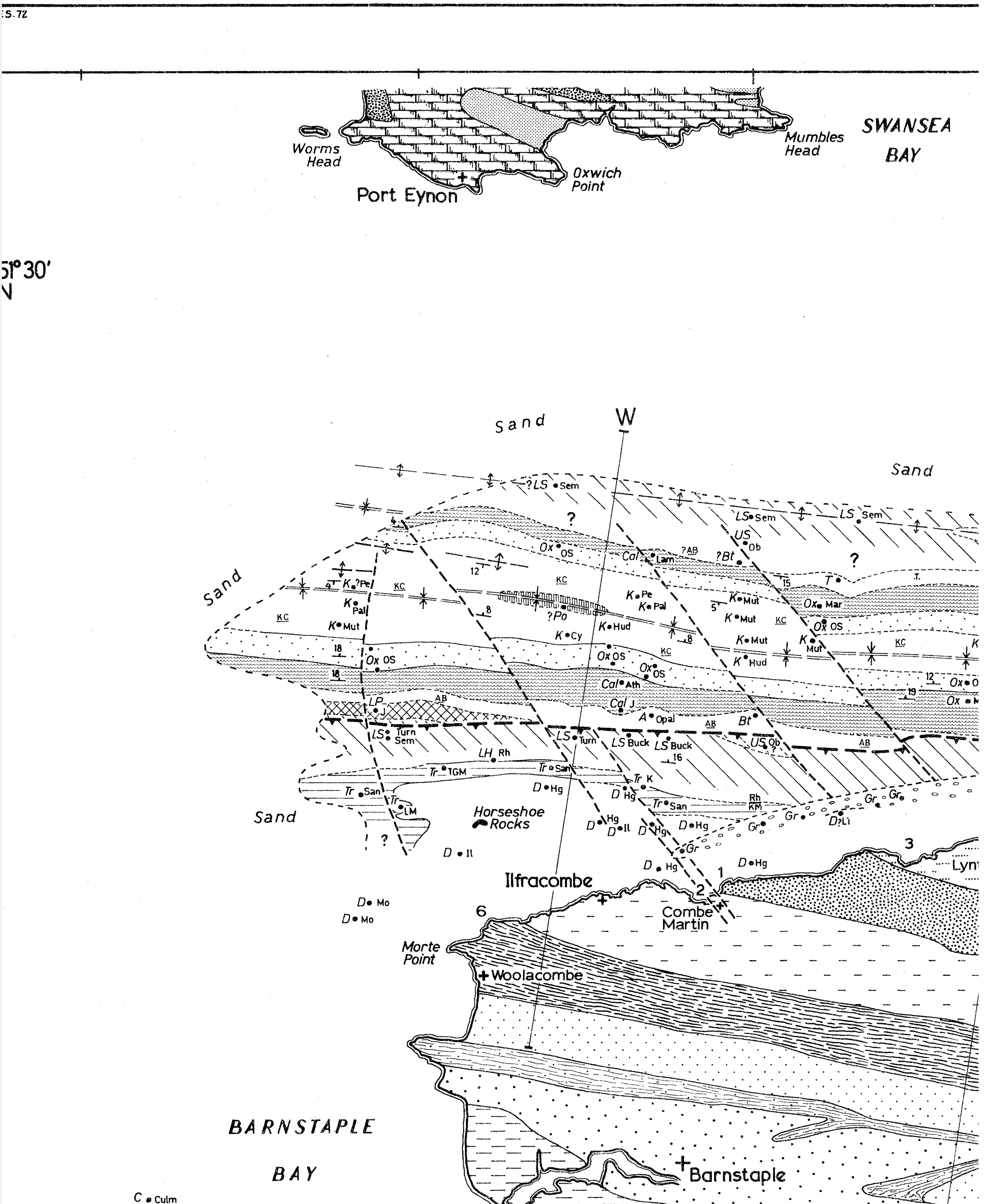

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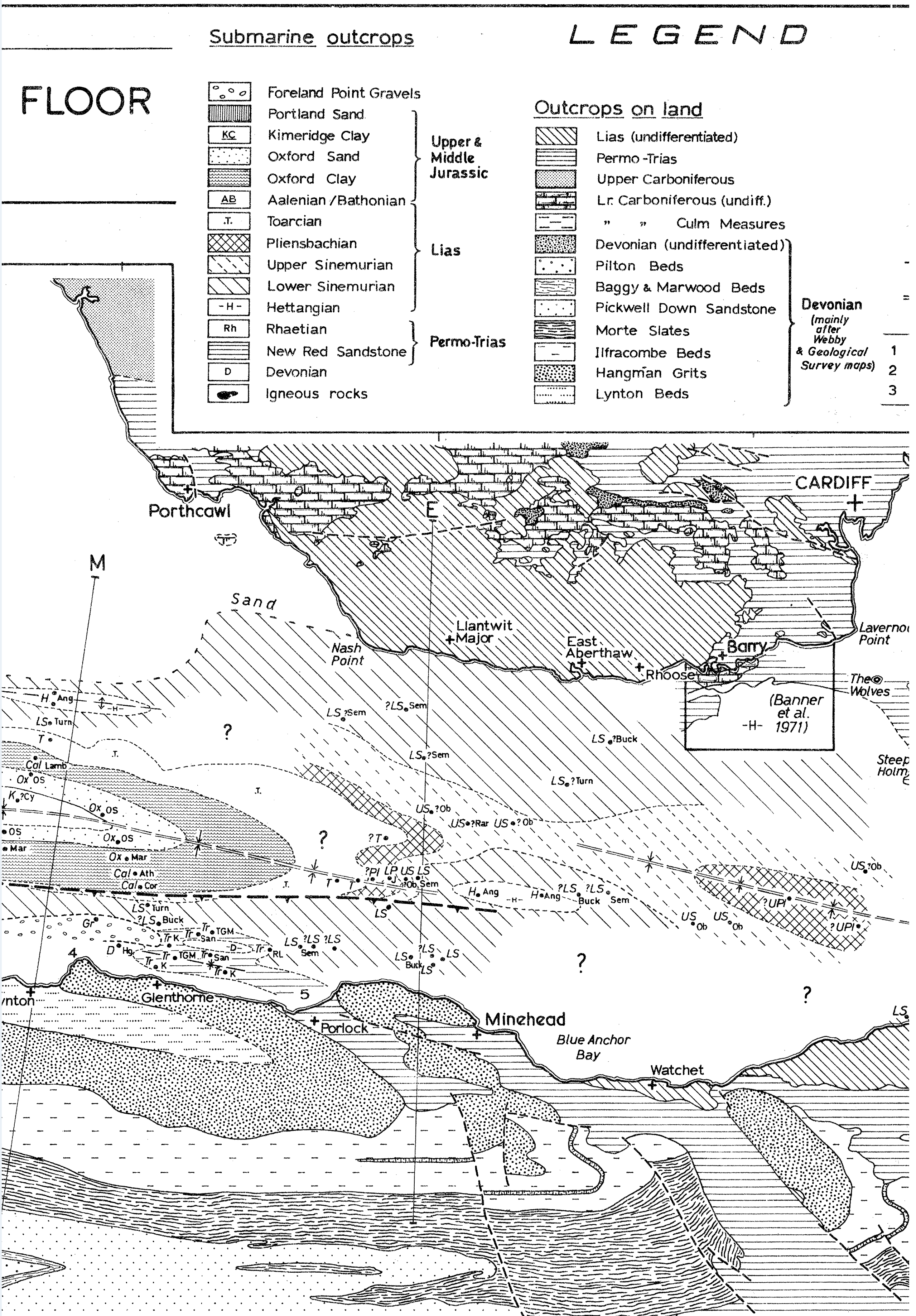

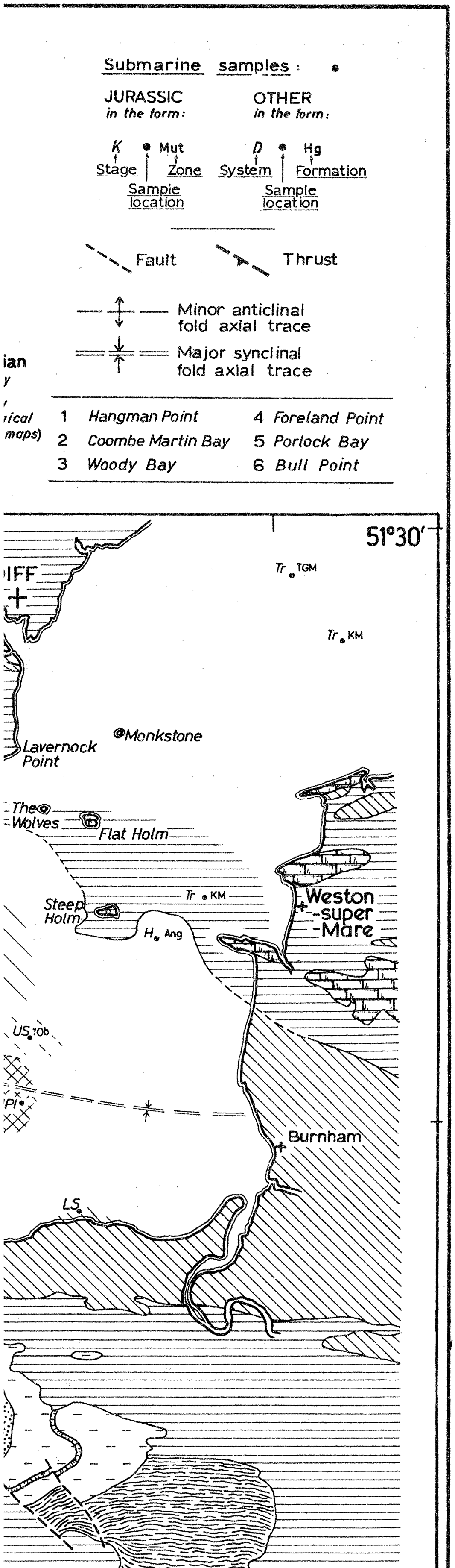

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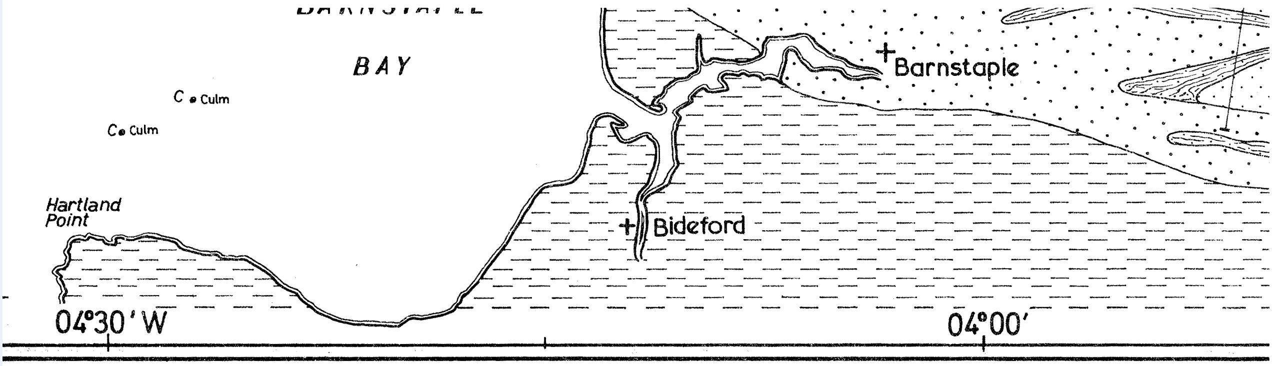

Figure 3. Solid geology of the Bristol

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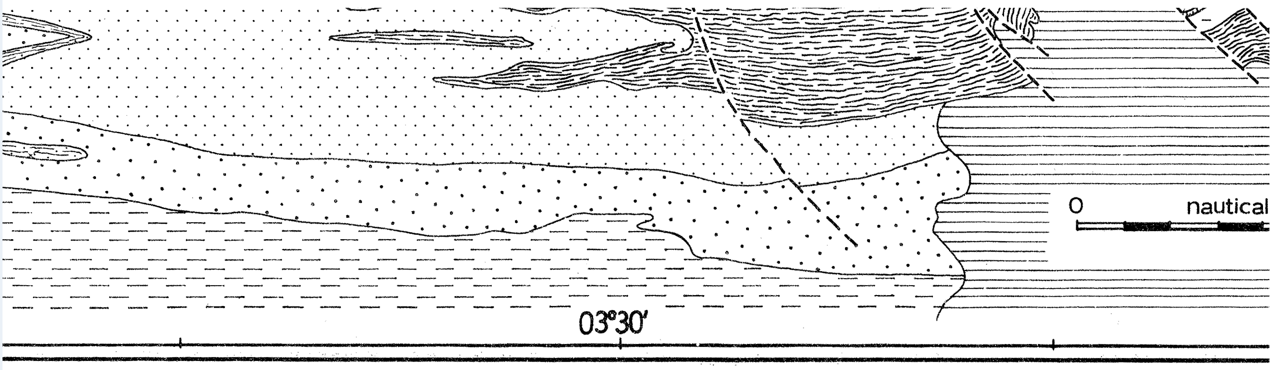

tol Channel floor. The structural sections W, M and E are shown in figure 4.

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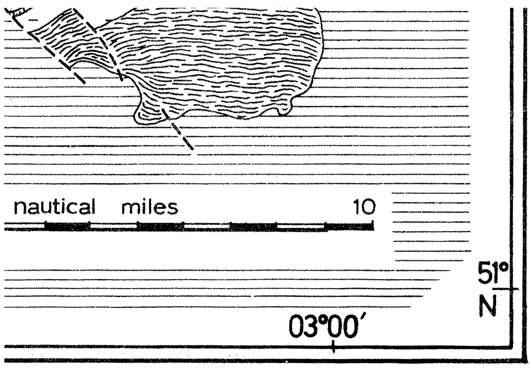

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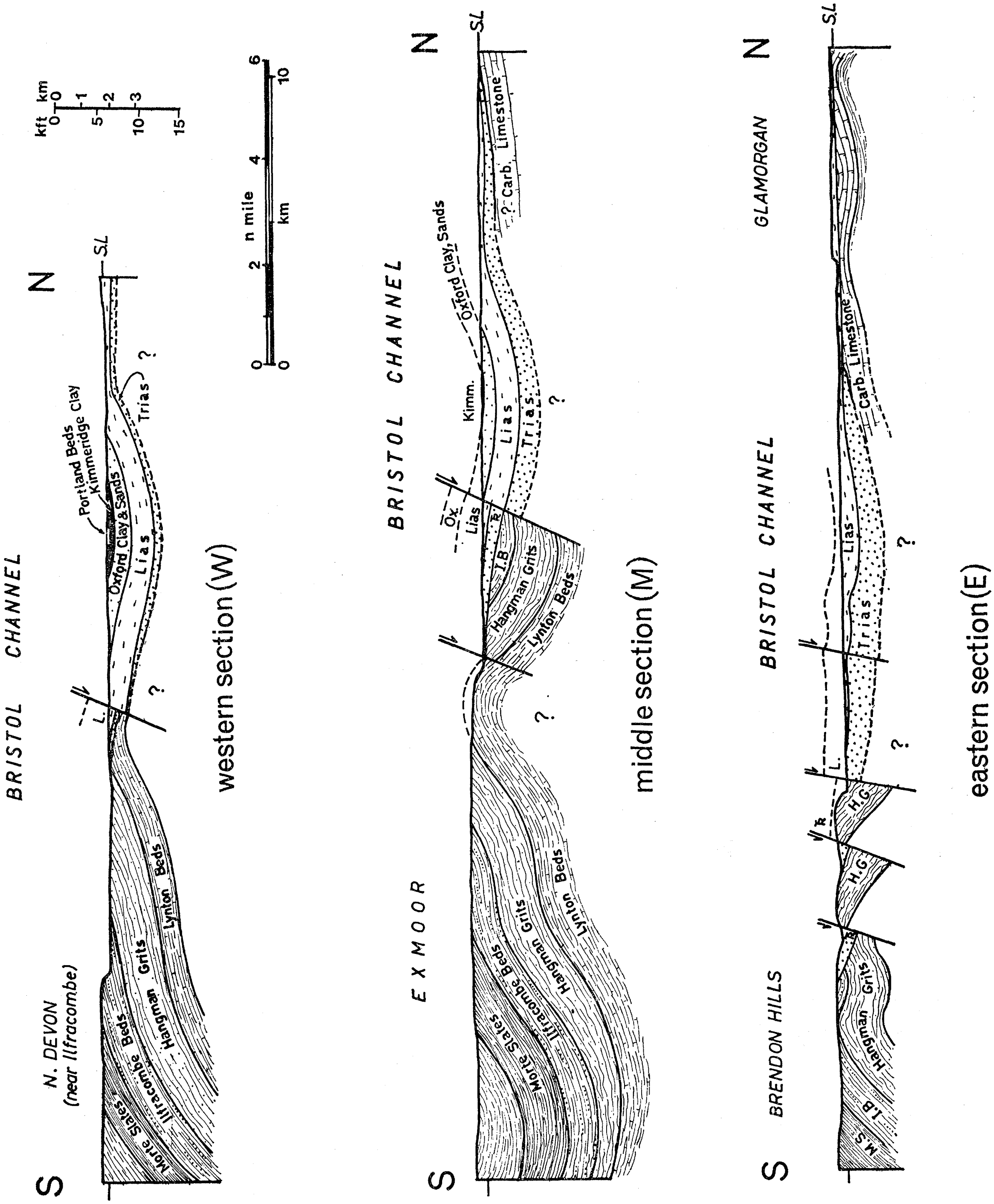

FIGURE 4. Three structural sections across the Bristol Channel and neighbouring ground. For locations see figure 3.

Thomas 1965) and north Devon (Edmonds, McKeown & Williams 1969, p. 27) continues seaward.

Eight cores were obtained from the Hangman Grit facies; five of them from west of the Combe Martin fault and three east of that fault. Station Dy 4300/1 is identified as Hangman Grit on the grounds that Foreland Grit is equivalent to Hangman Grit; this station is separated from the next Hangman Grit record by Dy 4320. The sample from the latter station, about 1.3 nmile (2.4 km) northwest of Heddon Mouth, resembles Lynton Beds and shows steeply dipping bedding cut by a cleavage inclined in the same direction. As the cleavage at the coast has a dip of 30° to the south, the sample implies the existence of an overturned northern limb, which could be the main or only a minor fold. Northwest of Combe Martin Dy 4380 yielded a grey, non-calcareous, fine grained sandstone with grey slate which could be either from the top of Hangman Grit or from basal Ilfracombe Beds, while north of Ilfracombe Dy 4379 yielded grey Ilfracombe Slate. Station Dy 4368, 3 nmile (5.5 km) north of Morte Point, yielded a pale grey slate similar to that seen near the middle of the Ilfracombe Beds on the shore. The two stations west of Morte Point (Dy 4366 and 4367) yielded grey, non-calcareous, cleaved slate which is indistinguishable from Morte Slates. In Barnstaple Bay the only two successful stations (Dy 4331 and 4333) yielded grey micaceous slate, with low-grade cleavage, which could be either Culm or Pilton Beds, though their position would favour Culm.

In the area between Hartland Point and Lundy Island few samples were obtained, but sonographs suggest that pre-Permian rocks outcrop on the sea floor all the way from the coast to a point about 10 km northwest of Lundy. Northwest of that island the Devonian rocks were proved by three samples. A low-grade, grey micaceous slate with nearly vertical cleavage (Dy 4307/1), and a micaceous sandstone and slate (4309/1), were identified by Dr B. D. Webby as from the Pickwell Down Sandstone and from an horizon above it, respectively, indicating a dip to the north. The third sample (Dy 4310/2) was a micaceous slate with high angle cleavage, of a type that has been found on land at several levels in the Devonian. About 3 nmile south of Caldy Island, beyond the limit of figures 2 and 3, two cores of Carboniferous Limestone were obtained (Dy 4351 and 4352): neither specimen yielded a microfauna which would enable closer determination to be made.

5. Post-Palaeozoic structure

(a) *Mesozoic rocks*

The rocks of the main Jurassic outcrop on the floor of the Bristol Channel have been folded into an inclined syncline of broadly simple form, dips on the limbs commonly ranging between 10° and 20° on the steeper southern limb with some local irregularities shown by Boomer records. The outcrops of the northern and southern limbs are very nearly parallel, so that in our interpretation the westwards broadening of the structure is due mainly to successive downthrows across north-westerly trending oblique faults. This syncline has been traced westwards to about 04° 25′ W, where it disappears beneath superficials. East of Lynton the structure narrows due to westerly plunge and it appears to peter out into smaller folds at about 03° 35′ W. An anticlinal crest has been detected 3.5 nmile (6.5 km) north of the axis of the Bristol Channel syncline, and a culmination on it produces a Hettangian inlier 7 nmile (13 km) north of Foreland Point. The northern limb of this anticline is covered by superficials and has not been studied.

The Bristol Channel Syncline may be a homologue of the Glastonbury Syncline (Jones 1931) on land to the east. The two are not continuous, however, and the dips on the limbs of the Glastonbury Syncline are probably lower (5° or less) than those of the Bristol Channel Syncline. The wavelength of the major folds in the Jurassic is about 7 n mile, comparable with that of folds in the Jurassic of south Dorset (Donovan & Stride 1961 *b*; House 1961). The amplitude of the Bristol Channel Syncline is of the order of 1500 m.

In drawing the outcrops along the southern limb of the Bristol Channel Syncline, taking strikes revealed by side-scan sonar in conjunction with dated rock samples, we have had to postulate an extensive strike fault, downthrowing about 450 m to the north between Porlock and Ilfracombe. The trace of this fault can be accommodated as an almost straight line, but we have no evidence as to the dip of its fault plane. It is interpreted, however, as a thrust in keeping with the tectonic style of the region.

There remains an unexplained anomaly in that outcrops on the northern limb of the Bristol Channel Syncline are narrower than their counterparts on the southern limb, although the dip is believed to be lower. Brooks (see Donovan, Lloyd & Stride 1971) has suggested that strike faulting is the cause. However, the alternative explanation, appreciable northerly thinning of the Jurassic succession cannot be discounted.

There is evidence that the syncline is crossed by northwesterly strike-slip faults, like those described in southwest England by Dearman (1964) and Shearman (1968). For example, one of these is necessary to account for the Kimeridge Clay sampled along the strike from Oxford Clay on the northern limb near 04° 00′ W, which implies displacement of the synclinal axis of about 0.75 n mile (1.4 km). Like the faults on land, they probably have both horizontal and vertical components of movement. The Combe Martin Fault (Shearman 1968) displaces the Devonian–Mesozoic boundary northwest of Combe Martin. Minor faults indicated by side-scan sonar records have northerly to north-northeasterly trend perhaps being complementary to the main faults in the Bristol Channel.

(*b*) *Relationship of Mesozoic to Palaeozoic structures*

The strike of the Bristol Channel synclinal axis (about 8° south of east) corresponds nearly, but not exactly, with that of the north Devon anticline (about 15°; Edmonds *et al.* 1969, Figure 10). The structure of the Palaeozoics south of the Bristol Channel Syncline is not known in detail, but its easterly continuation, the Croydon Anticline (Webby 1965, Figure 5) is a broad flexure fold with dips of up to about 30° on the limbs. This fold is developed in the competent Hangman Grits, and to the south cleavage folds are developed in the Morte Slates. North and east of Foreland Point the Bristol Channel Syncline could overlie a Palaeozoic syncline and so could perhaps be a result of posthumous folding. West of Lynton, due to the convergence of the fold axes, this is unlikely to be the case, and so a hypothesis of posthumous folding, although attractive at a first glance, must probably be abandoned.

A similar discordance in fold direction is seen between the pre-New Red Sandstone folding of the Quantocks (Webby 1966) and the post-Triassic uplift as expressed by present relief; in this case the divergence is about 9°.

(*c*) *Age of the structures*

There is no stratigraphical evidence as to the age of the folding, except that it is post-Jurassic. A suggestion is made on page 615 that it began in the Lower Cretaceous, and this view was held (for independent reasons) by several speakers at a recent symposium (Donovan *et al.* 1971).

The northwesterly strike-slip faults have been regarded as chiefly Tertiary (Shearman 1968, p. 564). In drawing the geological map the control points were better accommodated if it was assumed that the thrust was dissected by these tear faults. Thus, it seems likely that the thrust was formed during the Lower Cretaceous or mid-Tertiary phases of folding.

6. Mesozoic stratigraphy

The area covered by our reconnaissance survey is large, the succession spans much of the Triassic and Jurassic Systems, yet the data available were meagre. Even when samples were taken along traverse lines it was found impracticable to space stations at closer intervals than 0.5 n mile (*ca.* 0.9 km) and attempts at sampling were not always successful, due mainly to patches of superficial sand through which our gravity corer could not penetrate. Then, not all the samples recovered were stratigraphically useful, and those that were must be regarded as point samples

Some basic determinations on the core samples are tabulated in appendix I. Details of micro-faunal determinations are too voluminous to be included, and would be largely meaningless without proper palaeontological documentation, but the number of Foraminiferid species and Ostracod genera found in each sample have been quoted. Figure 7, plate 6, illustrates some representative foraminiferid faunas. It can be seen from this list that most of the clay samples yielded both foraminiferids and ostracods as well as recognizable fragments of macrofossils. The majority of stratigraphical determinations are based on foraminiferid determinations. In rare cases the ostracods proved to be of greater value, but, for the most part, they gave a similar, though less precise date, to that suggested by the foraminiferids.

In studying the foraminiferids the author responsible (A. J. L.) relied in the first instance on his general knowledge of the sequence of Jurassic faunas, but for three levels this estimate could be refined by the use of guide forms. For the Lower Lias, Barnard (1956, 1957) has described the zonal occurrence of variants in the *Ichthyolaria sulcata* and *Geinitzinita tenera* (*Lingulina* or *Geinitzina* auctt.) plexi and in many other papers has dealt with the sequence of faunas at this time. Lutze (1960) has described guide forms – foraminiferids and ostracods – from the Callovian and Oxfordian of northwest Germany, and the present author has dealt with the Kimeridge Clay foraminiferids (Lloyd 1959, 1962, and unpublished work). Of the scores of further papers that were consulted, only one deserves special mention – the classic work by Bartenstein & Brand (1937) on the Lower and Middle Jurassic Foraminifera of northwest Germany. No trace of microfauna was found in our rock samples which were thought to be of Triassic age on lithological grounds.

To complete the stratigraphical account, two further aspects had to be considered – litho-facies and thickness of the formations. Evidence for the former derives largely from the samples recovered, though for some areas sonographs yielded useful information (for example, the belt of strong echoes showing stone bands of the Oxford Sands on the southern flank of the Bristol Channel Syncline). Structural data was insufficient for reliable determinations of thickness, but in one transect across the southern limb of the Bristol Channel Syncline dip determinations from the Boomer runs allow some estimate to be made. A line of section was selected to the north of Ilfracombe (51° 21′ N, 04° 06′ W to 51° 15′ N, 04° 04.5′ W) so as to pass close to the few known dips where there were frequent samples. By means of strikes taken from the sonographs sample horizons were projected on to the line of section and a scale profile was

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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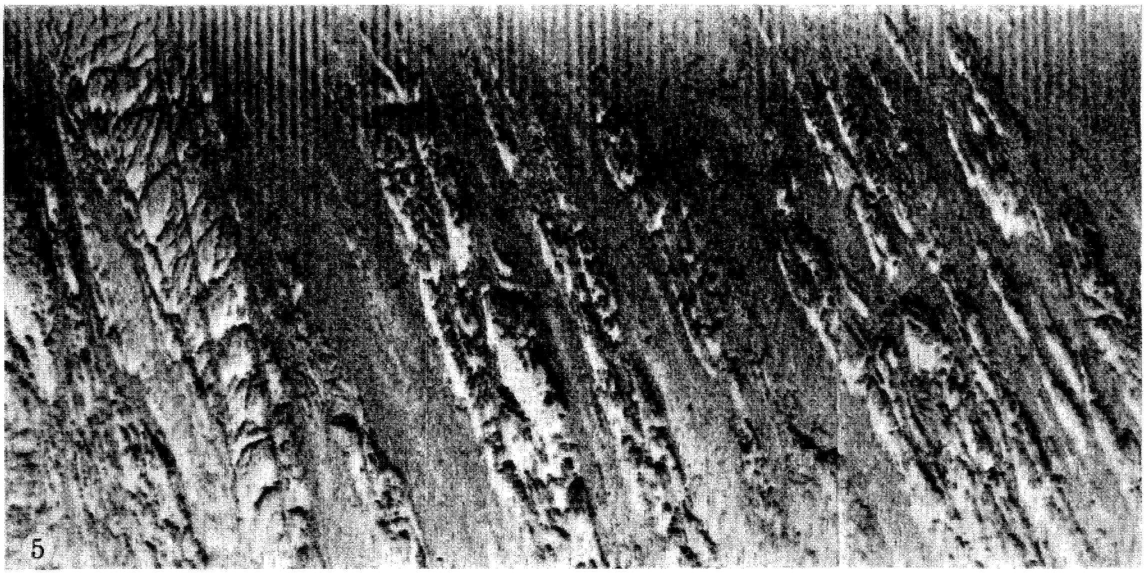

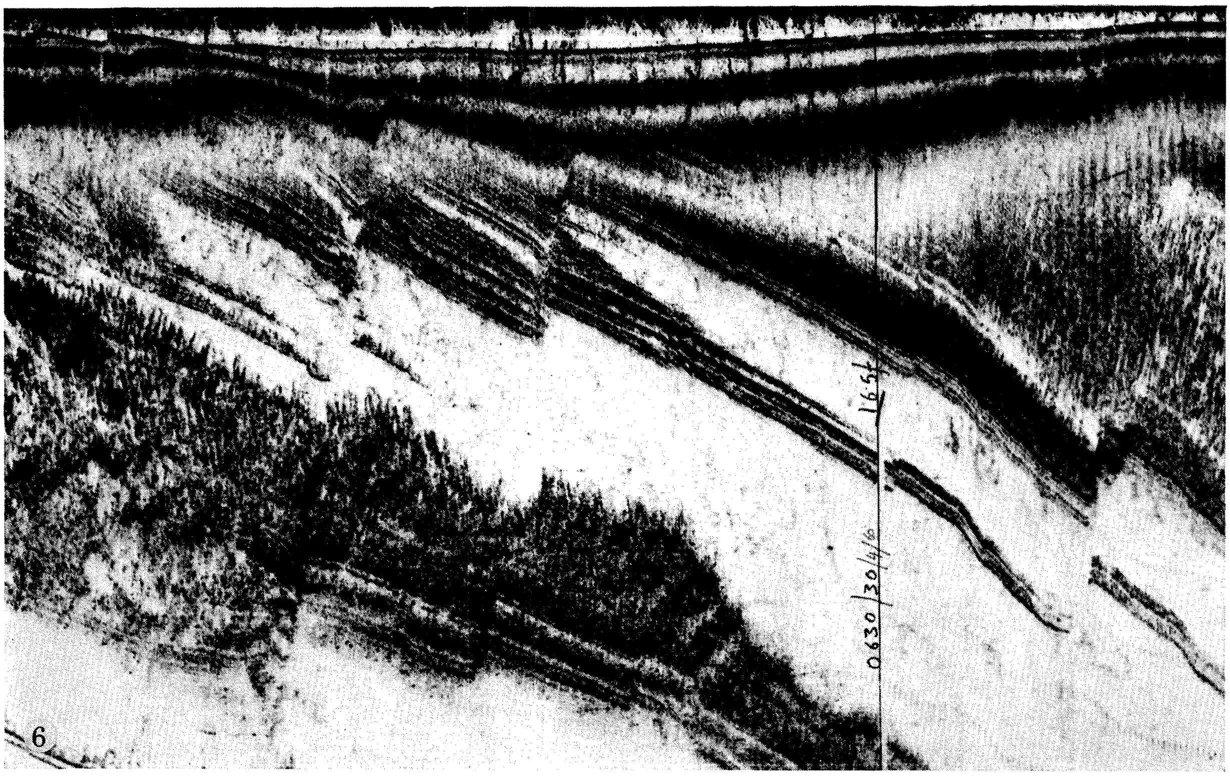

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FIGURE 5. An oblique view of an area of about 2.5 n mile (3.7 × 0.9 km) of floor situated 4.5 n mile (8.3 km) northwest of Hartland Point. The east–west strike is well shown by ridges of relatively hard rock, presumably sandstones, which are broken by fractures and have a Palaeozoic aspect. The intervening ground is smooth and is probably floored by softer slatey material. The mid-point of the upper edge of the sonograph is located at about 51° 04.9′ N, 04° 36.2′ W. Shadows are white.

FIGURE 6. An oblique view of an area of about $2\frac{1}{3} \times \frac{1}{2}$ n mile (4.3 × 0.9 km) of floor, with a 'horizon' (vertical profile) along the top. The mid-point of the profile is located at 51° 17′ N, 03° 47.3′ W, on the southern limb of the Bristol Channel Syncline, and 2 n mile (3.7 km) north of Foreland Point. Bold, east–west strike ridges of Liassic rocks, dipping north, cast long shadows (white) and are displaced by small north–easterly trending faults. The main thrust fault is located along the trench. Range exaggeration (top to bottom) is about $2\frac{1}{2}$.

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

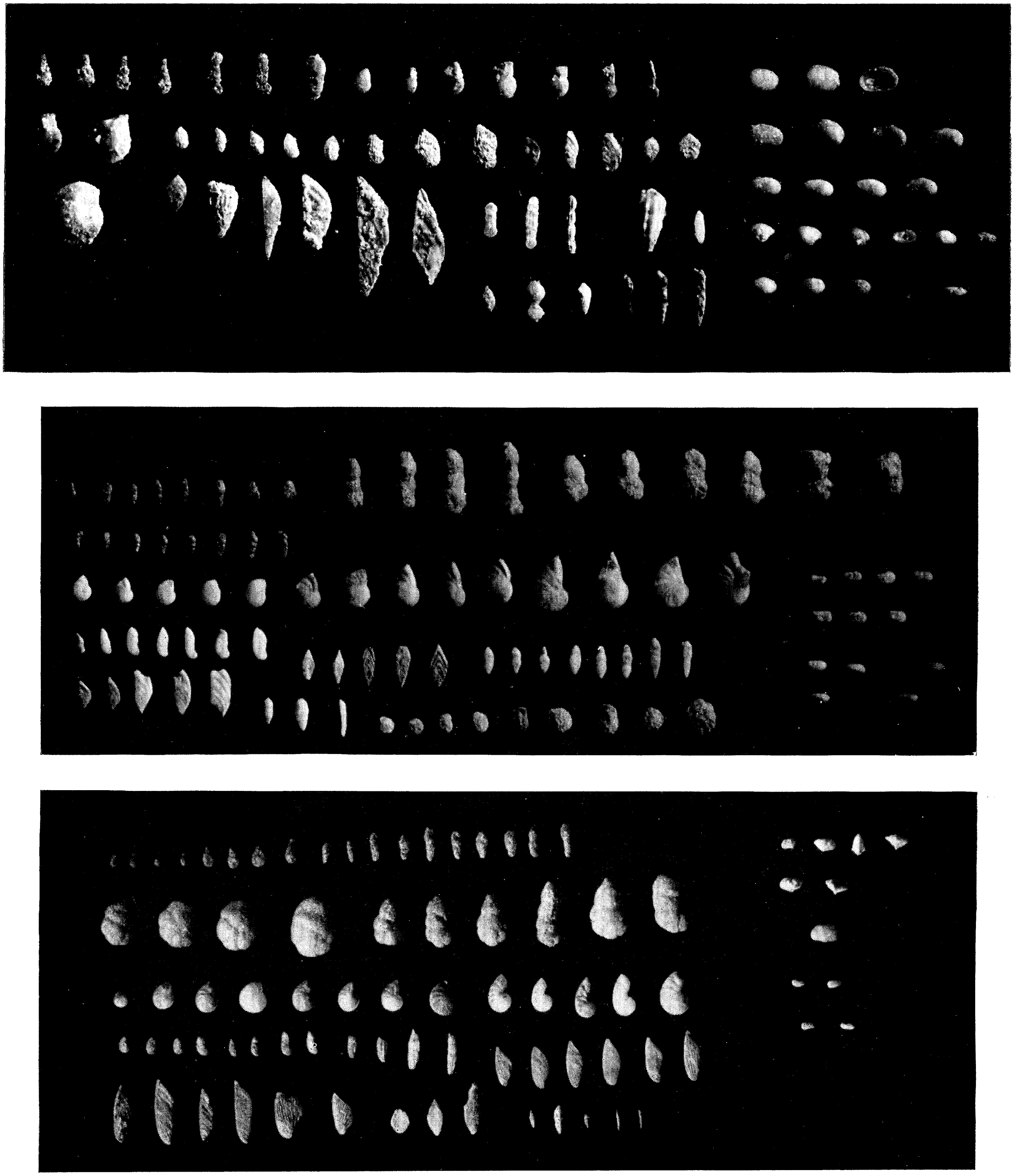


FIGURE 7. Representative microfossils from three samples of Jurassic rocks from the floor of the Bristol Channel. *Discovery* 4868 is Toarcian or Aalenian (upper group); *Sarsia* 125 is Callovian (middle group); *Discovery* 4340 is Kimeridgian, Mutabilis zone (lower group).

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

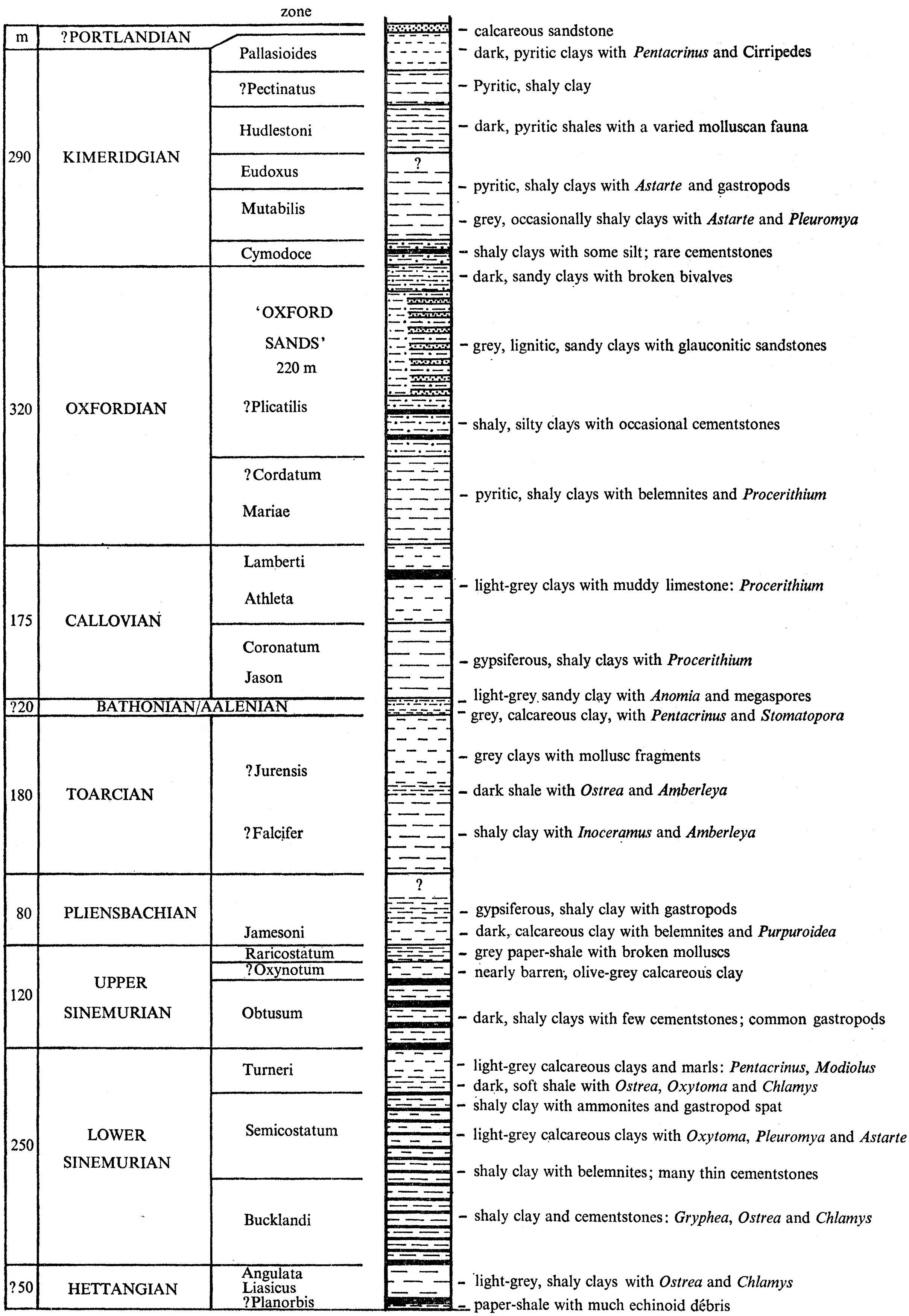


FIGURE 8. A generalized stratigraphical sequence of the Jurassic rocks found on the floor of the Bristol Channel.

constructed using the appropriate apparent dips. Topography was ignored since the maximum difference in depth below chart datum was only 11 m, a negligible quantity compared with other errors inherent in this method, particularly those stemming from the assumption of a regular change in dip between the known points. This assumption is patently not tenable when applied to the southern end of the section – it would give a thickness in excess of 680 m from the base of the Lias to the top of the Bucklandi zone, whereas Palmer (1972) has shown that these beds total only about 130 m at Watchet. A more serious error stems from the fact that the line of section crosses what is thought to be an important thrust fault whose throw cannot be determined in this area.

Despite these shortcomings, the estimates give an indication of the relative thicknesses of the Jurassic stages and formations which are unlikely to be far from the absolute thicknesses of these rocks and are in broad agreement with a geophysical estimate mentioned above and by Mr D. Hamilton (unpublished report at the Bristol Channel Symposium, May 1970). The total thickness of Mesozoic rocks present is probably in excess of 1800 m (215 to 275 m for the Trias, nearly 1600 m for the Jurassic).

A summary of the Jurassic stratigraphy of the area is given in figure 8, but this is subject to two sorts of inaccuracy – both stemming from the point-sampling approach. First, with the exception of hard bands such as cementstone horizons and sandstone bands that can be detected from sonographs, minor changes in lithology are unlikely to be observed. Secondly, with the techniques available it was impossible to distinguish between unconformities, periods of condensed deposition and abnormal contacts due to strike faulting. The rocks represent a thick but incomplete sequence of Triassic and Jurassic rocks ranging from Keuper to Kimeridge Clay.

(a) *The Triassic sequence*

Rocks of Triassic age were found in two areas close to the southern shore of the Channel. The westernmost area forms a belt of nearly constant width between Devonian rocks to the south and Lias to the north, suggesting that there is little variation in thickness, which is estimated as between 215 and 275 m. It emerges from beneath superficial sands some 5 n mile (9.2 km) northwest of Morte Point and appears to be uninterrupted, except for oblique faults, until it is obscured by gravels 2 n mile (3.7 km) north of Hangman Point. Most of the samples were of a red, silty clay reminiscent of Keuper Marl, but between 120 and 150 m above the base some Red Sandstones were obtained with Devonian pebbles near their base, a possible equivalent of the Dolomitic Conglomerate of areas farther east. Above these there comes the usual sequence of Keuper Marl, Tea Green Marls and Rhaetic Beds – grey shales and a buff siltstone reminiscent of the Westbury beds of Langport.

These rocks can be compared with the New Red Sandstone of west Somerset (Thomas 1940). At first there were two separate basins of deposition, the Cleeve lowland and the Vale of Porlock, in both of which locally derived rocks with coarse clastics were laid down. Later the two areas were united and 'Keuper', at first as sandy beds, and then as red marls, was laid down throughout. The red marls were followed conformably by Tea Green and Grey Marls and then by Rhaetic, and are probably of late Triassic age. No evidence for the earlier rudaceous series has been found offshore and it seems likely that the Triassic along the south flank of the Bristol Channel Syncline is to be correlated with the 'Keuper' of west Somerset.

The pebble deposits that constitute Foreland Ledge obscure the solid geology for up to 1.5 n mile (2.7 km) from the coast and some 10 n mile (18.5 km) along it. About half a mile

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

offshore from Glenthorne, Keuper Marl was collected by a diver and from this point Triassic rocks follow the WNW–ESE trending coast towards Porlock Bay, apparently flanking a minor pericline with Devonian rocks exposed in its core. A single sample (Dy 4376/2) is in the Red Sandstones, followed in normal sequence by Keuper Marl and Tea Green Marl. Keuper Marl samples were also taken in the Severn Estuary south of Newport and in Weston Bay.

(*b*) *The Jurassic sequence*

The most complete sequence is found in the Bristol Channel Syncline, whose core preserves Kimeridge Clay at least as young as the Pallasioides zone (*sensu* Casey 1967). Its more steeply dipping southern flank has few structural complications, apart from an important strike fault that in places brings Upper Sinemurian strata into contact with the Oxford Clay (figure 6, plate 5, and figure 9). A greater density of successful samples were taken in this region than

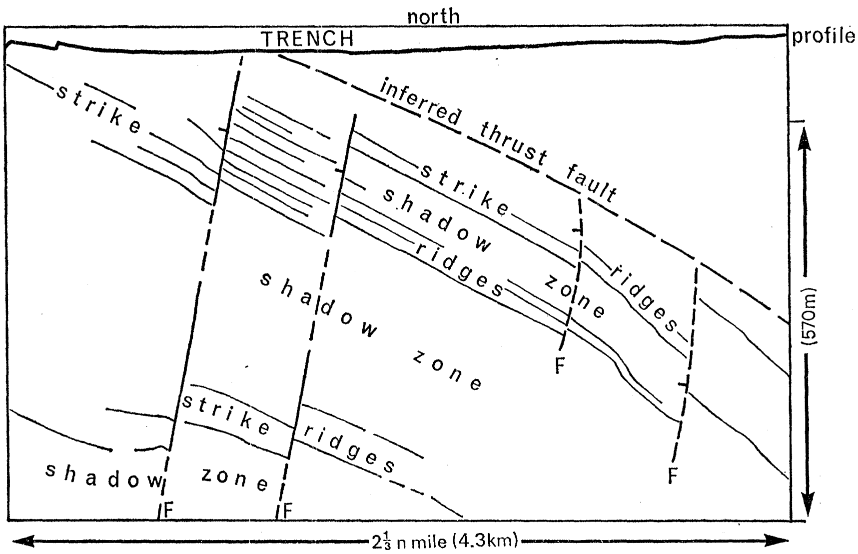


FIGURE 9. A geological interpretation of the sonograph shown in figure 6, plate 5.

anywhere else and the geophysical controls are good. For these reasons the following account is based largely on this area. The northern flank of this syncline is formed by a series of gentle flexures with dips rarely exceeding 5° and variable strikes (figure 10, plate 7). Here the base of the Jurassic is not seen, but Boomer records suggest that the Jurassic–Carboniferous boundary runs sensibly parallel to the axis of the syncline at a distance of some 7 n mile (13 km).

(i) *Lower Jurassic*

The lower part of the Lower Lias is unusually thick, amounting to 300 m for the Hettangian and Lower Sinemurian – which are developed in a facies closely similar to that of the Watchet cliffs (Palmer 1972). Calcareous clays with a prolific microfauna alternate with close-set cementstone bands as high as the top of the Semicostatum zone, the succeeding Turneri zone forming a featureless band on the sonographs below the widely spaced cementstones of the Obtusum zone. By contrast, Upper Sinemurian to Aalenian strata total only 230 m in thickness on the southern flank of the Bristol Channel Syncline, but Pliensbachian and some Toarcian Beds are not present here due to the thrusting.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The major strike fault on the southern flank of the Bristol Channel Syncline has largely cutout beds of Pliensbachian age. The Jamesoni zone, represented by dark calcareous clays, certainly occurs near the western limit of solid exposures and again on the axis at the eastern end of the syncline, but higher beds have not been dated with certainty. Some sandy clays in the core of the Glastonbury Syncline may be the local equivalent of the Middle Lias. The suggested thickness of 80 m for these beds was estimated from outcrop width at the eastern nose of the Bristol Channel Syncline. Unless there is a marked increase in plunge at this point, for which there is no evidence, this represents a dramatic decrease in thickness compared with equivalent beds around Brent Knoll.

The lower part of the Toarcian stage is developed in shaly clays with *Inoceramus* as the dominant bivalve and *Alaria* and *Amberleya* representing the gastropods. These are succeeded by grey clays, sometimes micaceous, with much comminuted shell material which is predominantly ammonite. This Upper Lias sequence is about 180 m thick. It is thus thicker than any development on land in the west of England and comparable to the thickness present in the Mochras Borehole in Cardigan Bay (Wood & Woodland 1968).

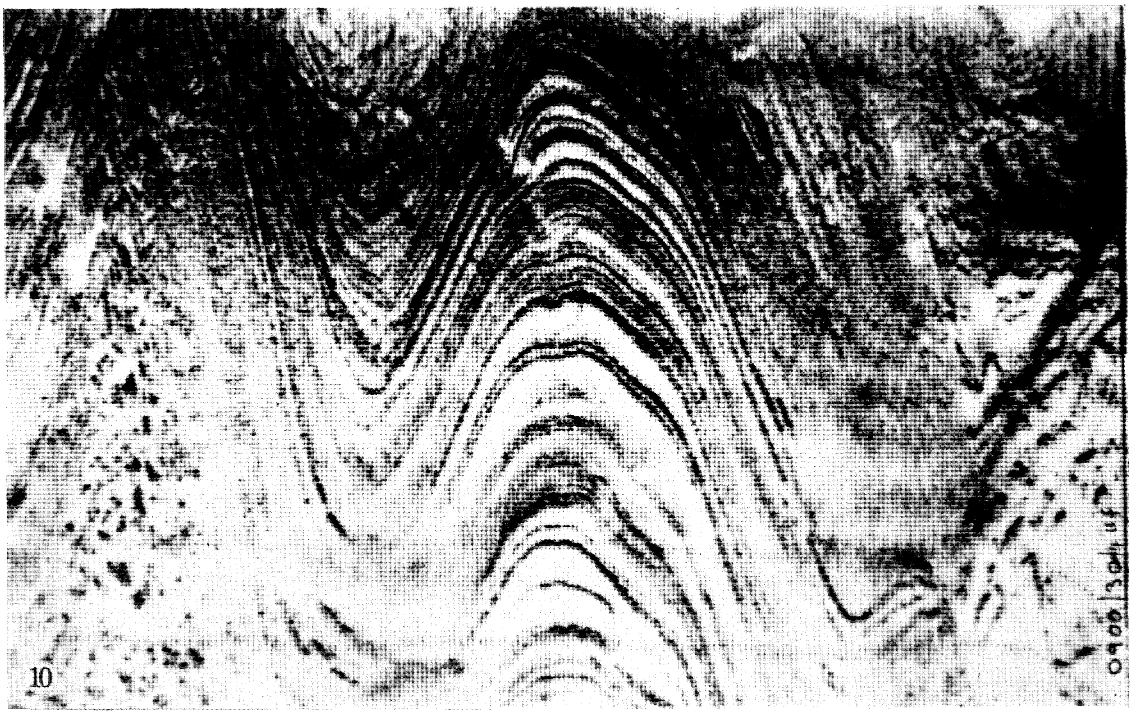
The total thickness of the Lower Jurassic beneath the Bristol Channel may be about 680 m, which is comparable with a value of about 540 m at Brent Knoll, near Burnham (figure 3), as indicated by recent boreholes (Whittaker 1972) and surface evidence.

(ii) *Lower Lias details*

Hettangian stage. Strata of Hettangian age were identified with certainty in the cores of two small periclines, one centred on a point some 10 n mile (18.5 km) WSW of Nash Point on the northern flank of the Bristol Channel Syncline, the other 5 n mile (9.25 km) north of Blue Anchor Bay. They are known to occur in the eastern part of the Channel, particularly around the Holms, but along the southern margin of the Bristol Channel Syncline their occurrence has not been established, although two samples barren of microfauna were taken so close to known Triassic outcrops that they are likely to be of this age. Dy 4363/3, taken 4.5 n mile (8.35 km) due north of Bull Point, was in a paper shale with wafer-thin limestone partings full of echinoid radioles and interambulacral plates. It bears a strong similarity to the paper shale found elsewhere in southern Britain at the base of the Lias. Sa 116, collected 1.5 n mile (2.8 km) north of Glenthorne, was a hard shaly clay with cementstone. It is on a strike with Dy 4374/1 (Tea Green Marls) so must be close to the base of the Lias. Its lithology can be matched best with that of the Bucklandi zone samples, suggesting the possibility that in the southern and western parts of the Bristol Channel the Hettangian Beds are overlapped, with the Bucklandi zone resting directly on Trias.

Close to the eastern end of the Bristol Channel Syncline four samples yielded abundant foraminiferids characteristic of the Angulata zone (Sa 135, 138, 188 and 189). The lithology was a light to medium grey clay, often shaly, but with few cementstone bands. The macrofauna was dominated by bivalves with *Ostrea*, *Protocardia* and *Chlamys* identified from young stages, while the echinoderms were represented by ophiuroid ossicles, echinoid radioles and pentacrinite stem ossicles. In addition, Sa 188, thought to be from near the top of the zone, yielded rare scolecodonts and cirripede plates. Sh 215 from near the Holms differed from the western samples in containing holothuroid spicules.

Lower Sinemurian. These beds, to which 27 samples can be assigned with confidence and a further four with less certainty, are known in more detail. Most of the samples come from the



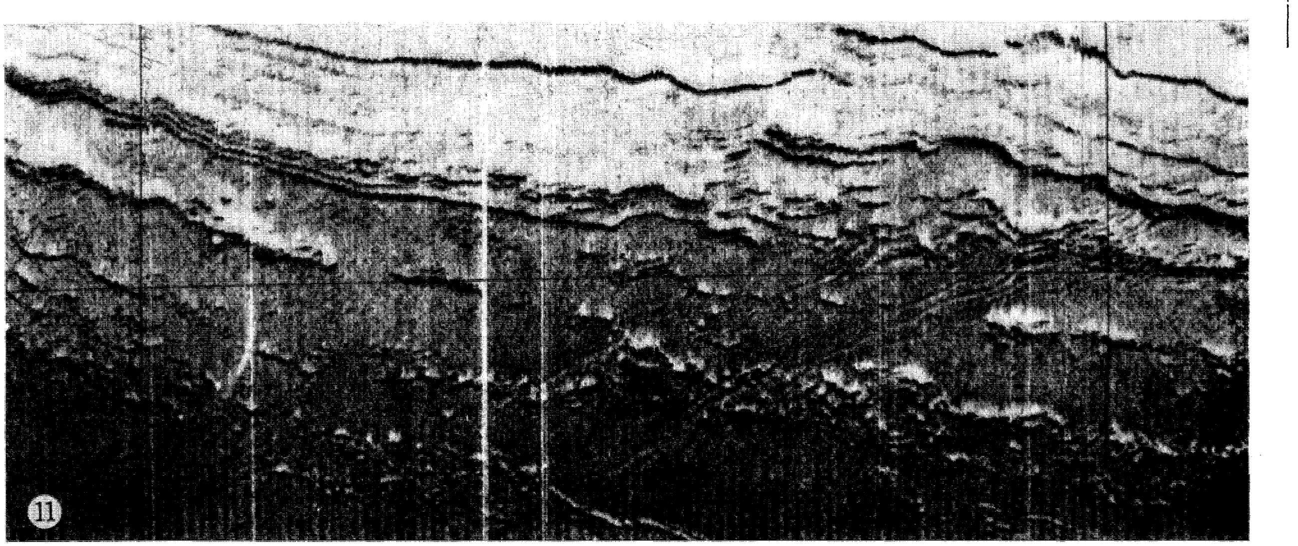


FIGURE 10. An oblique view of an area of about 1.8 × 0.3 n mile (3.3 × 0.6 km) of floor in the Bristol Channel, the mid-point of the upper edge of the sonograph being at about 51° 18′ N, 03° 19.4′ W, 5 n mile (9.3 km) south of Rhoose in southernmost Glamorgan. This pattern of wandering and broken outcrop lines shown by Sinemurian cementstones (whose scarp edges appear black) is typical of much of the northern and eastern parts of the Bristol Channel Syncline, where dips are low but there is some broad relief superimposed on that due to the hard layers. Range exaggeration (top to bottom) is about $2\frac{1}{2}$.

FIGURE 11. An oblique view of an area of about $1\frac{1}{3} \times \frac{1}{3}$ n mile (2.5 × 0.6 km) of floor, the mid-point of its southern edge being located at about 51° 19.2′ N, 04° 08.5′ W, 6 n mile (11.1 km) north of Ilfracombe. Thin layers of sandstone within the Oxford Sands strike east–west along the southern limb of the Bristol Channel Syncline. Some are continuous for more than a mile while others appear to be intermittent, probably because of their lesser resistance to erosion.

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

perimeter of the Bristol Channel Syncline where, on the northern flank, beds of the Bucklandi zone disappear under loose sands at the longitude of Lynton and those of the Semicostatum zone at the longitude of Ilfracombe. On the southern limb both the Semicostatum and Turneri zones have been found close to the western limit of exposures – the absence of samples from the Bucklandi zone here is thought to be due to collection failure as there is space enough for them to occur between known Semicostatum zone beds and the Trias and they are well developed only 6 n mile (11.1 km) to the east. As is the case with the coastal exposures in Glamorgan and around Watchet, the main development of cementstone bands occurs in the Bucklandi and Semicostatum zones. Side-scan sonar records commonly show many hard bands at these horizons, numerous gravity cores brought up cementstones and divers working north of Minehead described a typical Blue Lias sequence at this level. The dark coloured shaly clays or calcareous dicey clays of Bucklandi zone age yielded a macrofauna dominated by bivalves and echinoderms. Young stages of *Ostrea* and *Chlamys* were identified from every clay sample, usually accompanied by ophiuroid ossicles and, more rarely, echinoid radioles and plates. Dy 4866/4 contained the most varied fauna, yielding also ammonite nuclei and holothuroid spicules. It appears that towards both the base and the top of the Semicostatum zone dark shaly clays are developed. Dy 4301/2, obviously close to the base of the zone, is still in the dark shaly clays with the bivalve/echinoderm fauna that predominated in the Bucklandi zone. Sa 147 and Dy 4857/1 (that yielded the first belemnite of the sequence) were lithologically identical and Sa 101 and 168 differed only in their lighter colour, but all these samples contained *Geinitzinita tenera* Form D (Barnard 1956) showing that they belong high in the zone.

Between these shaly beds come a series of calcareous clays of medium to light grey colour which usually provide residues with abundant shell fragments. Most samples contained many ophiuroid ossicles and echinoid radioles, but only in Dy 4338/1 were crinoid ossicles found. Dy 4303/1 was particularly rich in echinoderm debris, which included keeled teeth and fragments of Aristotle's lanterns besides the usual radioles, and it also provided the first terebratulid of the sequence. While the echinoderms are like those from samples of older rocks, there seems to have been a change in the bivalves – identifiable genera including *Pleuromya*, *Oxytoma* and an *Astarte*-like form. Sa 132, a light-coloured shaly clay thought to be high in the zone, contained ammonite nuclei and a young asteroid. Finally, Dy 4338 had abundant gastropod spat, of rare occurrence before the Upper Sinemurian in other Bristol Channel samples, though one Turneri zone sample yielded many naticoid early stages.

The Turneri zone samples were found in areas of smooth floor stratigraphically below which sonographs show many stone bands and stratigraphically above which there are some widely spaced stone bands (probably Obtusum zone). The main lithologies encountered were a dark-coloured soft shale with *Chlamys* and echinoid fragments (Sa 155 and 187, the latter with cirripede plates) which possibly underlie a sequence of lighter coloured calcareous clays and marls with *Modiolus* and terebratulids. Ophiuroid and pentacrinite ossicles together with ammonite nuclei and fragments of *Ostrea* and *Oxytoma* were found in both lithologies. With one exception all samples yielded prolific microfaunas. The Turneri zone age is indicated by developments in both the *Geinitzinita tenera* and *Ichthyolaria sulcata* plexi, but these were invariably accompanied by *Planularia inaequistriata* which, according to Barnard (1960, p. 46), died out in the Semicostatum zone.

Upper Sinemurian. This period is documented by fewer samples than the lower part of the stage, but is known or presumed to occur over much the same area. It was found on both flanks of the Bristol Channel Syncline and both north and south of the Glastonbury Syncline axis. The Obtusum zone was represented by dark shaly clays yielding a characteristic microfauna and traces of macrofauna that show significant differences from that of lower beds. While the echinoderm remains were similar to those found in older samples, the only bivalves that could be identified were species of *Oxytoma* and for the first time in this Jurassic sequence gastropod nuclei become common. Forms close to *Natica* and *Procerithium* were found together with some pupate forms.

Sonographs in the vicinity of known Obtusum zone samples commonly show some isolated ridges thought to indicate the presence of cementstones. Dy 4297/1, a dark cementstone, was taken from one such feature 4.5 n mile (8.3 km) south of Llantwit Major. These features have been found along the southern flank of the Bristol Channel Syncline to the north of Turneri zone samples (Dy 4878/1 and Sa 117 and 155). On the northern flank they occur adjacent to Dy 4858/2 of known Obtusum age, and it is thought that records farther west on the same strike may be in these beds. Evidence for the occurrence of this zone in the seaward end of the Glastonbury Syncline is not so clear. Sh 211, a shaly clay with pupate and naticoid gastropods, contained few foraminiferids indicative of an Upper Sinemurian age. Sh 210, taken 0.1 n mile (185 m) to the east must be of a similar age if no faulting is present, but was in a different lithology – a barren olive-grey calcareous clay that could be matched with Sh 462 and 463 taken 3.5 n mile (6.5 km) due north of Great Hangman in the southern limb of the Bristol Channel Syncline. These three samples may represent the Oxynotum zone and if so are the only record of it.

Dy 4296 taken from mid-channel between Llantwit Major and Minehead is the sole sample suggesting the presence of Raricostatum zone beds. The rock is a grey, micaceous paper shale with a macrofauna of gastropods, ammonite nuclei, bivalves (including *Astarte*) and echinoid fragments. The microfauna consisted of ostracods and a foraminiferid fauna of 8 elements. *Geinitzinita tenera* Form B (Barnard 1956, pp. 276, 280) is a long-ranging form, but recorded as the sole variant of the plexus through most of the Raricostatum zone. The *Ichthyolaria sulcata* variant – Form G of Barnard (1957) – has a range from the top of the Semicostatum zone to the Davoei zone, but the occurrence of a lingulinid element of *L. cernua* type suggests a late Sinemurian age.

Lower Pliensbachian. Beds of this age are represented by two samples of contrasting lithology and fauna. Dy 4879/1 from the western end of the Bristol Channel Syncline was a dark grey calcareous clay with abundant, mainly bivalve, shell fragments, young terebratulids, crinoid ossicles and echinoid spines. Microfossils were abundant and varied. The foraminiferid fauna of 22 elements presents some puzzling features, but the presence of *I. sulcata* Form K and *Lenticulina rectalonga* point to a Jamesoni zone age. Sa 103 from the eastern end of this syncline was a grey shaly clay yielding gastropods of *Purpuroidea* type, ammonite nuclei, belemnites, echinoid radioles and plates and fish teeth. No ostracods were found, but the few foraminiferids included *Lenticulina muensteri* and *Involutina liassica* suggesting a Jamesoni zone age or younger.

Upper Pliensbachian. It is unfortunate that the age of Sa 103 could not be determined more precisely as 1 n mile (1.85 km) to the east, down plunge, undoubted Toarcian Beds were found (Sa 106) and between these two came the problematical Sa 105 – a grey shaly clay with much gypsum, yielding *Procerithium* and echinoid radioles but no microfauna. This lithology is not very different from the green-grey sandy clays (Sh 503 and 504) with fragmentary bivalves found 9.7 km west of Burnham on the axis of the Glastonbury Syncline. If, as the present author (A. J. L.) suspects, these samples are of Upper Pliensbachian age, they are in a facies unusual for this country, but known from Lorraine, Luxembourg and Northern Germany. Dy 4868/5 of Opalinus zone age has similar geographical affinities.

(iii) *Upper Lias details*

Toarcian stage. Of the five samples thought to represent this stage two are from the northern limb of the Bristol Channel Syncline and the other three from its eastern end. No Toarcian samples were recovered from its southern limb (probably due to the thrust), though an Opalinus zone sample was taken north of Ilfracombe. The lower part of the stage – possibly of Falcifer zone age – consists of shaly clays with some shell fragments. Sa 106, taken close to the axial trace of the Bristol Channel Syncline north of Porlock Bay, yielded a macrofauna of ammonite nuclei, *Inoceramus* and gastropods, represented by young stages of forms close to *Alaria* and *Amberleya*. The microfauna of both foraminiferids and ostracods comprised few elements, but the occurrence of *Lenticulina orbignyi* is indicative of an age no older than Toarcian and the rest of the microfauna was consistent with this determination. Sa 145, 1.25 n mile (2.3 km) to the northeast, was a micaceous shale with *Ostrea*, *Amberleya* and echinoid radioles, but no microfauna. Higher in the stage the lithology changes to a grey clay, sometimes micaceous, with comminuted ammonite or bivalve shell fragments. Sa 107, from the eastern end of the Bristol Channel Syncline, contained a small microfauna in which *Lenticulina muensteri*, *L. subalata* and *Rectoglandulina vulgaris* predominated. The most prolific fauna came from Sa 185, taken on the northern limb of the syncline. Macrofossils present were bivalves including *Ostrea*, ophiuroid and echinoid ossicles. The foraminiferids included *Lenticulina orbignyi*, *Frondicularia lignaria* and *F. bisulcata*. Sa 171, from 5 n mile (9.2 km) to the west of the last sample, contained a similar microfauna and a macrofauna of spat – an *Astarte*-like form representing the bivalves; *Procerithium* and *Pleurotomaria* the gastropods.

(iv) *Middle and Upper Jurassic*

Aalenian–Bathonian stages. The only evidence of pre-Callovian Middle Jurassic rocks in the Bristol Channel came from two localities north of Combe Martin Bay on the southern limb of the syncline and one on the northern limb. Dy 4868/5 was a grey, micaceous, calcareous clay with comminuted ammonite shell. Echinoderms predominated in the macrofauna – pentacrinite ossicles, ophiuroid ossicles, echinoid plates and radioles. Stomatoporoid bryozoa and unidentifiable bivalves also occurred. The varied foraminiferid fauna (at least 18 species) included *Lenticulina orbignyi*, *Falsopalmula deslongchampsi*, *Citharina harpa* and *C. colliezi*. Though, in general, this fauna bears a close resemblance to that of the Opalinuston of northwest Germany, the affinities of both are clearly with the Toarcian fauna, and thus the possibliity of a late Toarcian age cannot be excluded.

Sa 196, from 4.5 n mile (8.3 km) due north of Great Hangman, is badly placed close to one of the major tear faults of the area and no reliably dated sample was taken within 1.5 n mile (2.8 km) of it. From its geological setting it must be of post-Sinemurian/pre-Oxfordian age and, if the strike projections are accurate, should represent beds in the otherwise unknown Opalinus zone/Jason zone interval. The six element foraminiferid fauna is not inconsistent with this attribution, but does not permit precise dating. By contrast, the ostracod fauna examined by Dr R. H. Bate was placed by him as 'certainly Bathonian, most probably Upper Bathonian'. Lithologically the sample is similar to some from the Oxford Sands – a light grey, sandy clay with much lignite – but the commonly occurring megaspores (identified by Dr Marjorie Muir as *Horstisporites areolatus*) again confirm its Middle Jurassic age. The macrofauna included ophiuroid ossicles, steinkerns of pupate gastropods and juvenile *Anomia*. While undoubtedly marine in origin, this sample represents a much shallower and more near-shore episode than those stratigraphically adjacent to it: an indication that the 'Bathonian regression' affected the Bristol Channel area. Dy 4859/1 from the northern flank of the syncline contained no fauna but is lithologically identical to the previously described sample. It could belong to the Oxford Sands, but for this to be so there must either be an anticlinal flexure or a fault downthrowing north, for neither of which is there any evidence.

The total thickness of Aalenian to Bathonian strata can be little more than 20 m. The lignitic Bathonian sandy clays are succeeded by Oxford Clay in normal development – shaly clays of Middle Callovian age followed by clays and shaly clays of Upper Callovian and Lower Oxfordian age (together about 275 m). The Corallian Beds of the English mainland are represented here by a sequence of sandy clays with common sandstone bands – the Oxford Sands – which are for the most part highly lignitic and devoid of recognizable fossils. However, the lower part with occasional cementstone bands has yielded an ostracod fauna that might be of Plicatilis zone age and the uppermost few metres, darker in colour and less lignitic, contain a poor foraminiferid fauna of Sandsfoot Beds aspect. The complex is some 220 m thick.

The Kimeridge Clay is similar to that of the Dorset coast. The lowest beds are shaly clays with some silt, passing up into the pyritic shaly clays of the Mutabilis and Eudoxus zones. Pyritic shales of the Hudlestoni zone are followed by shaly clays and then clays with a Pallasioides zone foraminiferid fauna. Where the Bristol Channel Syncline is at its deepest, a single sample (Sa 149) of calcareous sandstone was recovered. If this represents beds in place, they are likely to be either youngest Kimeridgian or an equivalent of the Portland Sand. The total thickness of the Kimeridge Clay is about 290 m.

(v) *Callovian–Kimeridigian details*

Strata of an age equivalent to the Oxford Clay and Corallian Beds of the mainland are represented in the present area by Oxford Clay – mainly shaly clays of Jason to Mariae zones – succeeded by the Oxford Sands from which few stratigraphically useful fossils were recovered. Oxford Clay samples were found as far west as the longitude of Ilfracombe; the Oxford Sands, which show up as a group of strong echoes on the sonographs (figure 11, plate 7), could be plotted a further 10 n mile (18.5 km) to the west before being obscured by superficial sands. These features could be traced with few interruptions for some 25 n mile (46.3 km) eastwards along the southern flank of the Bristol Channel Syncline to a closure almost due north of Glenthorne. From this point they could only be traced back westwards along the northern flank for 6 n mile (11.1 km). It is thought that the disappearance of these features reflects a facies change from a sequence with sandstone bands to one of sandy clays alone.

Oxford Clay. The lowest horizons sampled were in gypsiferous shaly clays with common bivalves (*Oxytoma* and *Anomia* could be recognized), procerithiid gastropods and echinoderm ossicles. Holothuroid spicules of both the *Chirodotites* and *Achistrum* types occurred. Ostracods were not common, but the prolific foraminiferid faunas indicate a Middle Callovian age for these beds. Sa 118 is of Coronatum zone age, while the occurrence in Sa 165 of *Lophocythere caesa* and *Citharina proxima* suggests a Jason zone age. These shaly clays are succeeded by light-coloured clays in which the macrofauna is much as before, but the poorer foraminiferid faunas indicate an Upper Callovian age. Sa 119 and 163, from the southern flank of the syncline, are probably from the Athleta zone while the larger fauna of Sa 125 is either from the Lamberti zone or the lower part of the Mariae zone. On the northern flank Dy 4873/3 yielded an undiagnostic, though probably Callovian, foraminiferid fauna, but the ostracods, particularly *Lophocythere cruciata*, *Monoceratina* and *Marslatourella* point to an Upper Callovian age. Sa 182, a grey muddy limestone associated with an isolated feature, seen on sonographs, is at a comparable horizon. Could this be the Lamberti Limestone? The overlying highly pyritic shaly clays yielded good foraminiferid faunas of Mariae zone age (represented by Sa 120 and Sh 465). In both the macrofauna is dominated by *Procerithium*, but dysodont bivalves and juvenile belemnites also occur.

Oxford Sands. On both flanks of the syncline this sequence begins with light-coloured shaly clays, often with much fine-sand to silt grade quartz, and occasional fawn cementstones (Sa 126). The macrofauna is dominated by bivalves, although Sa 177 was clearly taken in a crushed ammonoid bed. Few foraminiferids were found and all were long-ranging species, but the ostracod fauna of Sa 181 (*Macrodentina*, *Eocytheropteron* and *Paracypris*) is indicative of an Upper Oxfordian age. No microfauna was found in the succeeding beds and traces of macrofauna were rare; occasional bivalve fragments and ophiuroid ossicles. These beds consisted of grey sandy clays with much lignite and, along the southern flank of the syncline, there were fine-grained glauconitic sandstones. Sa 148 from the northern flank of the syncline south of Oxwich Point was a fawn, sandy, glauconitic limestone with lignite, that lies on a strike with the Oxford Sands. The sequence ends with a series of dark grey sandy clays with thin glauconitic limestones. These contain broken bivalves and a poor fauna of foraminiferids similar to that from the Sandsfoot Beds of Dorset.

Kimeridge Clay. These, the youngest beds found in the area, occupy the core of the Bristol Channel Syncline. In its western part the sequence has been proved from the Cymodoce zone to the Pallasioides zone (*sensu* Casey 1967), but to the east of the Woody Bay fault only Lower Kimeridgian beds were found except for one sample of Hudlestoni zone age. The lowest beds sampled were grey clays, sometimes shaly, with a sandy or silty residue. The macrofauna consists mainly of bivalves with common *Astarte* and *Pleuromya*. The foraminiferid faunas clearly show that these beds are of Cymodoce zone (Sa 150) and lower Mutabilis zone (Dy 4861) age. Sa 130, the most easterly Kimeridgian sample recovered, included fragments of a grey cementstone not unlike those of the Baylei/Cymodoce zone junction in Dorset (unpublished observation by A. J. L.). The succeeding beds are pyritic shaly clays with numerous small *Astarte* and nuclei of *Procerithium*. The foraminiferid faunas are prolific, particularly in the lower part where they clearly indicate a position high in the Mutabilis zone (Dy 4340 and Sa 178) and in the lower part of the Eudoxus zone (Dy 4862 and 4863).

The next beds seen are a series of dark pyritic shales with a varied macrofauna comprising mainly molluscs, although echinoderms are also common. In Dy 4864, 17 species of foraminiferids were found of which four are characteristic of the Hudlestoni zone, yet this sample occurs only a few metres higher in the succession than undoubted Eudoxus zone (Dy 4863). Sa 159 has a similar lithology and macrofaunal content but the poorer foraminiferid fauna included only *Saracenaria prolata* as a zonal guide. There can be little doubt that this, too, is of Hudlestoni zone age and it is also abnormally close to Lower Kimeridgian beds. Of the alternative explanations for this the responsible author (A. J. L.) is not inclined to accept that there is a stratigraphical gap. Ziegler (1962) has demonstrated the persistence of the Autissiodorensis zone throughout Europe and the Elegans zone (equivalent to the Gravesia zones) is equally widely developed. However, neither of these zones has been recognized to date in the Weymouth Bay sections of the Dorset coast (a point currently under investigation by A. J. L.) and the possibility that these zones thin out to the west cannot be discounted. The other explanation, a postulated thrust or reverse fault to the south of the synclinal axis is at least consistent with what is known of the structure of the area. Closely spaced sampling in Kimeridgian rocks of the northern flank of the Bristol Channel Syncline should allow a decision to be made between these alternatives, but unfortunately the most suitable area geologically, west of the Woody Bay Fault, is locally obscured by banks of superficial sand.

There are indications that the sequence is uninterrupted from the Hudlestoni zone to the Pallasoiides zone. Pectinatus zone foraminiferids tend to be less diagnostic than those of preceding and succeeding strata, yet Dy 4875 – a dark pyritic shaly clay, yielded a poor foraminiferid fauna that could be matched with that from the Dorset coast. The Pallasioides zone, including Cope's zone of 'Pavlovia sp.', consists of pyritic grey clays with a varied fauna including common pentacrinite ossicles and cirripede plates as is the case with samples from Hounstout. The foraminiferid faunas of Dy 4876 can be matched with faunas from the upper part of the Crushed Ammonoid Shales of Dorset (the Pallasioides zone in Cope's restricted sense), while Dy 4885 yielded an assemblage usually found near the middle of this formation.

It is, perhaps, significant that the Jurassic succession ends close to the Rotunda Nodule/Upper Lydite Bed horizon that Casey has shown to mark a period of condensed deposition across south central England. Sa 149, a calcareous sandstone may not have been in place, but if it were it must represent beds close to the Kimeridgian/Portlandian boundary.

(*c*) *Interpretation of the Jurassic stratigraphy*

The Jurassic sequence outlined above differs from those found on the adjacent land in one important respect. With the exception of cementstone bands there is a conspicuous lack of carbonate rocks in the sequence and, indeed, those periods of predominantly limestone deposition in the rest of southern England have not been recognized in the Bristol Channel. If we regard these limestone periods as representing times of comparatively low sea level and consider also the other shallow water episodes, the correspondence with gaps in the Bristol Channel sequence is remarkably good. The Middle Lias, the Inferior and Great Oolites, the Kellaways Beds and the Portland Beds all fit, but there is an equivalent of the Corallian episode in the Oxford Sands. The conclusions one might draw from this is that throughout the Jurassic the Bristol Channel area stood at a higher level than the rest of southern and central Britain, but this poses the problem of why those parts of the sequence that are represented should be as thick or thicker than their counterparts on the adjacent land and why they are not in a shallower water facies.

A second point to be made at this time is also palaeogeographical, but in a more parochial sense. It has for long been suspected that in Mesozoic times there were persistent land areas to both north and south of the Bristol Channel. The occurrence of a northern shore line, except for the well-known islands in Glamorgan, has recently been questioned (Wobber 1966; Owen 1968) and for the southern shore there is little direct evidence. It was hoped that the present study would throw some light on this problem and might even provide concrete evidence for or against the existence of a Cornubian land mass in Mesozoic times, but the results were largely inconclusive. Rocks of Lower Lias age are known from many areas in the Bristol Channel. Some are within a few kilometres of the high North Devon hills, others are in mid-Channel, far removed from any source of detrital material, yet everywhere the facies is uniform for a given horizon. For any visitor to the Glamorgan Coast who has observed the rapidity with which the Lias passes from a shore-line conglomerate into normal 'offshore' Blue Lias, the absence of a littoral facies in the submarine samples might be expected. The same is true for the other 'high sea-level' deposits; it is only with the sole 'low sea-level' formation preserved in the area – the Oxford Sands – that traces of a facies change have been found. These do, however, suggest the presence of a source area to the south. Along the southern margin of the Bristol Channel Syncline the Oxford Sands are thick and include a high proportion of sandstone bands compared with the sandy clays that make up most of the formation. These sandstones form a conspicuous group of features detected by side-scan sonar and traceable with few gaps from the western extremity of the syncline along its southern margin to the point where they are carried round by the plunge into the northern limb. However, they can only be traced back along the northern limb for 6 n mile (11.1 km) and, still farther to the west, the formation thins to about half its former thickness. It may be no coincidence that the sandstone groups are found no further north than latitude 51° 20′ N, a line running parallel to the present coast and, it is suggested, to the Jurassic coast also.

7. Mouth of the Severn

The islands of Steep Holm, Flat Holm, the Wolves (1 n mile (1.85 km) WNW of Flat Holm) and Denny Isle are known to be made of Carboniferous Limestone. Dolomitic Conglomerate, of Triassic age, is exposed at low tide at the western side of the wave-cut platform of Denny Isle (Strahan & Cantrill 1912, p. 26; Smith & Willan 1937). We have found no geological account of the Monkstone, 2 n mile (3.7 km) north by east of Flat Holm, or of Cockburn Rock in King Road about 1 n mile west of Avonmouth which is often covered by sediment.

There has been little exploration of the neighbouring sea floor. Keuper Marl was taken both 3.5 n mile (6.5 km) west of the Palaeozoic rocks of Clevedon and 1 n mile NNW of Brean Down (Sh 41 and 16, respectively). Echo-sounder records between Steep Holm, Flat Holm and Avonmouth, south of the large sand banks known as Cardiff and Middle Grounds, indicate a rock floor. Between Steep Holm and Flat Holm and for a mile to the northeast side-scan sonar revealed a floor of well-bedded strata with a low dip, tentatively equated with the Mesozoic rocks found in the outer part of the Bristol Channel. The English Grounds are taken to be a rock surface planed off by the sea to its present depth of about 4 m below low-water spring tides, but has not been sampled. In conclusion, the fragmentary evidence about the floor of the upper reaches of the Bristol Channel is in keeping with that occurring farther seaward, although here conglomerate is locally seen around the Palaeozoic rocks.

8. Igneous rocks

Horseshoe Rocks, about 6.4 km northwest of Ilfracombe, comprise an exceptional and localized group of rugged shoals, with a least depth of 9 m below low-water level, rising from a flattish sea floor of Upper Palaeozoic rocks at around 26–35 m. A contoured plan based on a detailed Hydrographic Department survey is shown in figure 12. Palaeozoic rock (Ilfracombe Beds) was cored about 1 n mile (1.85 km) to the southwest and New Red Sandstone was cored about 1.5 n mile (2.8 km) to the northwest of the Horseshoe Rocks. Two of the dredge hauls

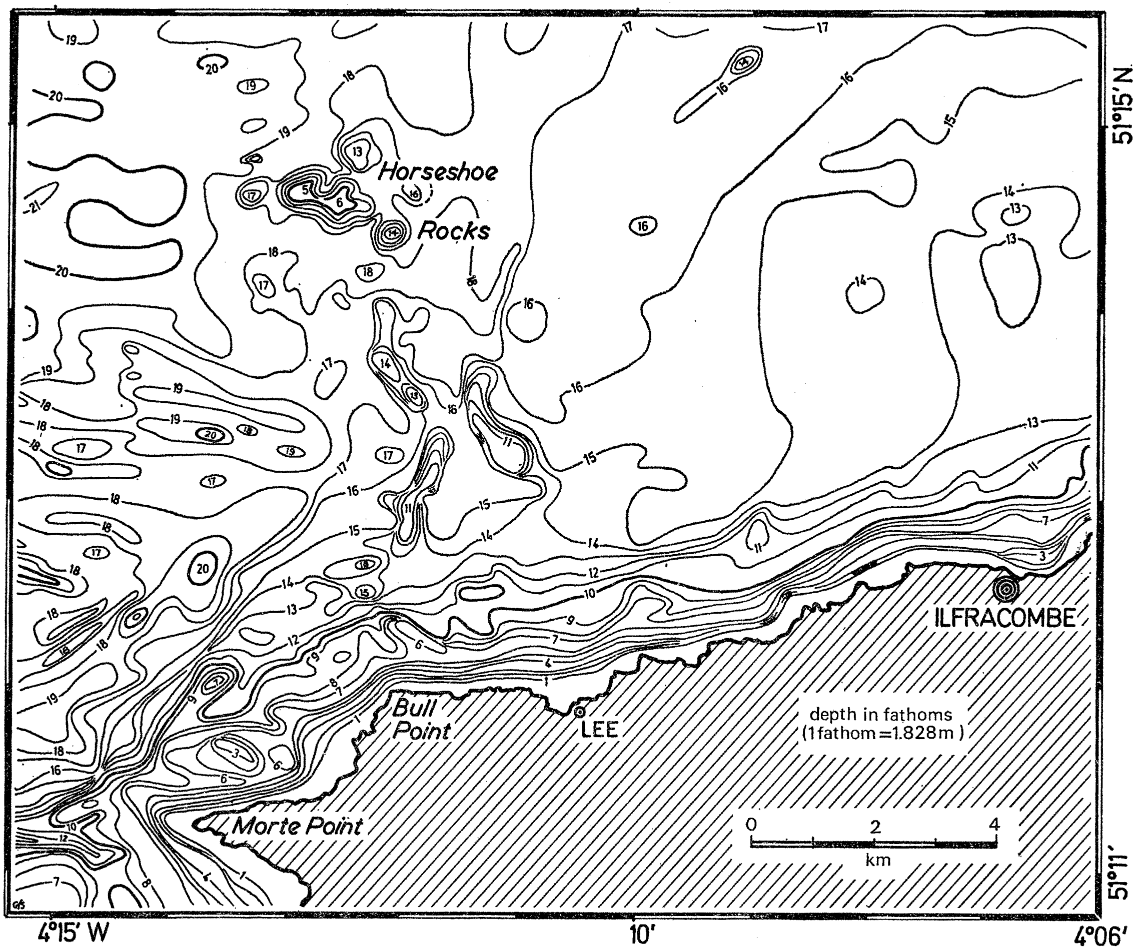

FIGURE 12. The relief of the Horseshoe Rocks 4 n mile (7.4 km) northwest of Ilfracombe (based on a survey made by the Hydrographer), which are interpreted as dolerite intrusions.

over these Rocks yielded several hundred specimens each (Dy 4378/2 and 4378/4). Three of the dredgings (Dy 4378/1, 4378/3 and 4382) yielded roughly 20 to 100 specimens each. Two stations (Dy 4372 and 4381) gave very small yields with less than 20 specimens.

Basic igneous rock occurred in all seven hauls, varying from 30 % of the total (Dy 4378/2) down to a few specimens; sedimentary rocks were present in all save one. Dy 4381 was the most remote from the Horseshoe Rocks, 1.5 n miles to the southeast; it yielded only a single pebble of a carbonated lamprophyric rock. Dy 4382 lay about 0.5 n mile (0.9 km) to the northeast and yielded a granite boulder together with a suite of sedimentary rocks, mainly grits and four pieces of Carboniferous Limestone. The remaining five hauls were all located close together on the Horseshoe Rocks and all contain igneous and sedimentary rocks.

The igneous rocks recovered show some variation, but all may be described as dolerites. In hand-specimen they are green in colour due to the presence of chlorite. Most of the specimens show obvious signs of having been sheared. Four examples were sectioned and the following provisional account is based on notes kindly supplied by Dr M. K. Wells. The felspar is fairly fresh plagioclase in randomly orientated laths. Possible Carlsbad-twinned orthoclase was detected in one section. Augite, originally ophitic and coarsely crystalline, has been extensively altered

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

to a pale-brownish chlorite mineral of moderate birefringence. This mineral also extends, independently of the augites, as interstitial patches, along micro-shears, and as veins. A second chlorite or serpentine mineral, very pale green and sensibly isotropic, is also present in these latter habitats. Calcite also extensively replaces the coloured minerals and to a lesser extent the plagioclase. It is particularly concentrated in veins and in parts of the rocks which have suffered the most intensive shearing and brecciation. The next most abundant secondary mineral in one section is (?)clinozoisite, occurring as granular aggregates of minute crystals which have obviously grown at the same time as the chlorites. Leucoxene is conspicuous in the same section, replacing ilmenite, but in another specimen the ore minerals are fresh and unaltered. All the sections are extensively sheared and since one shows clear evidence of low-grade (greenschist) regional metamorphism, it is probable that the other specimens sectioned have also been metamorphosed, though with very little effect on the felspars.

The isolated occurrence of a restricted range of igneous rock types in the vicinity of a group of isolated shoals, which are completely different in form to the floor made of sedimentary strata elsewhere in the Bristol Channel, strongly suggest that the igneous rocks are derived from the shoals. The presence of numerous, large (100 mm) subangular blocks in one dredge haul makes it highly probable that this haul was collected very near to an outcrop, probably on a scree below it. Accordingly, the Horseshoe Rocks are provisionally interpreted as a series of minor intrusions, individually of small size, but extending along a zone about 1 n mile (1.85 km) long, roughly parallel to the strike of the Devonian country rocks. In addition, three elongated, sharp relief features located between Horseshoe Rocks and the coast and of comparable size to the former shoal, may also be due to igneous intrusions. They have not been sampled.

If the rocks are intrusive, they must be younger than the Middle Devonian country rock. On this basis they are believed to be Upper Palaeozoic intrusives which were sheared and slightly metamorphosed during the Armorican orogeny. Basic intrusions, which would fall into this general category, are common in south Devon and Cornwall, but rare in north Devon. A very rotten alleged lamprophyre at Fremington Pill (Dewey 1910) is probably the nearest Palaeozoic intrusive to Horseshoe Rocks.

A dyke on the north coast at Lee (N.G.R. 478467) (Blundell 1957; Shearman 1968), is of comparatively fresh rock and appears to be related to the numerous dykes on Lundy. A Tertiary age was postulated for these on magnetic grounds by Blundell (1957) and is now proved since they cut the Lundy Granite, dated at 50–55 million years. Although Lee is almost the nearest point of land, the Horseshoe Rocks intrusions do not appear to belong to the same group as they are altered and sheared, features absent from the Tertiary dykes.

In view of the considerations outlined above, the other shoals between Horseshoe Rocks and the mainland might, if igneous, be either Tertiary or Palaeozoic in age.

9. Evidence on the origin of the Bristol Channel

The new data confirm that a trough of Triassic and Jurassic rocks underlies the Bristol Channel. The preservation of these rocks requires downwarping of the Channel trough to have taken place during or prior to the Lower Cretaceous, for otherwise they would have been exposed to erosion after the eastward tilt of England that preceded the deposition of the Upper Cretaceous. The south side of the Bristol Channel trough was emphasized by the strike fault (see p. 601), either during the early Cretaceous or mid-Tertiary episodes of folding. It was then sliced by the northwest trending tear faults that are generally considered to be Tertiary in southwest England. The complimentary anticline to the south of the Bristol Channel must have included Lundy, which itself requires a thick overburden during Eocene times to allow emplacement of the granites, unless the latter represent an up-faulted block.

The age of initiation of the present Bristol Channel seaway is not known for certain, but is probably late Tertiary. As the main rivers enter the eastern part of the Channel and the Severn Estuary roughly at right angles to the present coast and are strongly discordant to the geological structure (including the Jurassic rocks), it seems likely that such drainage is superimposed. It is difficult to see what formation this drainage could have been initiated upon other than the Chalk. Fragments of a broad valley extending along the line of the Bristol Channel and reaching its southern side may be indicated by the long steep slope of the coast, the base of which has been cut into by the present sea. The youth of the long upper slope and of the neighbouring valleys of north Devon and Somerset is strongly suggested by their steepness. Certainly the present seaway must have been in existence by Pleistocene times, as erratics of Chalk, flint, numerous igneous rocks and rocks of Carboniferous aspect are present even on such relatively high parts of its floor as around Horseshoe Rocks. Six samples (Dy 4298, 4318, 4319, 4321, 4375, 4376) of deposits resembling the head seen on the adjacent valley slopes, were taken near the south shore of the Channel between about 03° 40′ and 04° W, in water depths of between about 22 and 30 m. These supposedly subaerial deposits may indicate a sea level of 31 m or more lower than the present day. This would be in keeping with the depth to rock floor of about 31 m in the drowned valley of the Taw–Torridge estuary (McFarlane 1955). On land, glacial gravels have been described from Lundy (Mitchell 1968) and there is boulder clay at Fremington on the Devon coast (Edmonds 1972), for example. Glacier and river scour during low sea levels is indicated for the Bristol Channel floor, while scour by tidal sand streams must have occurred during interglacials, as at the present time.

The new evidence adds considerable weight to some of the previous ideas about the origin of the Bristol Channel (see p. 596). However, it seems unlikely that our strike fault (figure 3) near the southern side of the Channel corresponds to the thrust fault proposed by Falcon (in Cook & Thirlaway 1952) and Bott *et al.* (1958). The size of the Exmoor structure, required to satisfy the gravity field, is of a different order to the thrust fault required by our evidence, with the gentle folding of Triassic and Jurassic rocks in the trough and with known structures in Mesozoic rocks elsewhere in southern England. It remains a possibility, however, that the post-Armorican–pre-Triassic structure of the southern part of the Bristol Channel may follow the general line of (and be influenced by) more severe Armorican thrusting. Investigation of this possibility would require deep seismic reflexion traverses and deep boreholes which need not necessarily be sited offshore.

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Appendix 1. Palaeozoic, Mesozoic and Drift samples from the floor of the Bristol Channel

(All samples, except the last fifteen, were obtained by means of a gravity corer.)

Abbreviations

Ages

U., Upper	N.R.S., New Red Sandstone (Permo-Trias)
M., Middle	Carb., Carboniferous
L., Lower	Dev., Devonian
J., Jurassic	

Fauna

F (preceded by a number), the number of identified Foraminiferid species
O (preceded by a number), the number of identified Ostracod genera

Colour

Letters and numbers within brackets (such as 10YR 7/2) refer to colours on the Munsell system.

Samples taken from R.R.S. Discovery II *in* 1960

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Dy 4291/1	51° 21.10′	03° 21.85′	grey, silty crystalline limestone; *Gryphaea*, crinoid ossicles; no microfauna	L.J.: Hettangian or L. Sinemurian
Dy 4293/1	51° 19.80′	03° 23.95′	grey micaceous marl; *Modiolus ?laevis* J. Sow.; no microfauna	L.J.: ?Turneri zone
Dy 4294/1	51° 19.15′	03° 25.20′	dark grey limestone	J.
Dy 4295/1	51° 18.65′	03° 26.45′	grey, micaceous marl; unidentifiable ammonites, bivalves	?
Dy 4296/1	51° 18.70′	03° 28.70′	grey, micaceous, calcareous paper shale with gypsum; *Astarte gueuxii* d'Orb., *Lucina* aff. *limbata* Terquem & Piette, echinoid plates; 9 F; 7 O	L.J. ?Raricostatum zone
Dy 4297/1	51° 19.05′	03° 30.35′	hard, grey limestone	J. (lithology suggests Lower Lias) ?L. Sinemurian
Dy 4298/2	51° 14.90′	03° 28.75′	(no core) small quantity of brownish pink clayey sand	?N.R.S.

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Dy 4299/2	51° 14.70′	03° 29.95	pale grey, micaceous calcareous clay with quartz and muscovite: no fauna	?L.J.: L. Sinemurian
Dy 4300/1	51° 14.70′	03° 31.45′	dark grey limestone; dark grey calcareous clay, very small mica flakes; ophiuroid fragments; 12 F; 2 O	L.J.: Angulata or early Bucklandi zone
Dy 4301/2	51° 14.95′	03° 33.30′	grey, banded, fine grained limestone; dark grey (N. 3) calcareous shaly clay; fish scales, ophiuroid and bivalve fragments; 12 F; 6 O	L.J.: Semicostatum zone, close to base of zone
Dy 4302/2	51° 14.95′	03° 35.05′	very calcareous grey clay; grey argillaceous limestone; *Modiolus laevis* J. Sow., *Liostrea* sp. and other, unidentifiable bivalves; ophiuroid fragments; ?*Diademopsis*	L.J.: Lower Lias Bucklandi zone
Dy 4303/1	51° 15.15′	03° 36.60′	grey, calcareous clay; abundant echinoid debris including keeled teeth, spines, parts of lanterns; terebratulid indet., 10 F; 3 O	L.J.: Semicostatum zone
Dy 4304/1	51° 14.97′	03° 38.15′	dark grey calcareous clay	J.
Dy 4307/1	51° 12.60′	04° 47.60′	grey, micaceous, non-calcareous slate; cleavage nearly vertical	Dev.: Pickwell Down Sandstone
Dy 4309/1	51° 14.20′	04° 43.85′	micaceous, non-calcareous sandstone and shale	Dev.: horizon above the Pickwell Down Sandstone
Dy 4310/2	51° 15.55′	04° 41.20′	pale grey, micaceous slate, cleavage at high angle	Dev.
Dy 4314	51° 14.70′	04° 07.25′	hard, purplish brown non-calcareous sandstone	Dev.: Hangman Grits
Dy 4315/1	51° 14.50′	04° 04.80′	hard, cleaved, grey, non-calcareous, micaceous sandstone	Dev.: Hangman Grits
Dy 4316/1	51° 14.60′	04° 03.20′	hard, cleaved, brown, non-calcareous, micaceous sandstone	Dev.: Hangman Grits
Dy 4318/1	51° 14.70′	03° 59.90′	mottled, pale pinkish grey (near 10 YR 7/2) and orange-brown (near 10 YR 6/4) calcareous, clayey fine sand, with slate fragments and carbonaceous root-like structures	Pleistocene: Head
Dy 4319/1	51° 14.80′	03° 58.30′	brown (near 10 YR 6/2) micaceous sandy clay with pebbles	Pleistocene: Head
Dy 4319/2	51° 14.80′	03° 58.10′	breccia of slate fragments in pale pinkish brown (5 YR 6/4) clay matrix; friable	Pleistocene: Head
Dy 4320/1	51° 14.90′	03° 56.70′	dark reddish brown micaceous sand, alternating with grey slaty shale, bedding at high angle to horizon	Dev.: probably Lynton Beds
Dy 4321/1	51° 15.10′	03° 54.90′	breccia of slate and sandstone fragments, in matrix like that of 4319/2	Pleistocene: Head
Dy 4323/2	51° 15.60′	03° 45.60′	hard, grey non-calcareous sandstone	Devonian
Dy 4331/2	51° 03.80′	04° 30.60′	grey, micaceous slate; low-grade cleavage at high angle	Dev./Carb.: Culm or Pilton Beds
Dy 4333/1	51° 04.40′	04° 27.40′	grey slate, weak vertical cleavage	Dev./Carb.: Culm or Pilton Beds
Dy 4337/1	51° 15.20′	04° 15.25′	‘Red’ (5 YR 5/4) non-calcareous clayey silt with light greenish grey (5 G 8/1) spots	N.R.S.: Keuper Marl
Dy 4338/1	51° 17.05′	04° 16.65′	grey, finely micaceous marl, with gypsum; gastropod spat abundant; ophiuroid and echinoid fragments, crinoid ossicles; *Oxytoma*, *Pleuromya*; 23 F; 4 O	L.J.: Semicostatum zone

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Dy 4340/1	51° 20.15′	04° 18.45′	grey, shaly, calcareous clay, with highly pyritic residue; fish teeth; *Procerithium*, bivalves including *Plicatula*; echinoid fragments; 20 F; 3 O	U.J.: Kimeridge Clay, Mutabilis zone (upper part)
Dy 4344/2	51° 21.80′	03° 34.60′	grey, fine grained, impure limestone, with bivalve shell fragments: no microfauna	J.: lithology suggests Lower Lias, L. Sinemurian
Dy 4344/3	51° 21.90′	03° 34.55′	like 4344/2	J.: lithology suggests Lower Lias, L. Sinemurian
Dy 4345/1	51° 22.10′	03° 31.60′	soft, grey impure limestone; bivalve shell fragments; *Oxytoma*, etc.: grey, calcareous clay; no microfauna	J.: L. Lias, ?L. Sinemurian
Dy 4345/3	51° 22.10′	03° 31.50′	mottled greyish yellow calcareous, micaceous clay, overlying hard, grey, fine-grained impure limestone: no microfauna	J.
Dy 4346/1	51° 20.60′	03° 30.70′	grey, micaceous, silty limestone: barren	J.: L. Lias, ?L. Sinemurian
Dy 4351/1	51° 34.70′	04° 41.60′	hard, grey, fine-grained limestone; calcite vein; fragment of ?brachiopod	Probably Carb.: Carboniferous Limestone
2	51° 34.60′	04° 41.40′		
Dy 4352/1	51° 35.00′	04° 39.60′	angular fragments of hard limestone	Probably Carb.: Carboniferous Limestone
2	51° 35.10′	04° 39.50′		
Dy 4361/1	51° 15.45′	04° 17.75′	red (near 10 R 5/3) fine grained, friable sandstone with pebbles and fragments of quartz, quartzite and slate: no fauna	N.R.S.
Dy 4362/2	51° 16.30′	04° 14.00′	light olive grey (near 5 Y 6/1) slightly calcareous clay; 1 F	probably N.R.S.: Tea Green Marl
Dy 4363/2	51° 16.45′	04° 11.80′	pale brown (near 5 YR 5/2), passing into more yellowish brown, slightly calcareous sandstone	? Rhaetic; Westbury Beds
Dy 4363/3	51° 16.50′	04° 11.85′	grey, calcareous paper shale with gypsum; *Modiolus*, echinoid spines, fossil wood: no microfauna	Rhaetic or L.J., ?Pre-Planorbis Beds
Dy 4364/1	51° 16.15′	04° 09.20′	'red' (near 2.5 YR 5/4) slightly calcareous silt: no fauna	N.R.S.: probably Keuper Marl
Dy 4371/1	51° 15.15′	04° 04.10′	'red' (near 10 R 5/4) micaceous fine sand and clay; no fauna	N.R.S.
Dy 4365/1	51° 15.75′	04° 09.60′	grey and red-brown non-calcareous sandstone; fragments only	Dev.: Hangman Grits
2, 3	51° 15.65′	04° 09.65′		
Dy 4366/1	51° 12.50′	04° 17.50′	grey, non-calcareous slate, cleavage at about 60° to horizontal	Dev.: Morte Slates
Dy 4367/1	51° 12.10′	04° 18.20′	grey slate, cleavage at about 40° to horizontal	Dev.: Morte Slates
2	51° 12.00′	04° 18.15′		
Dy 4368/1	51° 13.90′	04° 13.40′	pale grey slate, cleavage at about 60° to horizontal	Dev.: Ilfracombe Beds, probably middle part
Dy 4373/1	51° 15.45′	03° 41.70′	'red' (near 2.5 YR 4/4) non-calcareous silt or claystone: no fauna	N.R.S.
Dy 4374/1	51° 15.55′	03° 41.10′	yellowish grey (5 Y 7/1) calcareous clay	probably N.R.S.: Tea Green Marls
Dy 4374/2	51° 15.50′	03° 40.90′	yellowish grey (5 Y 7/1) calcareous clay	probably N.R.S.: Tea Green Marls
Dy 4375/1	51° 14.80′	03° 39.75′	light brown (5 YR 6/4) clayey, impure fine sand with rare larger grains; carbonaceous root-like structures: not calcareous	Pleistocene: Head
Dy 4376/2	51° 14.80′	03° 40.95′	'red' (near 10 R 5/5) clayey fine sand fragments of slate and sandstone	N.R.S.

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Dy 4377/1	51° 14.80′	03° 42.65′	yellowish grey (5 Y 7/2) slightly calcareous mudstone or siltstone	probably N.R.S.: Tea Green Marls
Dy 4377/2	51° 14.75′	03° 42.70′	yellowish-grey (5 Y 7/1) slightly calcareous clay	probably N.R.S.: Tea Green Marls
Dy 4379/1	51° 14.40′	04° 06.40′	purple, calcareous micaceous sandstone	Dev.: Ilfracombe Beds
Dy 4379/2	51° 14.65′	04° 06.45′	grey slate, cleavage at about 45° to horizontal	Dev.: Ilfracombe Beds
Dy 4380/1	51° 13.95′	04° 03.60′	grey, fine grained, non-calcareous sandstone; grey slate	Dev.: ?upper Hangman Grits or basal Ilfracombe Beds
			Samples taken from R.R.S. Discovery II *in* 1962	
Dy 4857/1	51° 23.15′	04° 00.25′	dark grey, micaceous, pyritic, calcareous shaly clay; *Ostrea*, echinoid spines, 5 F; 3 O	L.J.: Semicostatum zone, upper part
Dy 4858/2	51° 22.45′	04° 00.60′	Lithology as 4857/1. Gastropods, *Oxytoma* sp. and other bivalves, echinoderm fragments: 15 F; 3 O	L.J.: Obtusum zone
Dy 4859/1	51° 21.80′	04° 00.75′	fine sand (grain size up to 0.05 mm); grey sandy clay; glauconite, mica and lignite fragments: no fauna	J.: ?Bathonian
Dy 4861/2	51° 20.82′	04° 00.95′	grey, slightly calcareous, silty clay; fine sand, glauconite and pyrite in residue; bivalves (?*Astarte*); 15 F; 3 O	U.J.: Kimeridge Clay, Mutabilis zone, lower part
Dy 4862/2	51° 20.35′	04° 01.00′	grey, clayey, calcareous fine sand; sand grains are clear quartz *ca.* 0.02 mm diameter; a little pyrite: no macrofauna; 5 F	U.J.: Kimeridge Clay, Eudoxus zone, lower part
Dy 4863/1	51° 19.70′	04° 00.50′	dark grey, slightly calcareous, pyritic shaly clay, abundant shell fragments; *Natica* sp., *Astarte*, ?*Dentalium*, Ophiuroid fragments; 11 F; 2 O	U.J.: Kimeridge Clay, Eudoxus zone, lower part
Dy 4864/1	51° 19.20′	04° 00.65′	dark grey calcareous, pyritic, hard, dicey clay; very fine grained mica present; *Natica*, *Purpurina*, *Exogyra*, *Plicatula*, hastate belemnites; echinoid plates, spines; ophiuroid fragments; 17 F; 1 O	U.J.: Kimeridge Clay, Hudlestoni zone
Dy 4866/4	51° 16.90′	04° 04.25′	grey, pyritic, micaceous shaly clay, abundant shell fragments; ammonite fragments, *Chlamys*, *Plicatula*; echinoid spines, plates, ophiuroid fragments; 15 F; 6 O	L.J.: Lower Lias, Bucklandi zone
Dy 4868/5	51° 17.70′	04° 04.85′	grey, micaceous, calcareous clay, mottled (?weathered) with khaki; bivalves, echinoderm fragments, *Stomatopora*; 18 F; 5 O	J.: ?Opalinus zone or high Toarcian
Dy 4870/1	51° 18.74′	04° 04.95′	mottled, grey and khaki, slightly calcareous clay; ophiuroid and bivalve fragments	J.: as above
Dy 4871/2	51° 18.90′	04° 04.65′	dark grey, calcareous fine grained sandstone: no fauna	—
Dy 4873/3	51° 22.07′	04° 04.70′	grey (10 Y 5/1) clay with abundant shell fragments; *Chlamys*, *Plicatula*, echinoid spines, *Chirodota*, holothurian spicules; 6 F; 5 O	U.J.: Oxford Clay
Dy 4875/4	51° 21.00′	04° 05.46′	dark grey (near N 3) calcareous clay, pyrite aggregates in residue; fish teeth, scales and otoliths, gastropods, bivalves, echinoid spines; 1 F; 1 O	U.J.: Kimeridge Clay, ?Pectinatus zone

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Dy 4876/3	51° 20.72′	04° 04.96′	grey calcareous clay, with pyrite nodules and aggregates; gastropods, *Cucullaea*, echinoderm fragments, cirripedes; 12 F; 2 O	U.J.: Kimeridge Clay, Pallasioides zone, *sensu* Casey
Dy 4878/1	51° 17.20′	04° 16.70′	grey, calcareous clay and marl with very fine grained mica; ammonite nuclei, bivalves, crinoid plates; 15 F; 4 O	L.J.: Lower Lias, Turneri zone
Dy 4879/1	51° 17.85′	04° 16.80′	dark grey, micaceous, calcareous clay with abundant shell fragments; bivalves, terebratulids, crinoid ossicles, echinoid spines; 24 F; 5 O	L.J.: Lower Lias, Lower Pliensbachian, ?Jamesoni zone
Dy 4881/3	51° 19.00′	04° 16.85′	greenish grey (near 10 Y 5/1) calcareous clay, mottled with yellow-brown; fine white quartz sand (*ca.* 0.05 mm) with mica, glauconite, lignite: no fauna	—
Dy 4882	51° 19.60′	04° 17.20′	grey, yellowish weathering, slightly calcareous fine grained sandstone; pyrite, ?glauconite: no fauna	—
Dy 4883/3	51° 20.20′	04° 18.00′	dark grey calcareous clay: no fauna	J.
Dy 4885/3	51° 20.80′	04° 18.00′	dark grey, calcareous, pyritic clay; silt grade quartz, mica, rare glauconite; gastropods, *Protocardia*, *Discina*, *Lingula*; echinoderm and cirripede fragments; 17 F; 2 O	U.J.: Kimeridge Clay, Pallasioides zone *sensu* Casey
Dy 4886/1	51° 20.30′	04° 18.05′	mottled grey (5 GY 6/1 and N 3) hard, non-calcareous dicey clay; bivalves, crinoid ossicles: no microfauna	U.J.: ?Kimeridge Clay

Samples taken by R.V. Sarsia *in* 1963

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Sa 101	51° 17.00′	03° 31.00′	grey shaly clay with limonite grains; bivalve fragments (?*Astarte*); 11 F; 1 O	L.J.: Lower Lias, Semicostatum zone, upper part
Sa 102	51° 17.00′	03° 31.60′	grey paper shale, plant remains: no fauna	—
Sa 103	51° 17.00′	03° 32.40′	grey, micaceous shaly clay, some lignite and pyrite; ammonite nuclei, belemnites, *Purpuroidea*, fish teeth, echinoid fragments; 4 F	L.J.: Lower Lias, ?Jamesoni zone
Sa 105	51° 17.10′	03° 33.00′	dark grey shaly clay, much gypsum; *Procerithium*, echinoid spines: no microfauna	L.J.: ?U. Pliensbachian
Sa 106	51° 17.00′	03° 34.00′	grey clayey shale with gypsum, lignite; shell fragments, ammonite nuclei: ?*Alaria*, *Amberleya*, *Inoceramus*; 7 F; 3 O	L.J.: Upper Lias, ?Falcifer zone
Sa 107	51° 17.00′	03° 34.90′	grey clay with rust-coloured shell fragments; 4 F; 4 O	L.J.: Upper Lias, ?Falcifer zone
Sa 115	51° 15.10′	03° 43.00′	(no sample) trace of red marl on corer	N.R.S.: Keuper Marl
Sa 116	51° 15.70′	03° 43.50′	dark grey cementstone with hard shaly clay, lignite: no fauna	L.J.: L. Sinemurian
Sa 117	51° 16.30′	03° 44.00′	greyish yellow, mottled, plastic clay; *Natica*, *Ostrea*, ophiuroids	L.J.: Lower Lias, Obtusum zone
Sa 118	51° 16.60′	03° 44.50′	grey, shaly clay with some gypsum; *Anomia*, *Oxytoma*, *Anchistrum*, holothurian spicules; 20 F; 4 O	U.J.: Oxford Clay, Coronatum zone
Sa 119	51° 17.25′	03° 44.60′	yellow, (?) decalcified clay; streaks of grey clay with recent rootlets; *Natica*, *Procerithium*; ?*Anomia*; 4 F	U.J.: Oxford Clay, probably Athleta zone

station number	latitude (N)	lougitude (W)	description	stratigraphical horizon
Sa 120	51° 17.75′	03° 45.00′	hard, grey shaly clay, much gypsum, some pyrite; *Natica*, *Procerithium*; dysodont bivalves; belemnites; 13 F; 2 O	U.J.: Oxford Clay, Mariae zone
Sa 121	51° 18.20′	03° 45.40′	dark grey sandy clay with glauconite; no fauna	J.
Sa 124	51° 19.00′	03° 46.00′	dark grey cementstone with ?glauconite; silty, micaceous clay; bivalve fragments; 3 F	U.J.: Oxford Sands
Sa 125	51° 17.90′	03° 50.80′	grey, dicey clay with much pyrite, rare gypsum and lignite; *Procerithium*, bivalve fragments; 14 F; 2 O	U.J.: Oxford Clay, Lamberti zone or lower part of Mariae zone
Sa 126	51° 18.40′	03° 50.80′	grey shale and yellowish grey cementstone; bivalve fragments; 2 F	U.J.: Oxford Sands
Sa 130	51° 19.30′	03° 50.20′	dark grey cementstone; ?glauconite; holothurian spicules; 6 F; 2 O	U.J.: Kimeridge Clay, lower part
Sa 132	51° 16.60′	03° 21.90′	grey shaly clay, streaked with yellow; sandy residue; ammonite, bivalve fragments; echinoderm fragments; baby asteroid; rare F; 1 O	L.J.: Semicostatum zone, upper part
Sa 133	51° 16.50′	03° 23.50′	grey shaly clay with shell fragments; a few quartz grains; no microfauna	L.J.: ?Bucklandi zone
Sa 135	51° 16.50′	03° 25.30′	grey dicey clay with shell fragments; *Protocardia*; echinoid spines, crinoid ossicles; 11 F; 4 O	L.J.: Lower Lias, Angulata zone
Sa 138	51° 16.50′	03° 28.30′	grey, shaly clay with much gypsum; some shell fragments; *Chlamys*; echinoid spines, ophiuroid debris. 15 F; 4 O	L.J.: Lower Lias, Angulata zone
Sa 144	51° 16.20′	03° 32.50′	grey, plastic clay; *Ostrea*, *Pteria*; terebratulids; ophiuroid and crinoid fragments; 18 F; 2 O	L.J.: Lower Lias, Turneri zone
Sa 145	51° 18.20′	03° 32.70′	grey, micaceous shale; *Amberleya*; *Ostrea*; echinoid spines; no microfauna	L.J.: Toarcian
Sa 147	51° 24.00′	04° 09.00′	dark grey shale, some gypsum; belemnite, bivalve fragments, ophiuroid fragments, echinoid spines: no microfauna	L.J.: probably Semicostatum zone
Sa 148	51° 20.80′	04° 09.00′	light-fawn sandy limestone, with gypsum, glauconite, lignite: no fauna	probably U.J.: Oxford Sands
Sa 149	51° 20.70′	04° 08.80′	light brown, calcareous sandstone: no fauna	probably U.J.: Sandy Upper Kimeridge or Portland Sand
Sa 150	51° 19.90′	04° 08.60′	dark grey, shaly clay, much gypsum; sand and pyrite aggregates in residue; *Astarte*, *Pleuromya*; *Ceritella*; 10 F; 1 O	U.J.: Kimeridge Clay, Cymodoce zone
Sa 155	51° 16.90′	04° 08.30′	dark grey, soft shale, with gypsum; bivalve fragments; echinoid teeth, spines, ophiuroid fragments; 13 F; 1 O	L.J.: Lower Lias, Turneri zone
Sa 159	51° 20.05′	04° 06.70′	dark grey shale, pyrite and gypsum aggregates; *Amberleya*, *Ceritella*; *Astarte*, *Cucullaea*, *Pleuromya*; fish teeth, crinoid ossicles; 5 F; 1 O	U.J.: Kimeridge Clay, Hudlestoni zone
Sa 161	51° 19.50′	04° 06.60′	dark grey clay with shell fragments; pyrite aggregates, lignite; 2 F	U.J.
Sa 162	51° 19.00′	04° 06.40′	grey clay with gypsum, lignite; sandy residue: no fauna	J. (?)
Sa 163	51° 18.40′	04° 06.10′	fawn, mottled clay with rare lignite, shell fragments; *Anomia*; fish otoliths, echinoid spines, ophiuroid fragments, cirripedes; holothuroid spicules; 10 F; 2 O	U.J.: Oxford Clay, probably Athleta zone

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Sa 165	51° 17.80′	04° 06.30′	fawn-grey shaly clay with much gypsum, pyrite aggregates, broken ammonite shell; *Procerithium*, bivalves, echinoid spines, ophiuroid fragments, cirripedes, fish otoliths; 11 F; 2 O	U.J.: Oxford Clay, ?Jason zone
Sa 167	51° 17.00′	04° 06.00′	dark grey, dicey clay, bivalve fragments; 11 F;	L.J.: Lower Lias, Bucklandi zone
Sa 168	51° 23.10′	03° 55.75′	grey, calcareous, shaly clay with shell fragments; echinoid spines; 13 F; 5 O	L.J.: Lower Lias, Semicostatum zone, upper part
Sa 171	51° 21.50′	03° 56.60′	grey clay with shell fragments; ?*Pleurotomaria*, *Procerithium*, *Astarte*; 2 F	L.J.: Upper Lias
Sa 177	51° 20.25′	03° 57.40′	grey, silty, shaly clay with shell fragments; no fauna	U.J.: Oxford Sands
Sa 178	51° 19.70′	03° 57.70′	dark grey shaly clay with pyrite aggregates, shell fragments; belemnites, *Ceritella*, *Procerithium*, *Anomia*, scolecodonts; 8 F; 3 O	U.J.: Kimeridge Clay, Mutabilis zone, upper part
Sa 181	51° 20.20′	03° 49.60′	grey silty, shaly clay; *Natica*, *Procerithium*, *Astarte*; 2 F; 4 O	U.J.: Oxford Sands
Sa 182	51° 20.70′	03° 49.30′	grey cementstone, grey clay; 1 F	?U.J.: Lamberti zone
Sa 185	51° 21.20′	03° 48.60′	grey, micaceous clay; *Ostrea*; echinoid spines, ophiuroid fragments; 7 F; 2 O	L.J.: Upper Lias ?U. Toarcian
Sa 187	51° 21.60′	03° 48.70′	dark grey, soft shale; ammonite nuclei, *Anomia*, *Chlamys*; *Pentacrinus*, echinoid teeth, spines; cirripedes; 12 F; 3 O	L.J.: Lower Lias, Turneri zone
Sa 188	51° 22.30′	03° 48.60′	fawn-grey and yellow mottled clay; *Anomia*, *Chlamys*; echinoderm fragments, cirripedes; scolecodonts; 13 F; 3 O	L.J.: Lower Lias, Angulata zone, upper part
Sa 189	51° 22.60′	03° 48.30′	dark grey, soft shale; bivalve and ophiuroid fragments; 12 F; 4 O	L.J.: Lower Lias, Angulata zone
Sa 196	51° 17.60′	04° 00.25′	sandy clay with lignite; gastropods, *Anomia*; ophiuroid fragments; trilete spores; 6 F; 8 O	M. J.: Bathonian, probably Upper
			Sample taken from H.M.S. Shackleton *in* 1958	
Sh 141	51° 27.00′	02° 57.03′	(small sample obtained by valve lead) pale red, fine grained rock	N.R.S.: Keuper Marl
			Samples taken from H.M.S. Shackleton *in* 1961	
Sh 202	51° 16.20′	03° 13.20′	light grey (N 8) and yellowish grey calcareous, ?silty, clay with lignite streaks	—
Sh 204	51° 15.60′	03° 14.20′	grey, strongly micaceous, finely laminated, shaly clay, with ferruginous coatings on bedding planes; gastropods: no other fauna	—
Sh 205	51° 15.60′	03° 15.60′	dark grey (N 3) calcareous clay: no fauna	—
Sh 206	51° 15.60′	03° 15.90′	dark grey (N 3) thinly laminated calcareous shale and shaly clay; belemnites; echinoderm debris; 11 F; 5 O	L.J.: Lower Lias, Upper Sinemurian
Sh 208	51° 15.60′	03° 17.90′	dark grey (N 3) micaceous, calcareous, shaly clay; pyrite aggregates and rods; ?*Natica*, *Procerithium*, bivalves, *Pentacrinus*, ophiuroid fragments; 15 F; 2 O	L.J.: Lower Lias, Upper Sinemurian
Sh 210	51° 17.10′	03° 09.50′	olive-grey, calcareous clay; like Sh 462–3: no fauna	L.J.: Lower Lias, ?Oxynotum zone

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Sh 211	51° 17.10′	03° 09.70′	yellowish grey clay with shale fragments; disturbed; small pupate and naticoid gastropods, echinoid spines; 8 F	L.J.: Lower Lias, ?Obtusum zone
Sh 215	51° 19.80′	03° 04.60′	like Sh 211; *Ostrea*, echinoid plates, spines, ophiuroid fragments; holothurian spicules; 6 F; 1 O	L.J.: Lower Lias, Angulata zone
Sh 216	51° 20.60′	03° 02.80′	'red' (near 10 R 4/4, wet) slightly calcareous, micaceous clay or fine silt, mottled with greenish grey (5 GY 7/1, wet)	N.R.S.: Keuper Marl
Sh 443	51° 15.70′	04° 05.20′	'red' (near 10 R 5/2, wet) clay with grey and yellow (near 10 YR 5/4, wet) clay	N.R.S.: Keuper Marl
Sh 460, 461	51° 15.70′	04° 05.20′	(samples from ship's anchor) 'red' (2.5 YR 5/4) calcareous clay; dark grey calcareous, laminated clay; yellowish green, slightly calcareous clay	N.R.S.: Keuper Marl, Tea Green Marl, and L. Rhaetic Beds
Sh 462, 463	51° 16.70′	03° 59.80′	olive-grey (near 5 Y 3/1, wet) calcareous clay; like Sh 210: no fauna	?L.J.: Lower Lias
Sh 465	51° 20.40′	03° 57.20′	dark grey (N 3) thinly laminated, slightly calcareous shale; residue of mica and pyrite; *Procerithium*, bivalve fragments; 6 F; 1 O	U.J.: Oxford Clay, Mariae zone
			Samples taken from H.M.S. Shackleton *in* 1962	
Sh 503	51° 15.60′	03° 10.25′	greenish-grey sandy clay with shell fragments	?L.J.: U. Pliensbachian
Sh 504	51° 15.75′	03° 10.40′	greenish-grey sandy clay with shell fragments	?L.J.: U. Pliensbachian
Sh 505	51° 28.85′	02° 59.20′	red and greenish grey marl	N.R.S.: Keuper Marl and or Tea Green Marl
Sh 506	51° 30.25′	02° 55.70′	traces of red marl (no sample retained)	N.R.S.: Keuper Marl
			Samples obtained by free divers	
3	51° 14.65′	03° 30.30′	hard, fine grained grey limestone	L.J.: Blue Lias
6	51° 14.45′	03° 30.20′	hard, fine grained grey limestone	L.J.: Blue Lias
14	51° 14.30′	03° 40.30′	angular pieces of red and green marl, not from outcrop but probably locally derived	N.R.S.: Keuper Marl
22	51° 15.00′	03° 36.00′	'blue' marl	L.J.: Blue Lias
52	51° 13.40′	04° 00.60′	green quartzite	Dev.: Hangman Grits
53	51° 13.30′	04° 04.60′	sandstone; quartz vein with ?copper	Dev.: Hangman Grits
54	51° 15.08′	04° 05.75′	fine grained, micaceous sandstone; doubtfully in place	Dev.: Hangman Grits
58	51° 13.50′	04° 05.60′	purple, fine grained, micaceous sandstone	Dev.: Hangman Grits
			Dredge Samples obtained from R.R.S. Discovery II *in* 1960	
Dy 4372	51° 14.7′	04° 12.6′	many pieces of grey (5 Y 5/1) lustrous slate, probably broken from outcrop; one boulder of dolerite	—
Dy 4378/1	51° 14.7′	04° 12.7′	well-smoothed pieces of quartzite of several kinds; vein quartz; one piece (> 30 cm) of dark greenish grey (near 5 G 3/1) dolerite	—
Dy 4378/2	51° 14.5′	04° 12.9′	about 30% of the haul was angular to subangular blocks of dolerite; subangular pieces of quartzite, vein quartz, and a little slate like that of 4372	—

station number	latitude (N)	longitude (W)	description	stratigraphical horizon
Dy 4378/3	51° 14.6′	04° 13.1′	about 20% of the haul was dolerite; the rest subangular to rounded quartzite, with pieces of conglomerate and limestone	—
Dy 4378/4	51° 14.3′	04° 12.6′	numerous flat pieces of [thin-bedded] grey and purple (5RP 4/2) fine grained quartzite; more massive grey quartzite; lustrous slate as in 4372; one subangular block of dolerite (15 cm)	—
Dy 4381	51° 13.3′	04° 11.8′	flat pieces of quartzite, as in 4378/4; one pebble of lamprophyre;	—
Dy 4382	51° 14.8′	04° 11.5′	flat pieces of [thin-bedded] greenish grey (5GY 6/1), brownish grey (5YR 5/1), and purple (5RP 4/3), fine grained quartzite. coarse purplish quartzite; conglomeratic quartzite with quartz pebbles up to 40 mm; one subrounded boulder of granodioritic rock; four pieces of Carboniferous Limestone.	—

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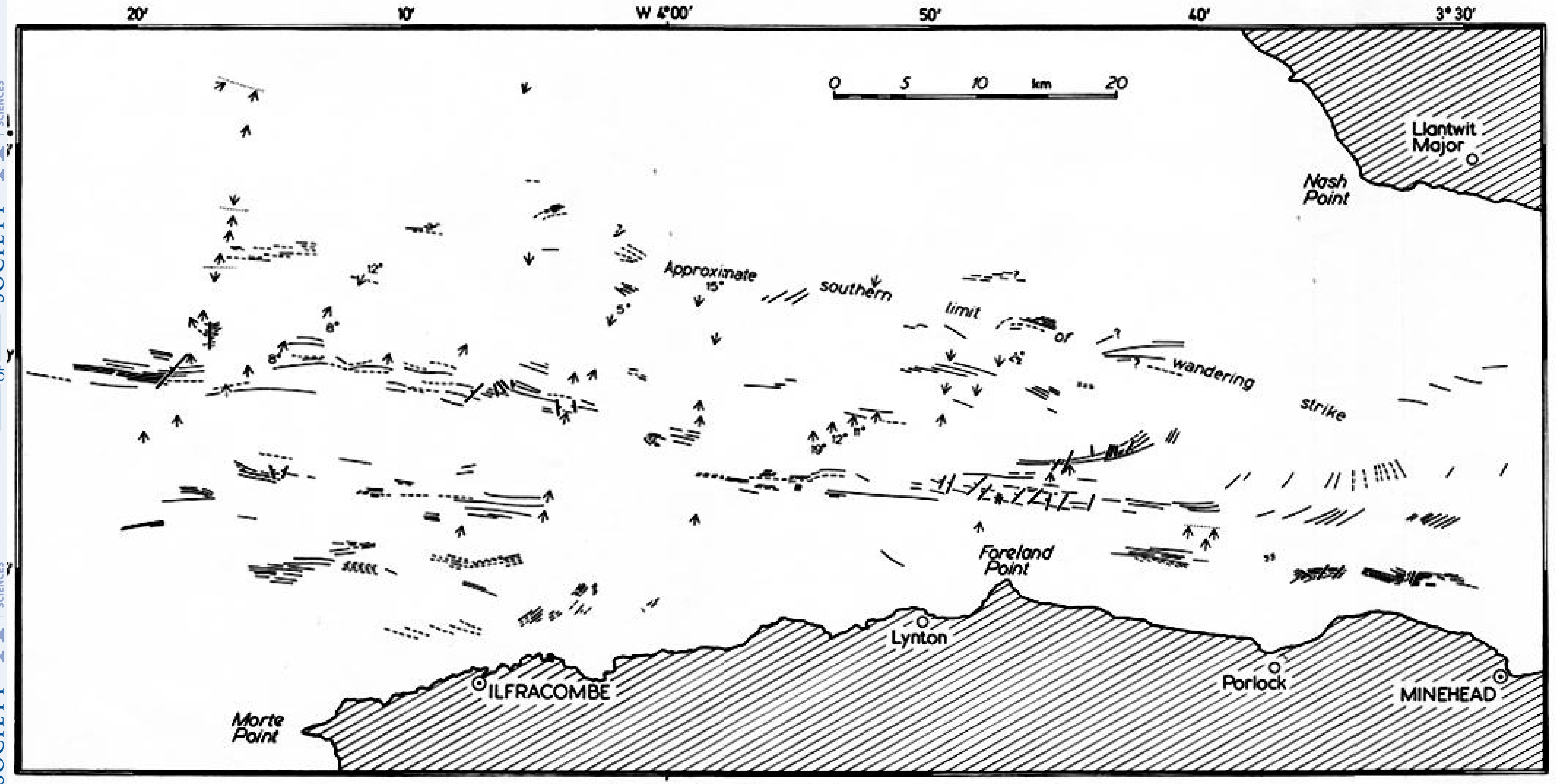

FIGURE 1. The location of 'strike' lines and dips used in the present study of the Bristol Channel.

Lloyd et al. Phil. Trans. R. Soc. Lond. A, volume 274

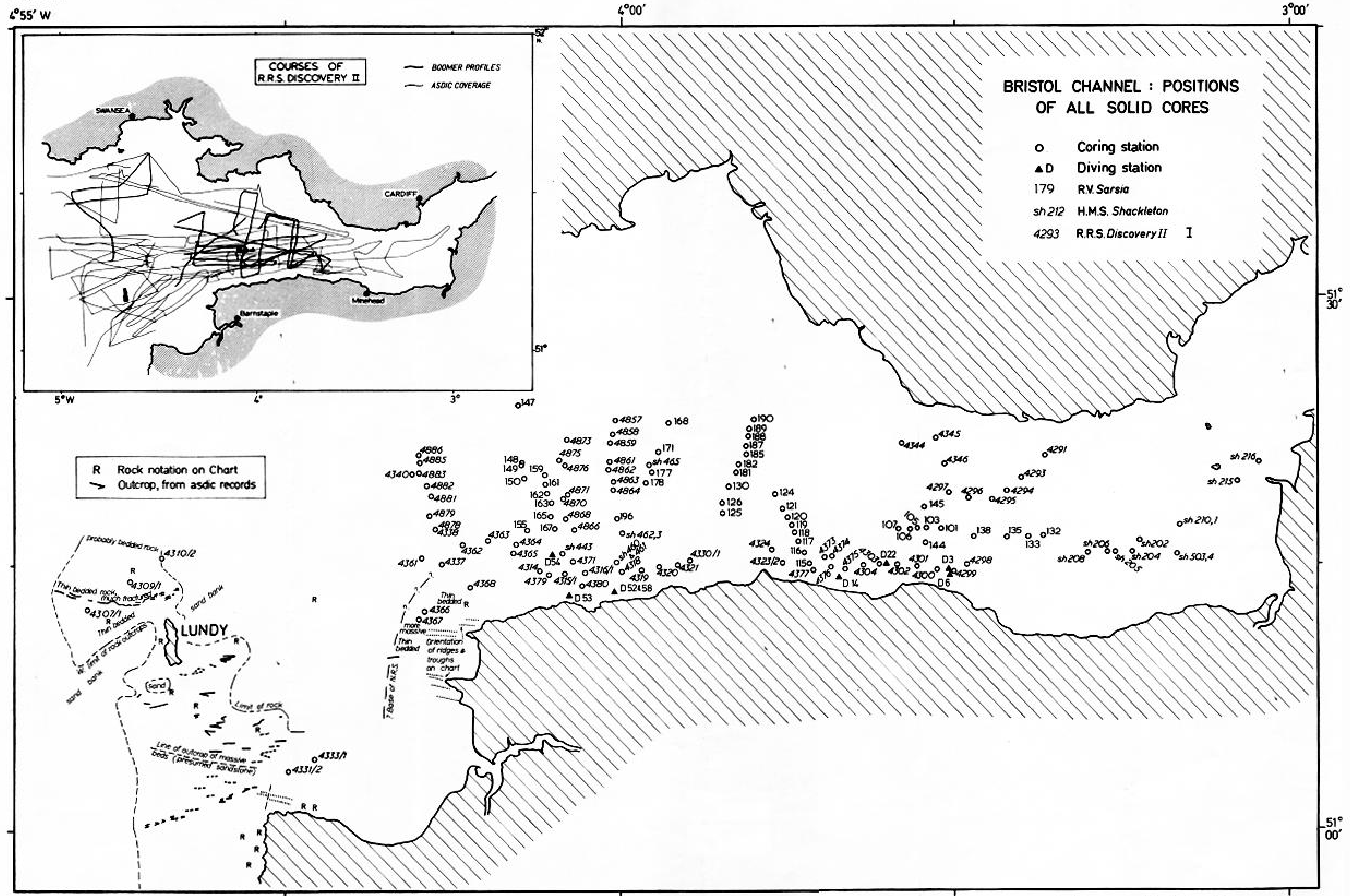

FIGURE 2. The location of coring stations on the floor of the Bristol Channel, together with strike lines and the approximate limit of outcrops of Palaeozoic rocks in the vicinity of Lundy. The inset figure shows the side-scan sonar (asdic) coverage and the location of Boomer profiles.

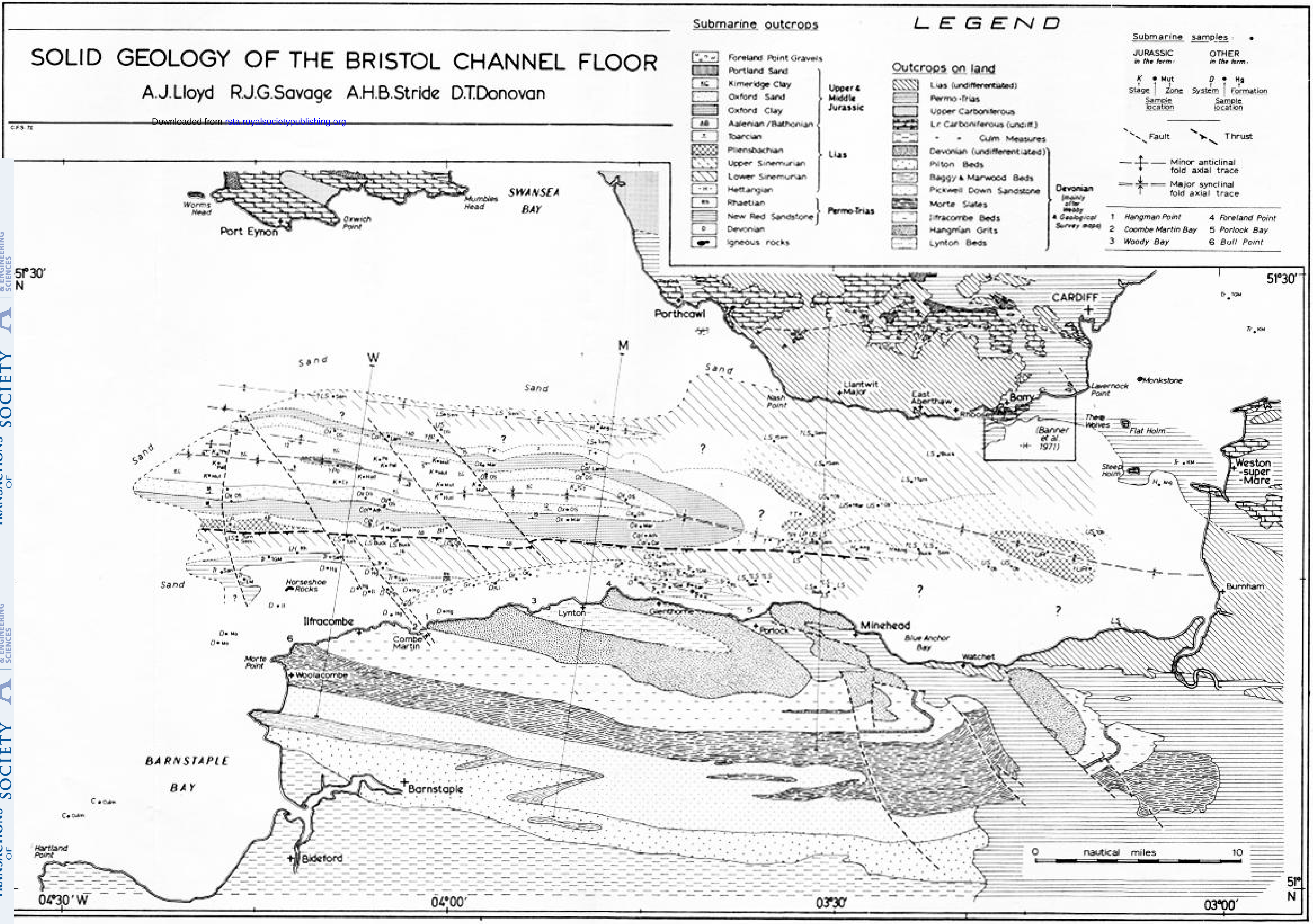

Figure 3. Solid geology of the Bristol Channel floor. The structural sections W, M and E are shown in figure 4.

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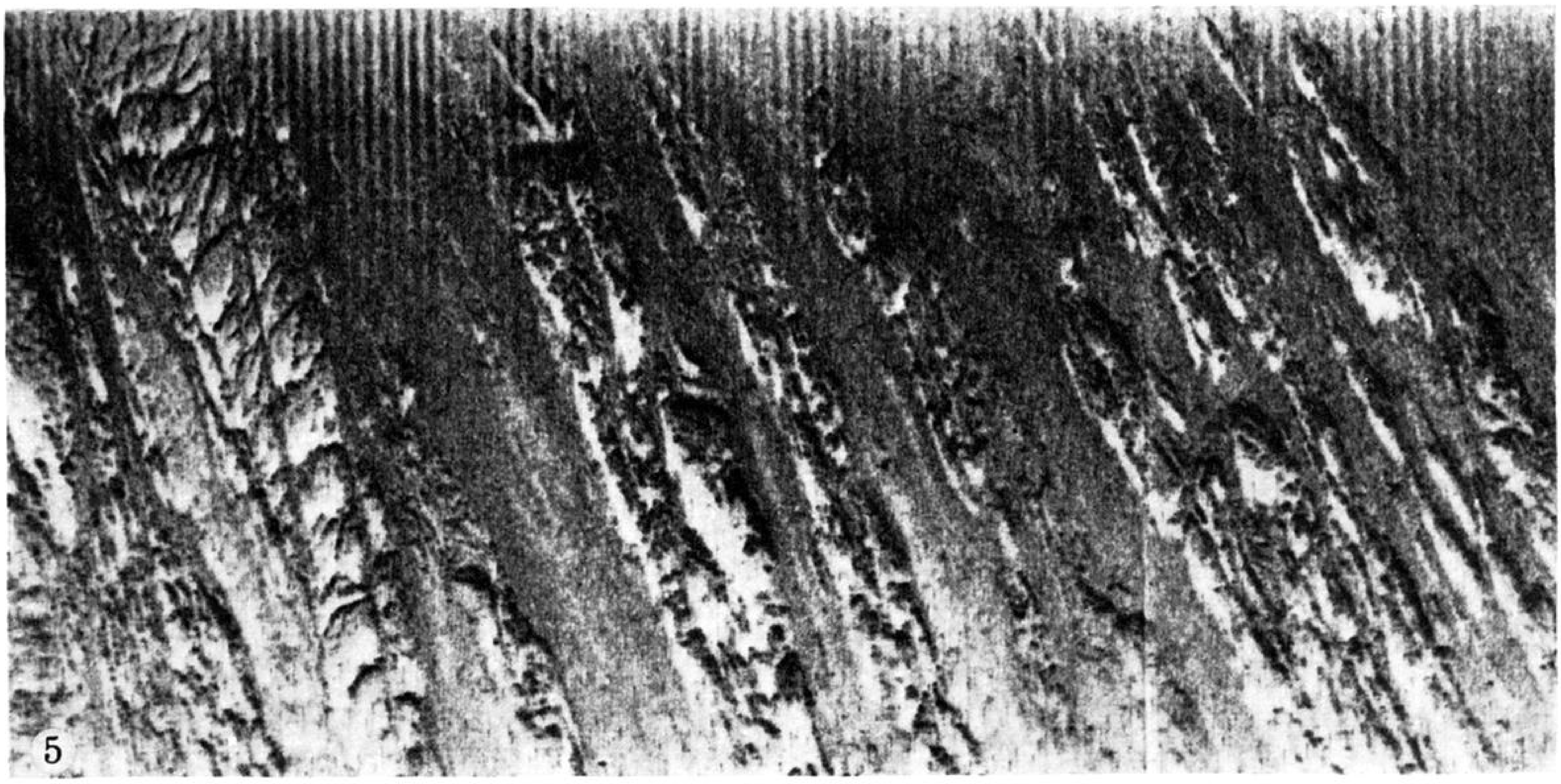
SW NE



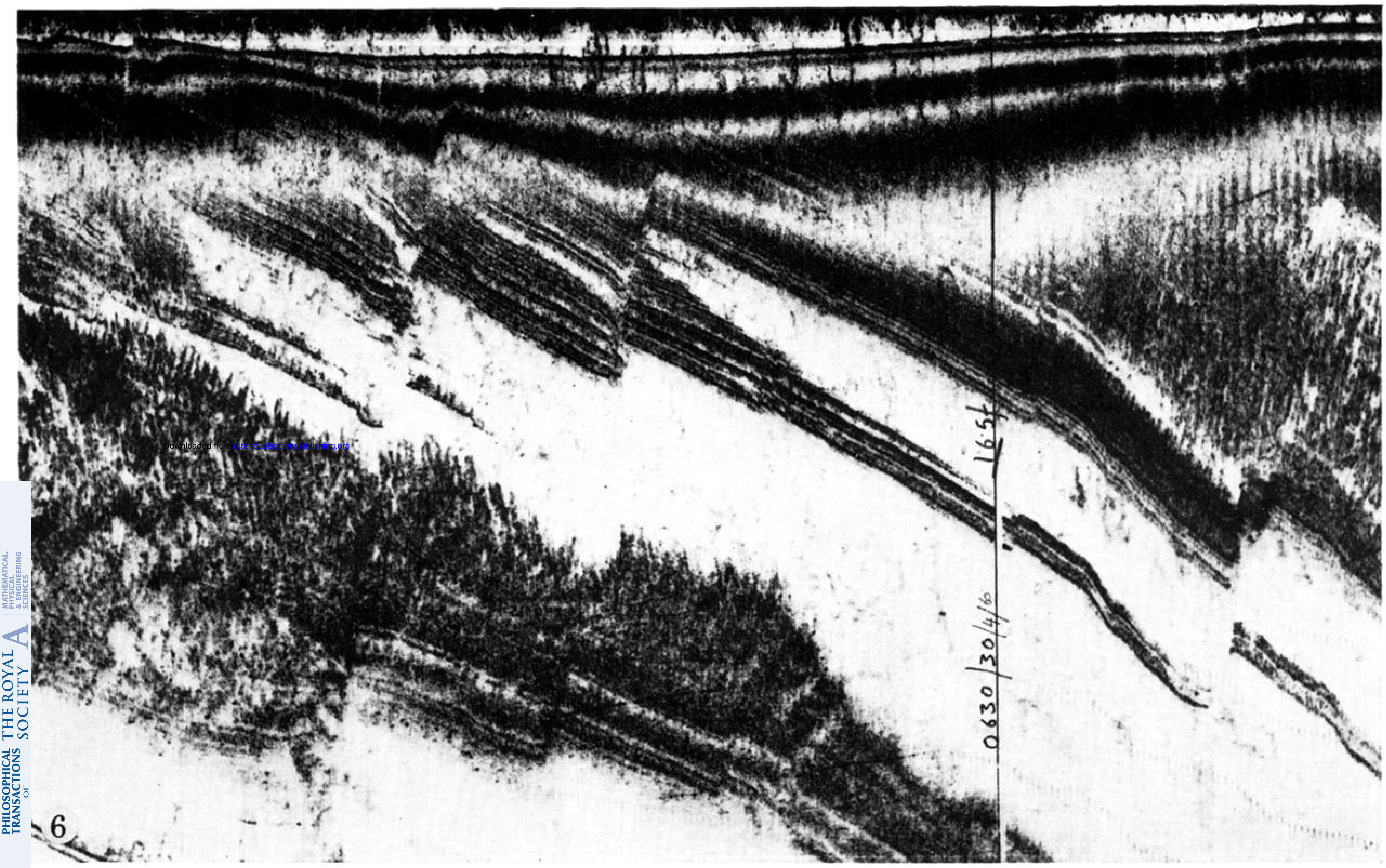


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Figure 5. An oblique view of an area of about 2.5 n mile (3.7 × 0.9 km) of floor situated 4.5 n mile (8.3 km) northwest of Hartland Point. The east–west strike is well shown by ridges of relatively hard rock, presumably sandstones, which are broken by fractures and have a Palaeozoic aspect. The intervening ground is smooth and is probably floored by softer slatey material. The mid-point of the upper edge of the sonograph is located at about 51° 04.9′ N, 04° 36.2′ W. Shadows are white.

Figure 6. An oblique view of an area of about $2\frac{1}{3} \times \frac{1}{2}$ n mile (4.3 × 0.9 km) of floor, with a 'horizon' (vertical profile) along the top. The mid-point of the profile is located at 51° 17′ N, 03° 47.3′ W, on the southern limb of the Bristol Channel Syncline, and 2 n mile (3.7 km) north of Foreland Point. Bold, east–west strike ridges of Liassic rocks, dipping north, cast long shadows (white) and are displaced by small north-easterly trending faults. The main thrust fault is located along the trench. Range exaggeration (top to bottom) is about $2\frac{1}{2}$.

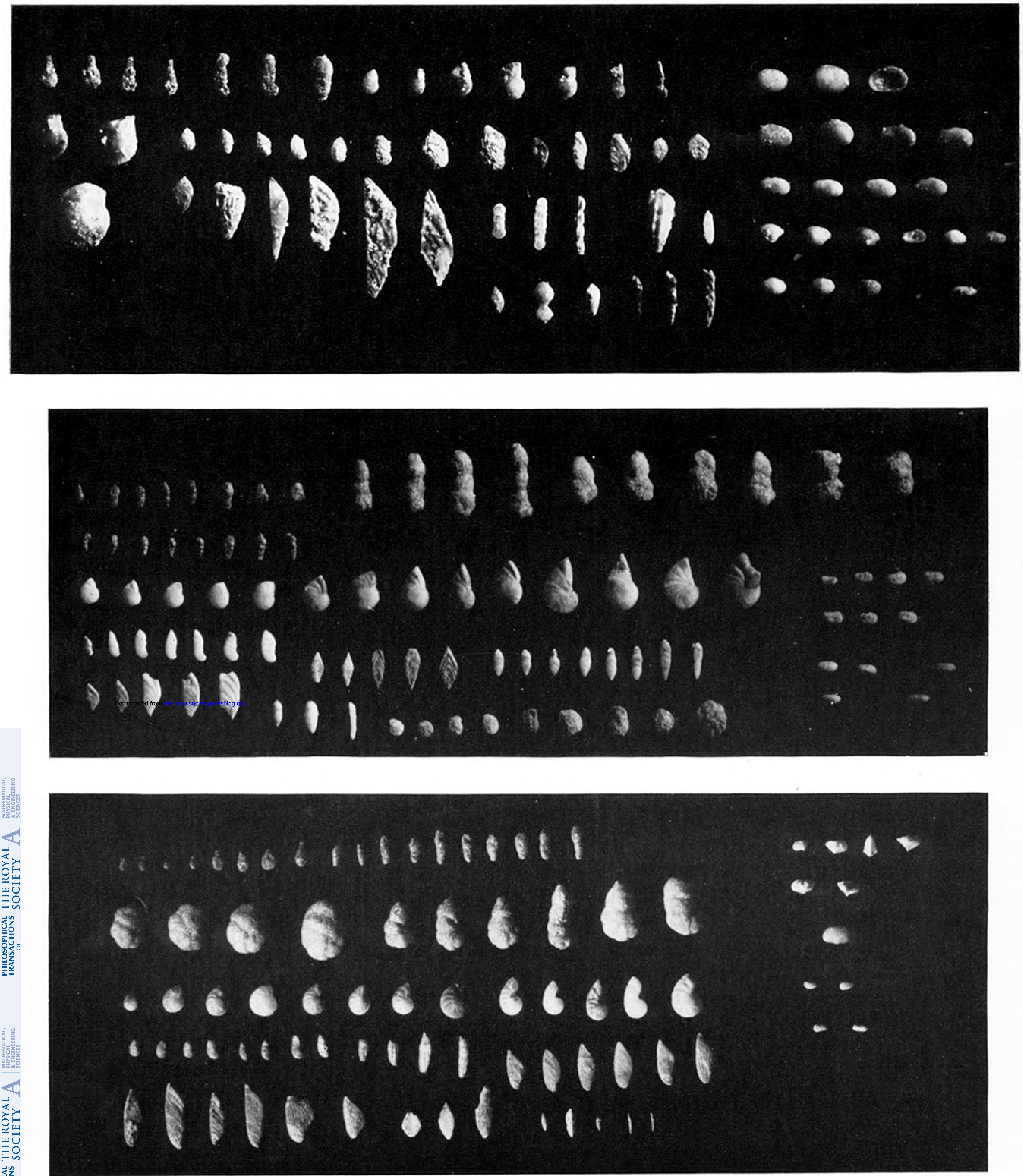
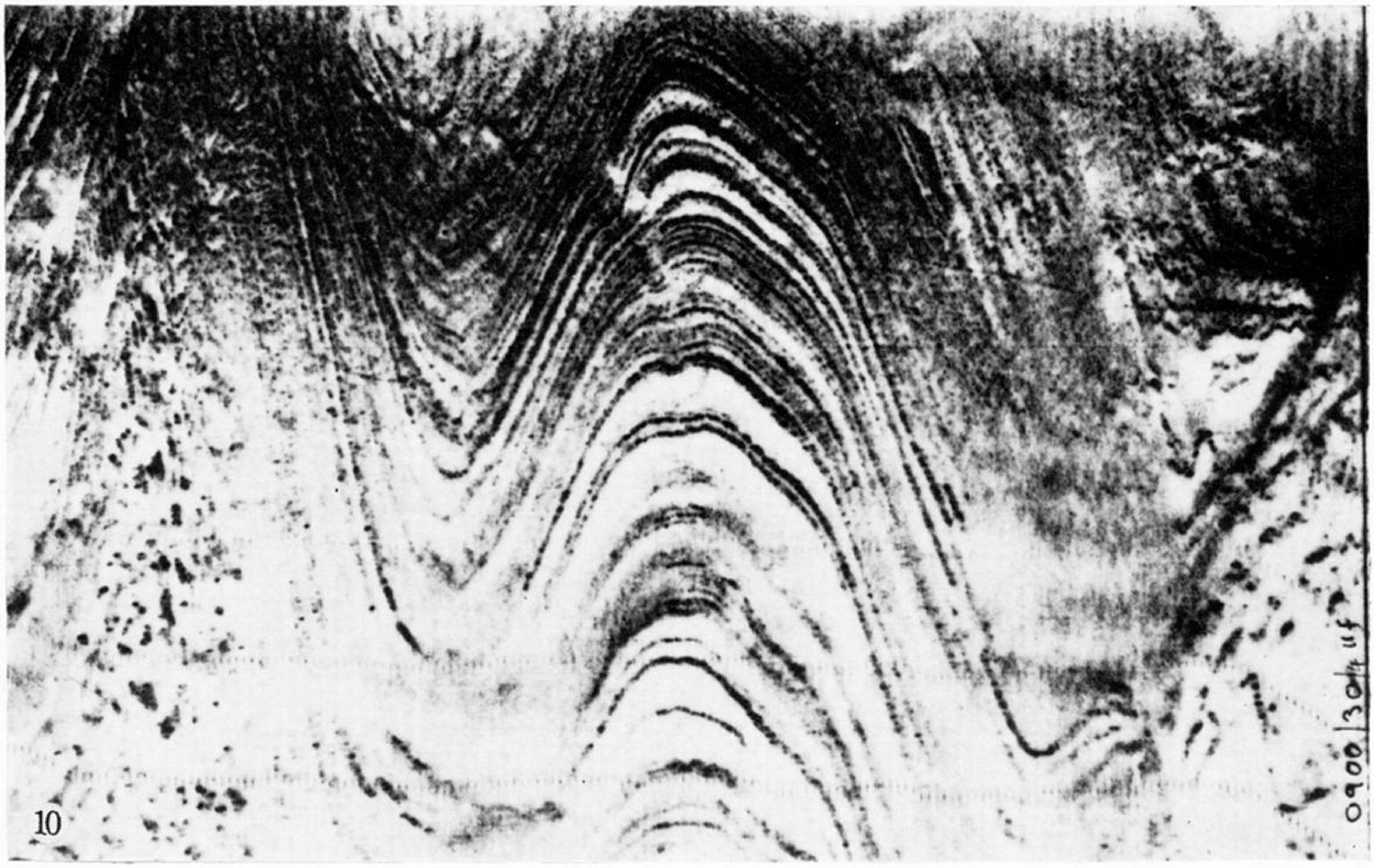


FIGURE 7. Representative microfossils from three samples of Jurassic rocks from the floor of the Bristol Channel. *Discovery* 4868 is Toarcian or Aalenian (upper group); *Sarsia* 125 is Callovian (middle group); *Discovery* 4340 is Kimeridgian, Mutabilis zone (lower group).



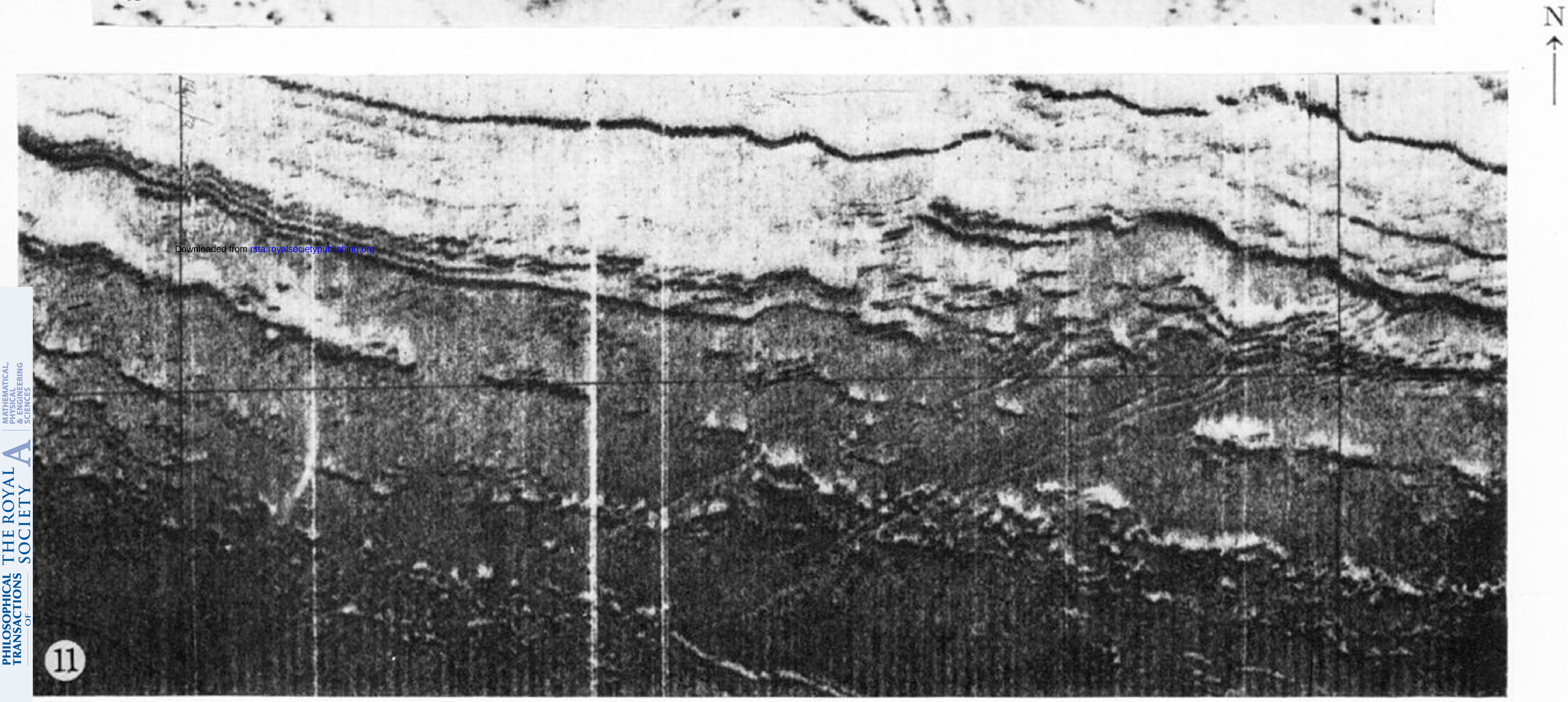


Figure 10. An oblique view of an area of about 1.8×0.3 n mile (3.3×0.6 km) of floor in the Bristol Channel, the mid-point of the upper edge of the sonograph being at about 51° 18′ N, 03° 19.4′ W, 5 n mile (9.3 km) south of Rhoose in southernmost Glamorgan. This pattern of wandering and broken outcrop lines shown by Sinemurian cementstones (whose scarp edges appear black) is typical of much of the northern and eastern parts of the Bristol Channel Syncline, where dips are low but there is some broad relief superimposed on that due to the hard layers. Range exaggeration (top to bottom) is about $2\frac{1}{2}$.

Figure 11. An oblique view of an area of about $1\frac{1}{3} \times \frac{1}{3}$ n mile (2.5×0.6 km) of floor, the mid-point of its southern edge being located at about 51° 19.2′ N, 04° 08.5′ W, 6 n mile (11.1 km) north of Ilfracombe. Thin layers of sandstone within the Oxford Sands strike east–west along the southern limb of the Bristol Channel Syncline. Some are continuous for more than a mile while others appear to be intermittent, probably because of their lesser resistance to erosion.