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

The Structure and Geological Evolution of the English Channel [and Discussion]

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The structure and geological evolution of the English Channel

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The Channel consists of three distinct provinces each characterized by its own geological style. The Western Province has rocks ranging in age from Lower Palaeozoic to Miocene with marked unconformities beneath the Upper Cretaceous and the Eocene strata. A major tectonic feature is a line of faults extending east–northeast up Channel. The Central Province is dominated by three fault or monoclinal structures and has rocks ranging from Jurassic to Eocene age. The Eastern Province is a relatively stable area dominated by a Tertiary syncline and a continuation of the Wealden anticline. Events related to the development of oceanic crust in Permian times are believed to have caused basic igneous activity, rifting and crustal thinning in the Western Channel and these factors and the subsequent opening of the Atlantic exerted a control over the development of the Channel. Alpine tectonism led to renewed movement on some structures. Folds are thought to be the surface expression of movements on old fault planes. The importance of a tectonic line between the Isle of Wight and northern France is emphasized.

Introduction

This paper is intended to fulfil three separate roles. First, it presents a general account of the geology of the Channel. This is, in part, to provide an introduction to the papers which follow and also act as a link with the last Anglo-French Colloquium on the geology of the Channel held in Paris in January 1971, published as Mémoire du B.R.G.M., No. 79, 1972, and the Anglo-French meeting in London in January 1974. To assist in this introductory role a map (figure 1) has been prepared which gives the location of the principal place names referred to in this and succeeding papers. In this same figure the opportunity has been taken to give both the French and English language names of those localities where different names are commonly applied. Secondly, the authors describe the principal geological structures found in the Channel; and thirdly, a possible geological evolution of the Channel is presented which attempts to place the geology of the Channel into the wider orbit of Western European geology. A simplified geological map (figure 2) has been prepared which incorporates much of the most recent work completed in the Channel and this is accompanied by a series of linked geological sections (figure 3).

The general geology of the Channel may best be described in terms of three provinces (see the inset to figure 1), each province is characterized by its own geological style and evolution and separated from its neighbours by distinct geological features. The Western Province is by far the largest of the three provinces reaching from the edge of the continental shelf to a line which has sometimes been called the Anglo-Norman Ridge – a name which can cause confusion since it resembles the French name for the Channel Islands. As the line extends from Start Bay, off Devon, to the Cotentin Peninsula of Normandy, a better name is the Start–Cotentin line, and this name is used throughout this paper. In this province rocks ranging in age from

Precambrian and Palaeozoic to Miocene and Pliocene are exposed on the sea floor. There are numerous unconformities and a major fault zone extends east–northeast from Ouessant to north of Alderney. The Central Province has rocks ranging in age from Permian to Eocene exposed on the sea floor; here unconformities are less apparent than in the Western Province. In this province there are three major structural features, two of which may have links to the Ouessant–Alderney fault zone, while the third and most northerly feature forms the Isle of Wight monocline. To the east of the island, this structure takes up a southeasterly alignment and forms the Bembridge–St Valéry-en-Caux line. This line is taken as the boundary between the Central and Eastern Provinces. The Eastern Province is the smallest of the three provinces and is dominated by a relatively undisturbed open syncline of Tertiary strata flanked to the northeast by continuation of the Weald anticline of southeastern England across into the Boulonnais area of northern France. The eastern limit of this province is the Strait of Dover.

The geology of the Provinces

The geology of the Western Province has been described in some detail by several authors, notably Curry, Hamilton & Smith (1970, 1971) and Andreieff, Bouysse, Horn & Monciardini (1970, 1971). In addition there have been numerous accounts of geophysical investigations, particularly of the western part of this province (Day, Hill, Laughton & Swallow 1956; Hill & Vine 1965; Day & Williams 1970). Briefly the geology may be described as follows: The folded Devonian and Carboniferous rocks of Cornubia extend west-southwestwards from Land's End and for some short distance off the south coast of Cornwall and Devon. Immediately to the south red rocks of Permian and/or Triassic age are exposed while, more locally, Jurassic strata similar to those of southern England outcrop, often as inliers in younger strata. On the south side of the Channel, the intensely folded and often metamorphosed rocks of the Armorican massif extend northwards for a considerable distance, partially under a thin cover of much younger strata. The central part of this province is dominated by a large broad syncline comprised of Upper Cretaceous Chalk and Tertiary strata; the Lower Cretaceous strata are only exposed in a horst structure caused by the principal faults of this province. There is no evidence as to the relationship between the Lower Cretaceous and the Jurassic rocks. The Upper Cretaceous strata rests unconformably on earlier strata and show clear evidence of a transgression from the west towards the east. There is evidence of non-deposition or removal by extensive erosion of the sediments of the highest Chalk zones in the western part of this province. The Chalk is succeeded by Palaeogene strata; those of the Danian and Thanetian are of limited extent but the Eocene strata composed of calcareous sands show evidence of transgression from west to east. The transgression reached far onto the Armorican platform even reaching around the Channel Islands. Again, as with the Chalk, subsequent erosion of these strata was greatest in the west. Oligocene strata, represented by freshwater limestones, occur only as small outliers. The succeeding Miocene strata are well developed and show some evidence of transgression from the west. Table 1 gives the successions, lithologies and observed thicknesses of strata of this and the other two provinces. Many small faults alined west-south-west have been recorded on seismic profiles but the major faults in this part of the Channel comprise the Ouessant–Alderney fault zone. Though the faults in this zone probably originated early in the geological history of the Channel, they have been active in post-Eocene times and indeed an earthquake in 1925 had its epicentre located within the Ouessant–Alderney fault complex. There is, furthermore, evidence of pre-Upper Cretaceous tectonic activity in this province with Lower Cretaceous and older strata affected by folding and faulting.

The succession and structures of the Central Province have already been described elsewhere, notably by Dingwall (1971) and several papers by Larsonneur, including his most recent account, which is presented elsewhere in this work. The basement, exposed only near the east Devon and Cotentin coasts, is succeeded by Permo-Triassic strata, probably Permian conglomerates and/or

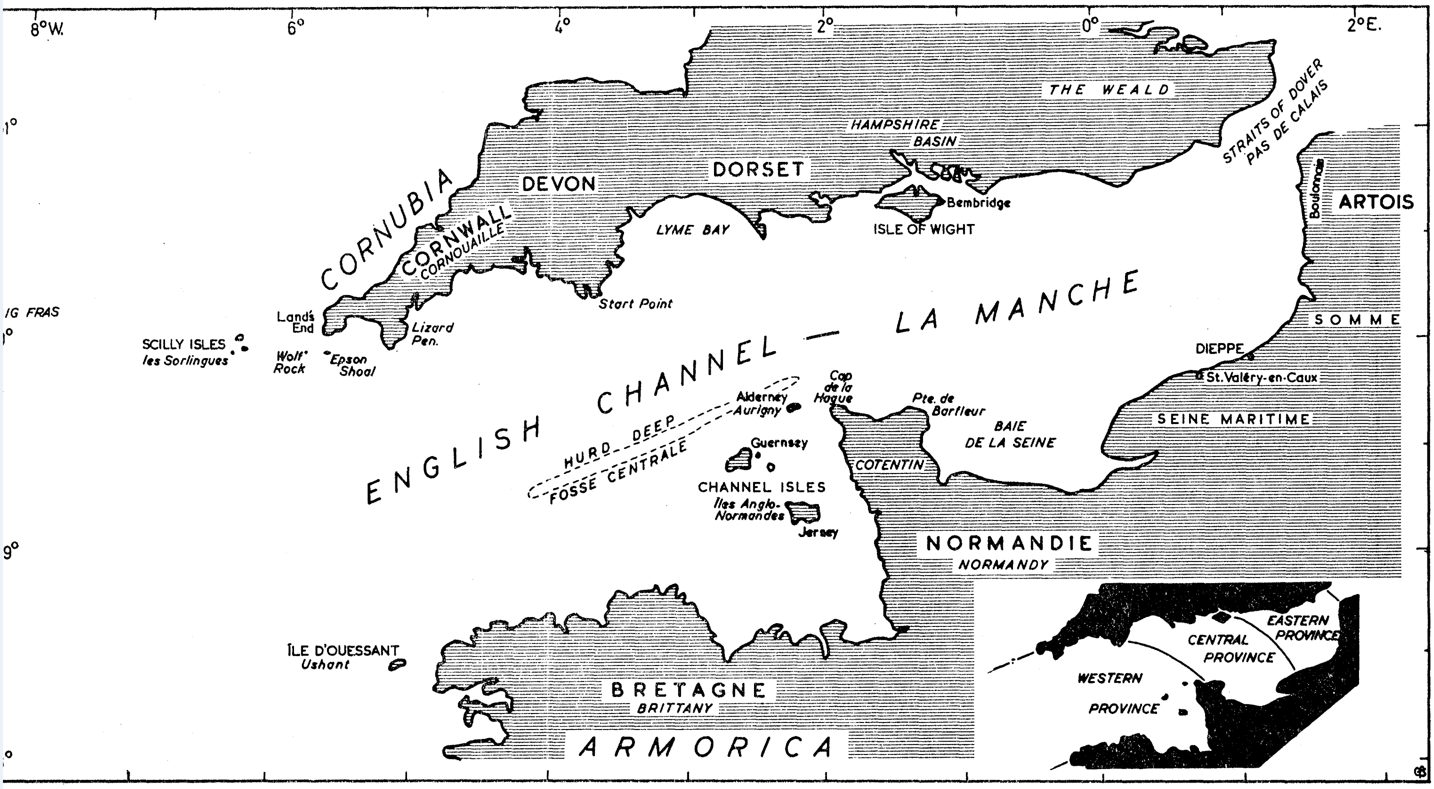

Figure 1. The English Channel. (Inset shows three provinces described in this paper.)

sandstones at first and later by Triassic marls. These rocks are succeeded by an extensive Jurassic succession, which, in mid-Channel, has strong affinities with the successions of southern England and includes Portland and Purbeck strata. The outcrop of these rocks north of latitude 50 °N has been mapped by the authors and appears in a map on the scale of 1:250000 to be published shortly by the Institute of Geological Sciences. The Jurassic succession in the Baie de la Seine is less complete, the upper stages apparently being absent. There may be a full Cretaceous succession with locally some intra-Cretaceous unconformities, as between the Albian/Aptian and Neocomian and below the Cenomanian. The Eocene strata occur in elongated outliers in this province. Generally, unconformities are less obvious in this part of the Channel and the Cretaceous transgressions appear to have been from the east towards the Start–Cotentin line, which is crossed by a thinned succession, mostly of later Upper Cretaceous strata. Three major tectonic structures dominate this province – all three are alined roughly west–east. In the north there is the major Isle of Wight monocline, with a northerly downturn of at least 1200 m, and its westerly extension as far as Lyme Bay. The mid-Channel structure is very similar to the Isle of Wight structure, though this time with an equally large downturn

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or downthrow to the south. South of this is the third structure – again with a downturn to the south, this time of about 500 m maximum. All three structures die away gradually to the east. Tertiary strata are exposed in asymmetrical synclines on the downturn side of the three structures and Jurassic strata are exposed in the complementary anticlines of the mid-Channel and southern structure. The northernmost of the three major structures becomes the Bembridge–St Valéry line. The successions of strata in Lyme Bay and Baie de la Seine give the impression of being deposited onto relatively stable platform areas since they are not affected tectonically to the degree found in the mid-Channel structures.

The Eastern Province is dominated by the Tertiary outcrops exposed as an elongated flat syncline, the Dieppe Basin of Robert (1971), which is now seen to link directly with the Tertiary

TABLE 1. STRATIGRAPHIC SUCCESSIONS AND PRINCIPAL LITHOLOGIES OF THE THREE PROVINCES OF THE ENGLISH CHANNEL (THICKNESSES, ARE ESTIMATES BASED ON OUTCROP INFORMATION)

	Western Province	Central Province	Eastern Province
Igneous rocks	Variscan granites in basement; very local lower Cretaceous phonolites in north	Variscan granite at Barfleur	none
Pliocene	not found	not found	not found
Miocene	globigerina silts, transgressive from west (> 150 m)	not found	not found
Oligocene	isolated outcrops of freshwater limestone	isolated outcrops of freshwater st.	not found
Eocene	calcareous, often glauconitic, sandstones transgressive from west; also unconformity between Ypresian and Lutetian (> 500 m)	Hampshire Basin succession type in mid-Channel; some Western Province type in in south (> 150 m)	strong affinities with Hampshire and northern France successions (> 400 m)
Palaeocene	Danian and Thanetian present in mid-Channel (> 120 m)	Sparnacian facies recognized; no Danian or Thanetian	Sparnacian and Thanetian; no Danian
Cretaceous	Upper Cretaceous represented by typical Chalk: transgressive from west resting unconformably on many older strata (> 500 m) Lower Cretaceous non-marine sediments found north of Armorican basement (> 150 m)	complete succession from Wealden through Albo-Aptian to Chalk successions; minor unconformities; evidence of transgression from east (> 1500 m)	full succession of strata as found in S England (> 400 m)
Jurassic	dark grey clays and marls of Lower Jurassic, pale clays and calcarenites of Mid-Jurassic; successions similar to those of S England (> 500 m)	Lower and Middle Jurassic as in Western Province; Upper Jurassic present; succession similar to those on land	Jurassic successions a continuation of those of the Boulonnais of northern France
Triassic and Permian	Red Keuper (?) marls and tea-green marls in north; Marls in mid-Channel; not known in south (> 300 m)	conglomerates off Devon and sandstones off E Cotentin; marls higher in succession (> 500 m)	not found
Basement	folded Devonian and Carboniferous strata and rocks of the Lizard–Start complex in north; folded and metamorphosed Precambrian and Palaeozoic rocks in south and around Channel Islands	not exposed except as seaward continuation of rocks of Start and Barfleur	not exposed

strata exposed in Hampshire and the Isle of Wight to form what is now called the Hampshire–Dieppe Basin. It seems clear that all the Tertiary strata of the Central and Eastern province once formed part of one depositional basin, the present separation being produced by the episode of post-early Oligocene folding. The form and succession of the Tertiary syncline is described in another paper by the authors and also one by Auffret *et al.*, both of which are published later in this volume (Curry & Smith 1975; Auffret *et al.* 1975). North of the Tertiary syncline, the Weald–Artois structure extends across the Channel exposing an almost complete succession of Upper Jurassic and Cretaceous strata. The former have been affected by pre-Upper Cretaceous earth movements in the Boulogne area.

Structures of the Channel

The geological unconformities and faults shown in figure 4 were recognized from mapping based on close sampling and by seismic surveying of the near surface geology: many small faults, usually with throws of less than 10 m, are not shown. The amount of vertical movements on faults and downturns shown in figure 5 is based upon the evidence of the surface outcrop map, however, it seems likely that many faults have had repeated movements, sometimes in a sense opposite to that apparent from the map. Some faults can be recognized to be of major significance because of their relationship to the pattern of magnetic anomalies discovered by surface and airborne surveys. The structures exposed on the floor of the Channel are believed to reflect movements on major crustal structures which, in addition, seem to be perennial structures capable of exercising some control over the sedimentation rates and thickness of the successions exposed on the Channel floor. The directional trends of all structures are clearly apparent on mapped information from sea-level and airborne magnetometer surveys of the Channel and its Western Approaches. Such results emphasize the fundamental nature of most of the faults, furthermore they clearly hint, especially in the Central Province and also north-east of the Bembridge–St Valéry line, that the depth to the basement is not always greater on the downthrow side of structures. This implies that movements have not always been in the same sense – that is, what is the downthrow side of a structure now may have been the upthrow side at an earlier time (cf. Terris & Bullerwell 1965, p. 209).

The basic structure of the Western Province is an elongated basin of Upper Cretaceous and Cenozoic rocks interrupted by widespread unconformities separated from the peneplaned northward extension of the Armorican massif by a zone of faults, the Ouessant–Alderney fault zone. The faults appear to have principally vertical movements and have produced, locally, horst and graben structures. Measured only by their effect on the youngest strata of the area, the vertical movement across the zone is small. However, it seems that the movement has been persistent and the cumulative effect has been to keep the Armorican extension as an uplifted area while leading to the depression of the floor of the basin to the north.

Between the Permo-Trias and the Devonian–Carboniferous rocks of the English coast there is another line for which, though it may have a tectonic origin, there is no clear evidence of activity in post-Permian times. It is best interpreted as an eroded fault scarp. It is suggested that the tectonic lines between the Lizard complex and the Devonian of Cornwall and the Start Complex and Devonian of Devon are Variscan structures which have been exposed by erosion and are thus older than the structures found nearer to the centre of the Channel. The old (375 ± 15 Ma) rocks of Eddystone probably had a similar tectonic origin and were part of a pre-Permian landscape.

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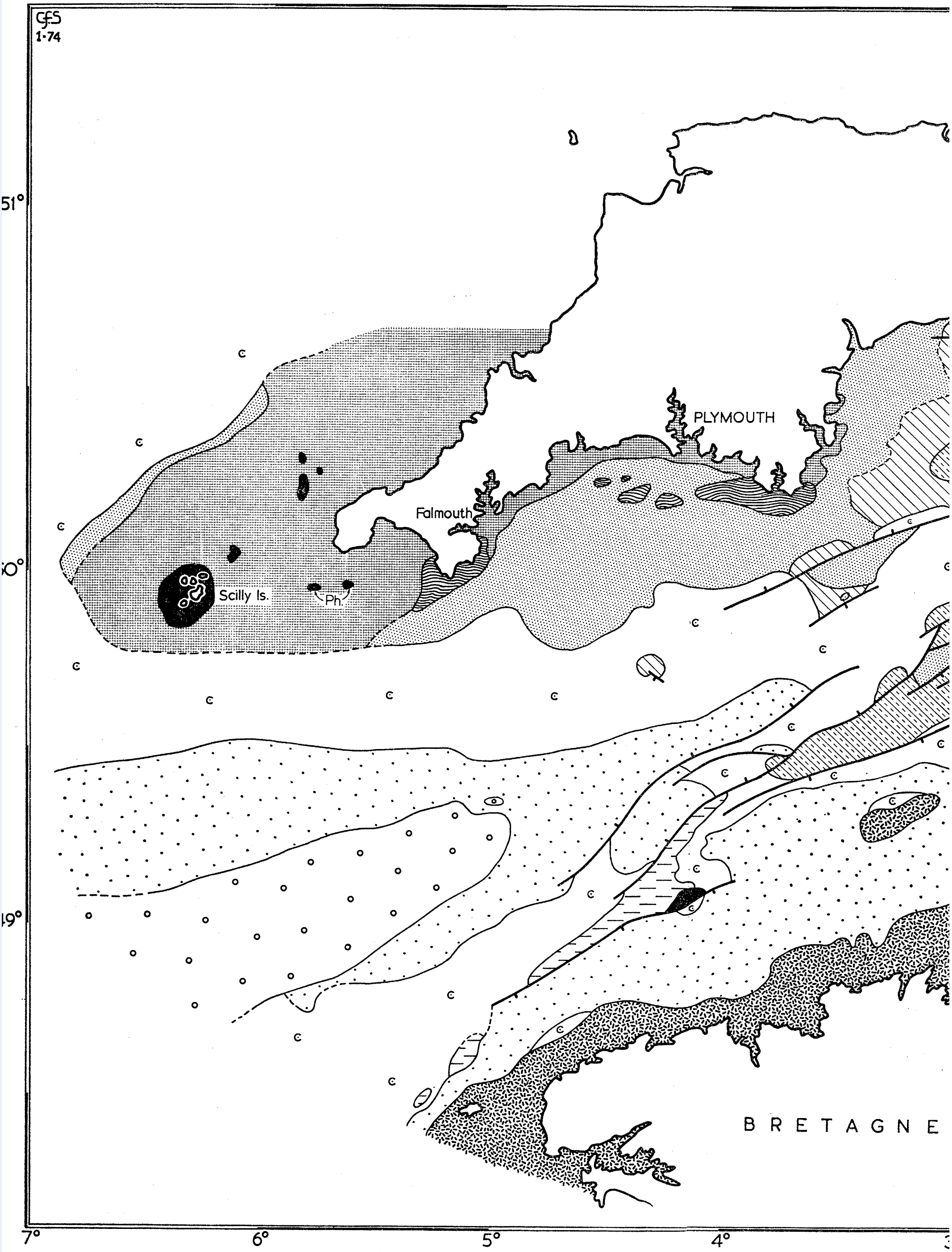

Figure 2. Geological map of the Channel.

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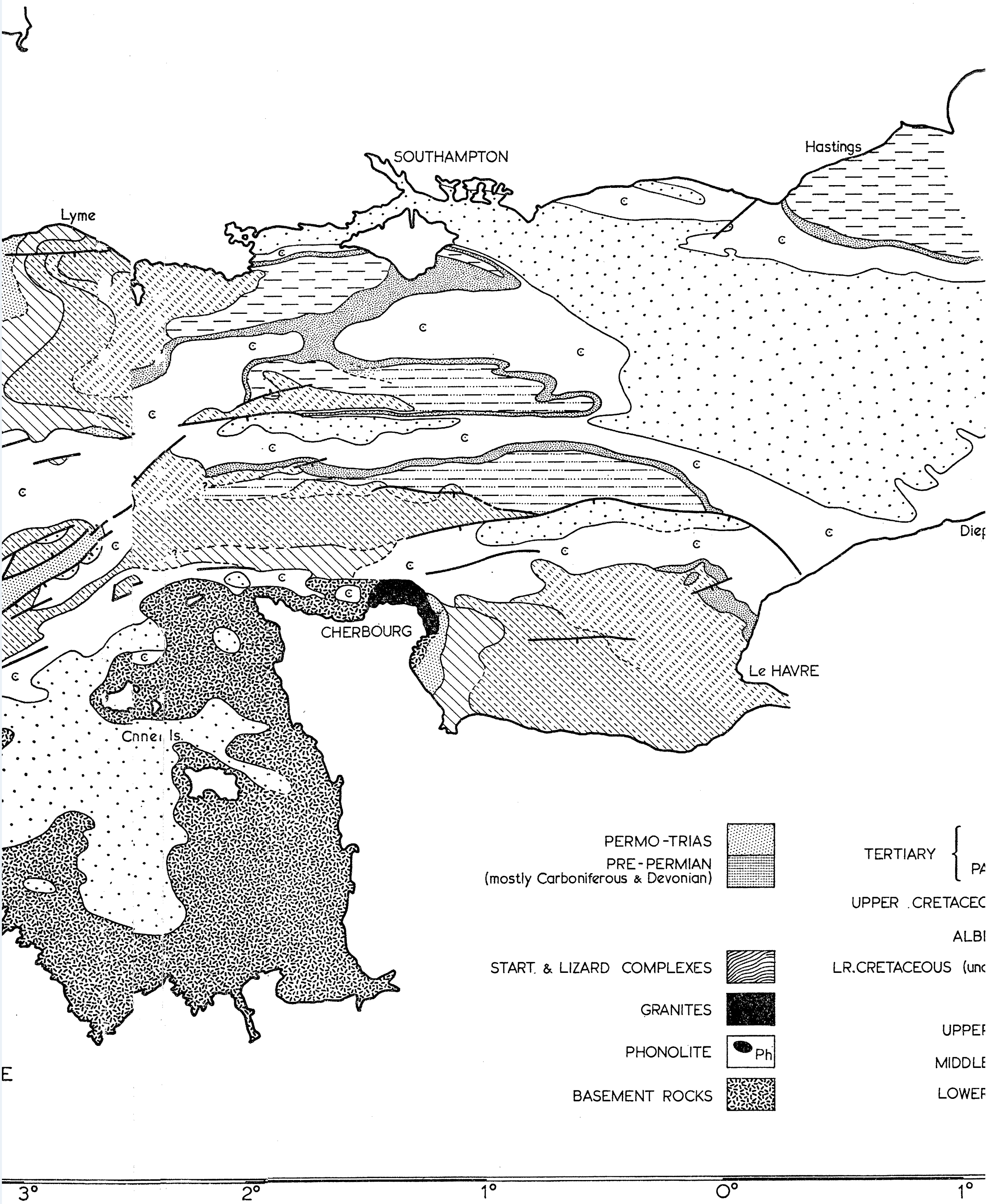

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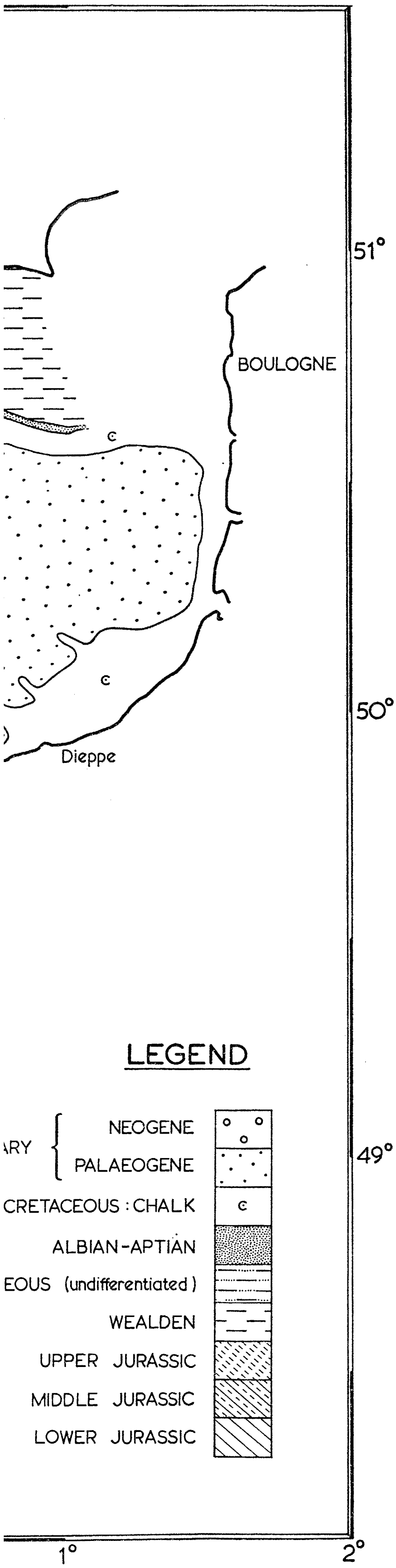

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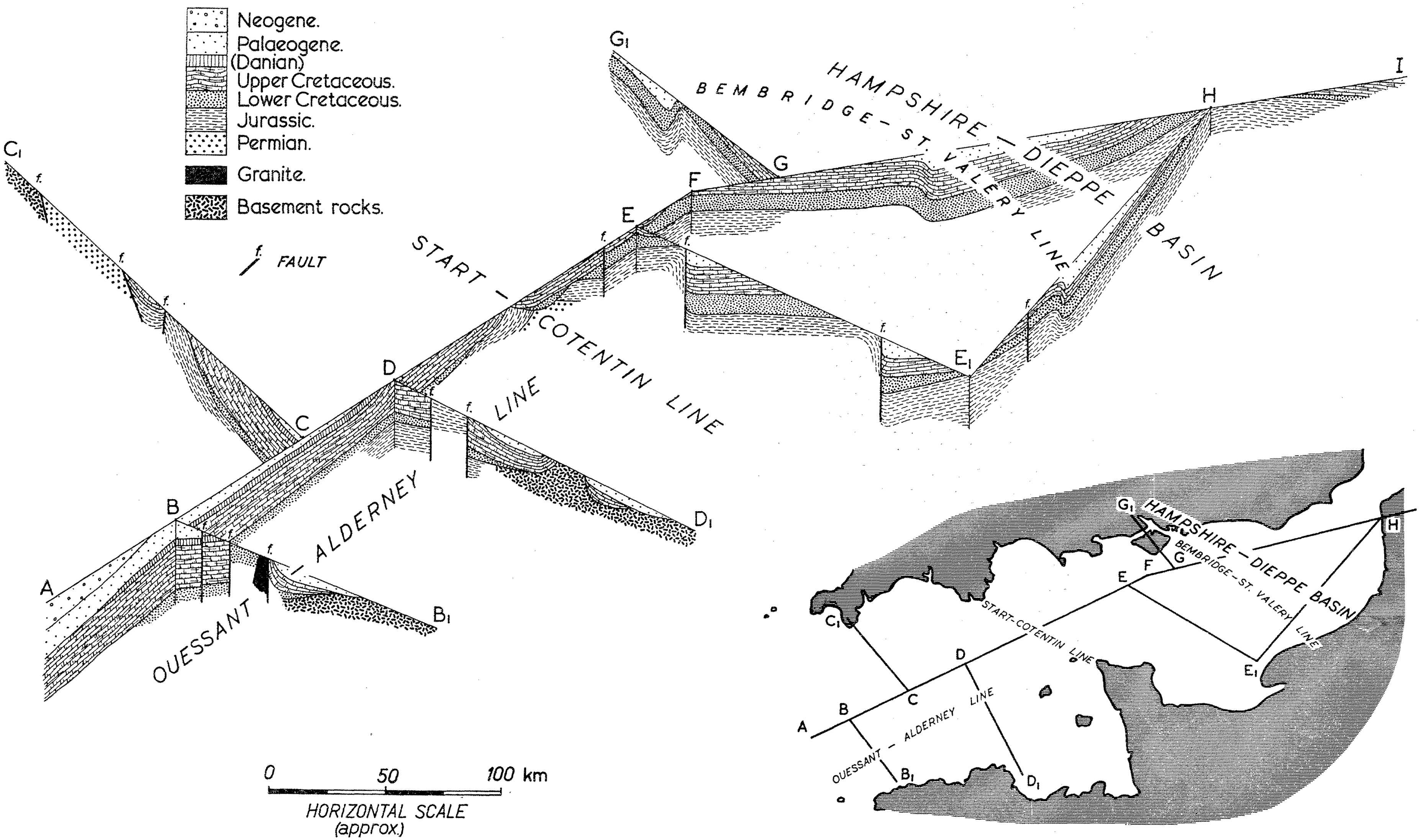

FIGURE 3. Transverse and longitudinal sections of the Channel to show the principal relations. The horizontal scale is only approximate. No vertical scale has been given since there is little subsurface information to substantiate thicknesses.

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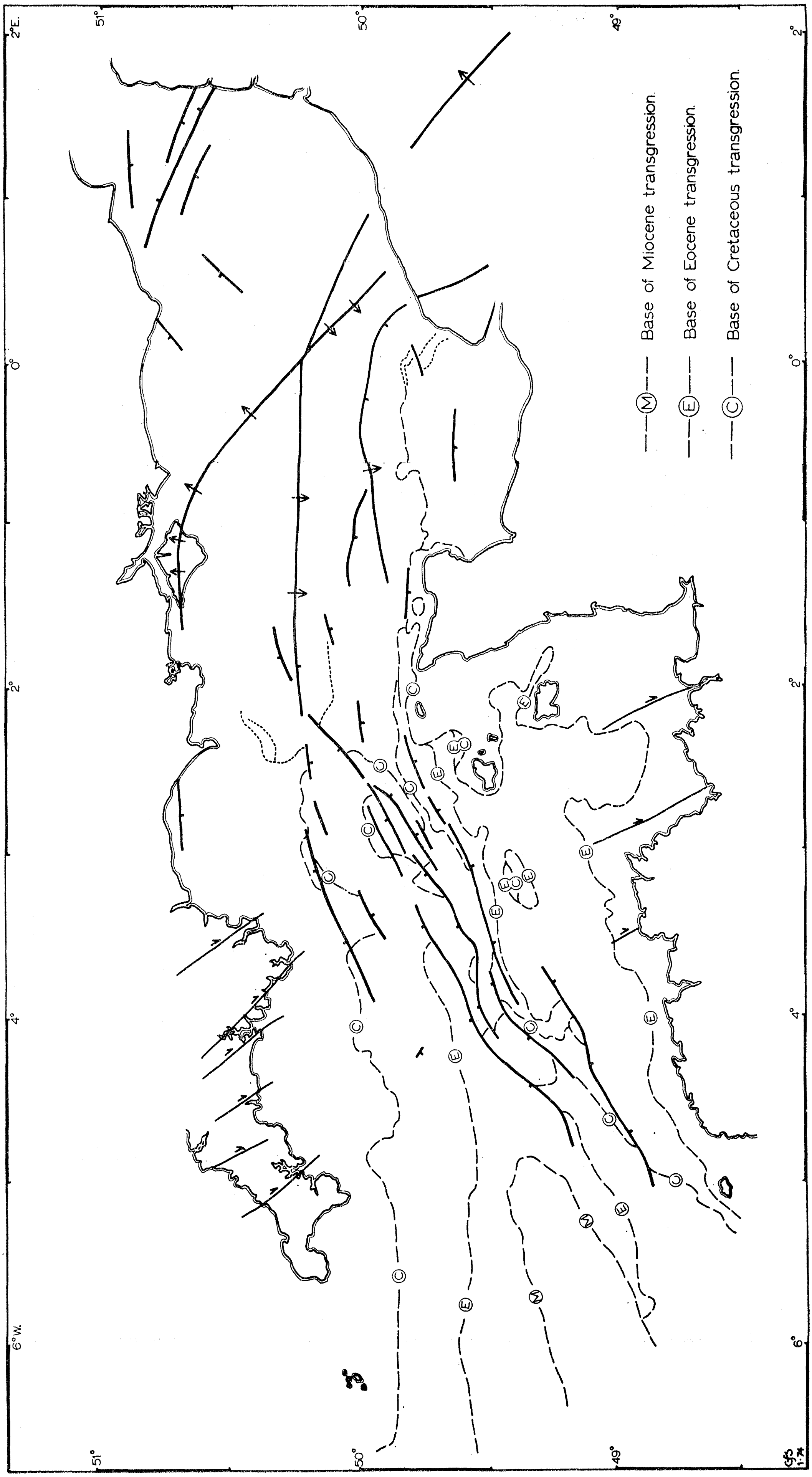

FIGURE 4. Principal unconformities and tectonic features.

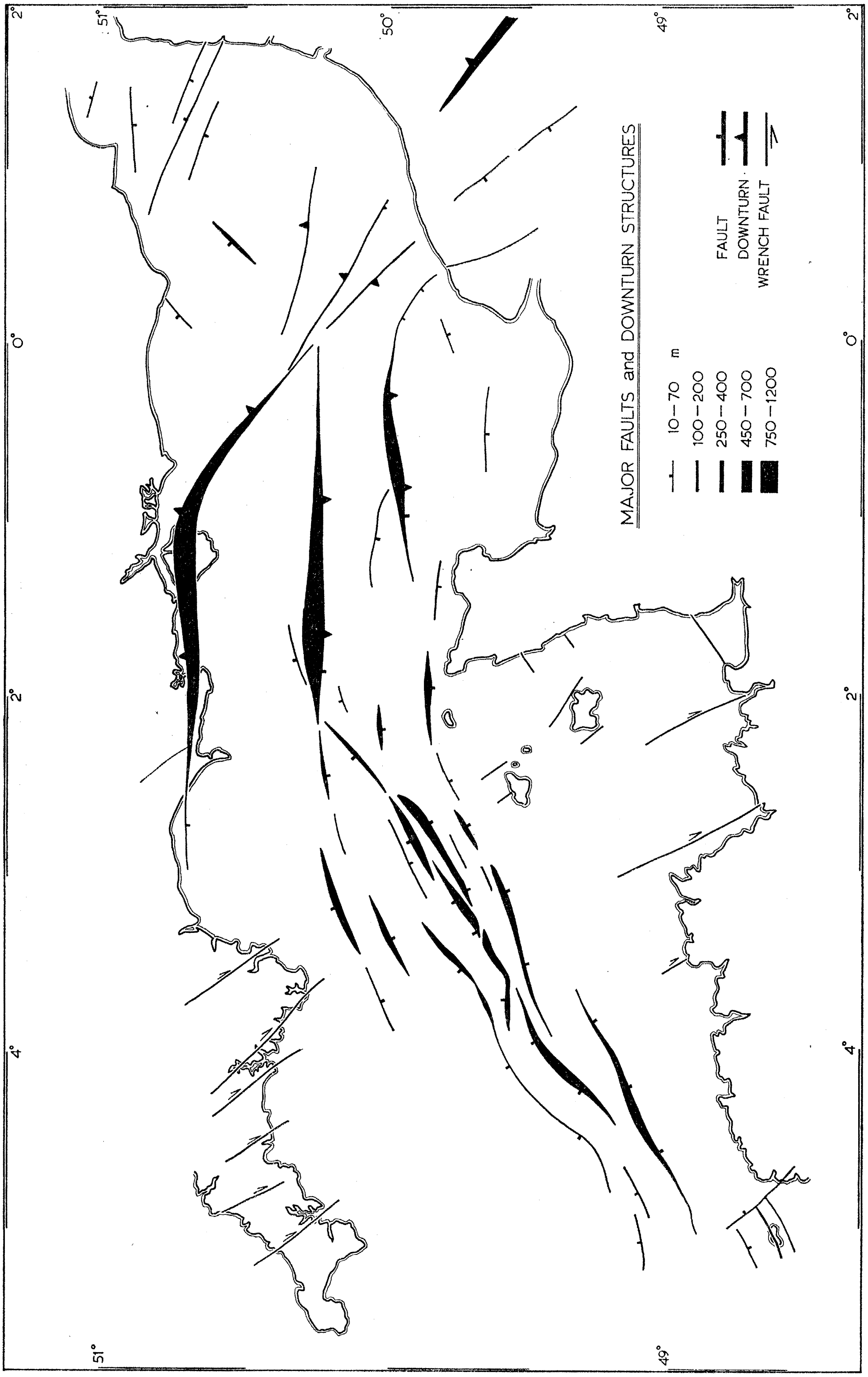

Figure 5. Faults and downturns with estimated vertical displacements based on surface outcrop data.

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Besides the very obvious west-southwest–east-northeast alinement of fold and fault structures in the province, attention must be drawn to a northwest–southeast alinement of faults which are well displayed in southwest England, in Armorica and in the northwards extension of the Armorican basement. So far few northwest–southeast structures have been noted affecting the Mesozoic and Cenozoic strata of the Western Province.

The Start–Cotentin line must also be regarded as a structural feature. It has clearly exercised a geological control on part of the Channel for a long time – indeed the marked narrowing of the present Channel reflects this. This line has been a gently positive area controlling Cretaceous

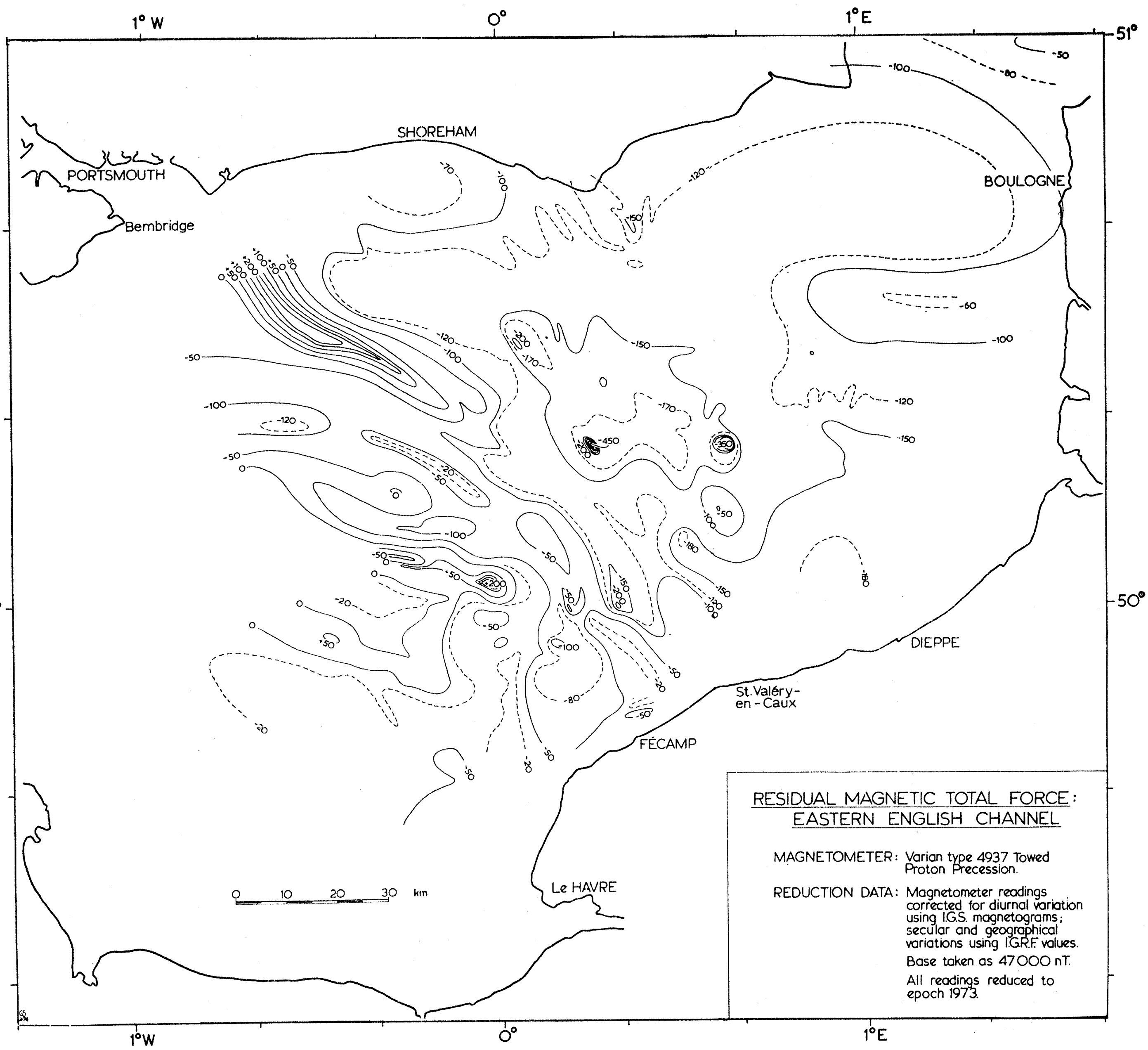

FIGURE 6. Sea-level magnetic map of the Bembridge–St Valéry line and the Eastern Province. Interpretation made by R. F. Mead.

(and possibly Jurassic) sedimentation: beds thin towards it and in the Cretaceous it was transgressed on to from the west and the east. The Eocene strata, too, thin towards this structure and there are facies contrasts between the principal Eocene developments on each side of it. It is along this line that there is a realinement of the fault and fold structures of the Channel, the west–southwest trend giving way to a west–east trend. This gentle ridge-like feature which so effectively separates the Western and Central Provinces may owe its origin to a postulated extension of the Cornubian granite mass southeastwards to link with the Barfleur granite. The presence of such a granite mass could explain the generally positive nature of the feature.

The major structures of the Central Province are monoclinal in form and in all three structures the axis of the complementary syncline is close to the structural line. Locally the Jurassic strata, particularly the Kimmeridgian, are much affected by close set faults of small vertical movement. Though as stated above, the movements on these major structures have not always been in the same sense throughout their history, the post-Eocene movements have been considerable. In places it is difficult to be sure whether or not the structures are faults or folds, however, whatever the surface expression, they are taken to be the product of movement on deep seated fault structures.

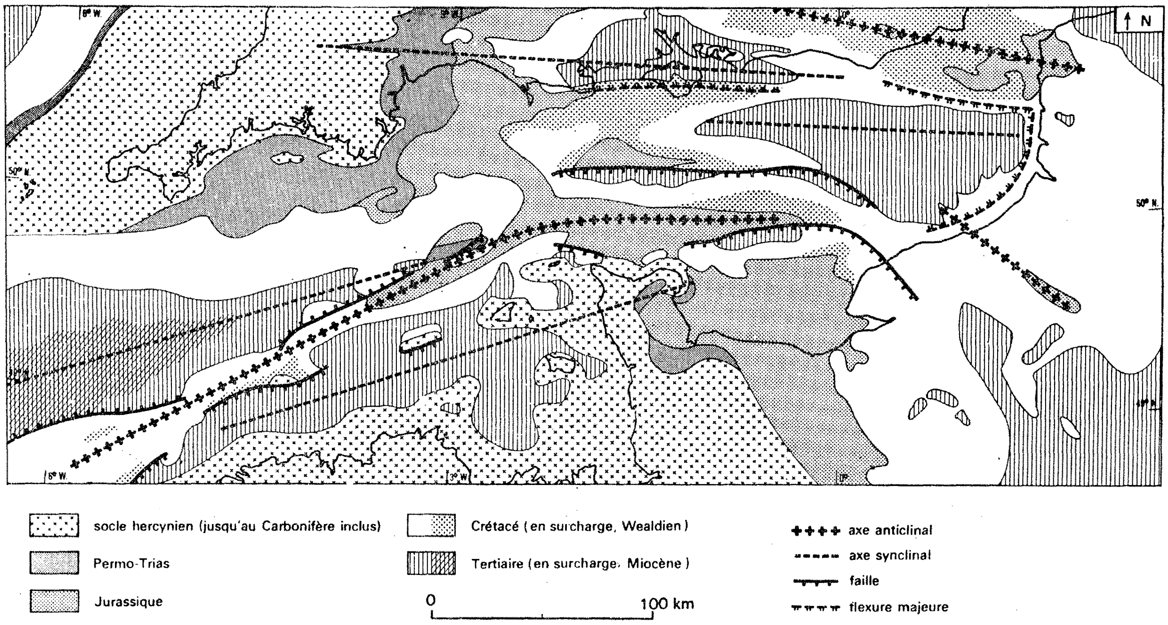

Figure 7. Map of Channel showing suggested directions of major structures before the publication of this paper. Map reproduced from *Ère Cénozoïque* by Charles Pomerol. Reprinted by permission of L'Encyclopaedia Universalis.

The eastern limit of this Central Province, as has been stated earlier, is a south easterly extension of the Isle of Wight monocline the axis of which changes direction just east of the Isle of Wight. The importance of this line is clearly shown in figure 6 which is based upon the interpretation by R. F. Mead of data collected on recent cruises in the English Channel. This structure has a monoclinal form with downturn towards the northeast and the amount of downturn decreases south eastwards counterbalancing the mid Channel structure. This can be clearly seen in figure 5. Further to the southeast, the Bembridge–St Valéry line divides into two features which though not significant as they cross the French coast, do connect with major structures in France recognized by surface geology and/or magnetic and borehole data. The cross channel nature of this line has not been recognized by previous workers (see, for instance, the illustration on p. 209 of Pomerol (1973), which is reproduced here as figure 7).

The Hampshire–Dieppe basin of the Eastern Province is tectonically smooth except for some flexures near the English and French coasts. Much of the central part of the basin is quite flat. The pre-Upper Cretaceous strata of the Weald–Artois anticline are, in contrast, affected by strike faulting, alined roughly west–east, though the throw on the faults is never more than some tens of metres. Approaching the Strait of Dover, a northwest–southeast trend in the gravity anomalies becomes evident, a direction supported by fault alinements in the Kent coalfield (Shephard-Thorn, Lake & Atitullah 1972) but not reflected in surface faulting.

A possible geological history of the Channel and its approaches

At the close of Variscan orogeny in late Carboniferous times the whole region had become a stable block possessing a marked west–east geological 'grain'. The Variscan structures extended 'westwards' into the North American continent and into northwest Iberia, both of which were adjacent to the region since at this time there was no Atlantic Ocean or Bay of Biscay. By early Permian times new oceanic crust was beginning to develop between North America and Iberia (see Williams & Mackenzie 1971). We believe that the trend of the opening was towards the Channel, indeed we think the Channel region was affected by the processes which precede the formation of new ocean crust: that is, that the area was subjected to uplift accompanied by rifting and furthermore that these processes led to widespread outpourings of basic lavas. While these events mostly affected the area of the Western Province, we believe that the structural effects extended up Channel until deflected by a major northwest–southeast feature which we now recognize as the Bembridge–St Valéry line.

The first effects of these processes in early Permian times were outpourings of lava. The Exeter Traps (Tidmarsh 1932) of south Devon may be part of this episode while the magnetic anomalies described by Hill & Vine (1965) may reflect the presence of widespread volcanics in the Western Province as well as the faulted nature of the pre-Permian basement. The high magnetic relief on the line of the Start–Cotentin ridge may similarly be due to the presence of basic volcanics and basement faulting. Evidence for the contemporaneous uplift of the Channel region exists in the Permian Budleigh Salterton Pebble Beds of south Devon (Laming 1966). These rocks were deposited under terrestrial conditions from sources which lay to the south and west. The lowest part of the succession is the coarsest and the formation contains pebbles with Armorican affinities as well as pebbles of two types of volcanic rocks. One of the latter types has affinities with the Exeter traps, the other comes from an unknown source. Deep drilling in the Western Province may reveal Permian conglomerates as well as volcanic rocks and the possibility that evaporites may also have been precipitated in this area in Permian times cannot be overlooked.

It seems clear that these Permian events produced a set of conditions which have exercised a control over the development of the Western Province and, less directly, of the whole Channel. This control, though diminished, may still exist today. The less dense areas with their Variscan granites, being relatively buoyant, have become the Cornubian and Armorican peninsulas while the area between, made dense by the Permian basic volcanics and depressed owing to crustal thinning became the Channel. It seems likely that some mechanism, such as that proposed by Collette (1968, 1971) to explain the North Sea basin, has been responsible for the crustal thinning. The Ouessant–Alderney line, first developed in Permian times, possibly as the axis of rifting prior to the abortive development of an ocean floor, became the boundary between the positive Armorican massif and the Channel basin. The cumulative downthrow on this line must be of the order of several kilometres and it effectively separates a source area from a basin of deposition. Only in Eocene times does the Armorican platform seem to have been an area of extensive deposition. As stated above, the Start–Cotentin line is the product of similar fundamental controls.

In Triassic times deposition was continuous in the Western Channel area. The northern boundary of Triassic marls is near the English coast against what may be a degraded fault scarp. The nature of the Triassic sediments suggest that there was deep weathering and possibly rapid erosion of the source areas. The Lizard–Start complex may have been exposed for the first time during the Triassic period – there is no evidence from the rocks of Devon of their exposure in Permian times. The red rocks called Permo-Trias by Curry *et al.* (1970, 1971) are widespread and it is difficult to estimate the full thickness of these beds, which may, however, be of the order of 1000 m. In a few localities pebbly deposits occur, but no continuous formations of coarse conglomerates and breccia have been discovered. Thus, in general terms, the West Channel was a subsiding area throughout Triassic times.

Jurassic sediments are not widespread in the Western Province, being confined mainly to the eastern part of that province and to the Central and Eastern Provinces. Jurassic rocks may, however, exist below the cover of younger sediments in the west of the Western Province. Should this be the case it is possible that they will resemble those of the Permian for this was a time of the continued development of the Atlantic with movements affecting the Bay of Biscay. Instead of the main trend of opening continuing to affect the Channel, there was a change in direction which led, ultimately, to the rotation of Spain and the opening of the Bay of Biscay (see Harland 1969). This would have caused uplift, rifting and volcanism at what is now the continental margin. Evidence for this is slender but the bentonites of the Fullers Earth formation of southern England are evidence of volcanicity at this time. Jurassic volcanism in the western part of the Province cannot be ruled out.

By early Cretaceous times the Atlantic ocean began to develop towards the northwest and further uplift of the continental margin was part of this episode. Certainly there is evidence to support this from the Channel where the most westerly lower Cretaceous strata, seen exposed in a horst structure which is part of the Ouessant–Alderney line, are non-marine in character. Much of Britain and western France was subject to erosion at this time. These developments were accompanied by more volcanic activity – the phonolites of Wolf Rock and Epson Shoals which have been dated as Lower Cretaceous (Miller & Mohr 1964) and bentonite deposits which occur in the Lower Greensand succession of southeast England are evidence of this.

The gravity anomalies described in the Western Province by Browne & Cooper (1952) and Day & Williams (1970) lend support to the possibility of widespread volcanics in the Permian to Lower Cretaceous rocks of this area. Knowing that the total thickness of sediments in this province must be of the order of several kilometres, negative rather than positive anomalies would have been expected. The reverse is the case and this is taken as evidence in favour of volcanic rocks in the pre-Upper Cretaceous successions.

The rifting of the Atlantic on what was to be its final trend concluded the first part of the history of the Channel. In its later history the Channel continued to receive sediments but th factors controlling events were modified. Now a true ocean existed at the western end of the Channel and the subsequent history of the Western Province is clearly affected by repeated vertical movements of the continental margin which led to transgressions and regressions. What controlled the vertical movements of the outer part of the continental crust at this time is a matter of conjecture. One mechanism might be the oceanward creep of the lower continental crustal material accompanied by the subsidence of the overlying brittle layer – a mechanism suggested by Bott (1971). This mechanism, however, seems to be a 'one-way' mechanism allowing for only the depression of the margin while events require repeated 'two-way' movements causing a succession of elevations and depressions over quite a long time-span.

The first and greatest transgression coincided with the widespread transgression of the Chalk Sea over northwest Europe and one cannot but reflect on a possible connexion between this event and the existence of a new deep ocean bordering the previously eroded continent. In the Western Province the transgression was eastwards towards the Start–Cotentin ridge. There the Upper Chalk successions are thin, possibly due to slower deposition or to pene-contemporaneous erosion. At some time after the end of the Maestrichtian there was widespread erosion of the Chalk, particularly in the west as a result of which the succeeding Palaeocene sediments are restricted to an elongate outcrop close to the Ouessant–Alderney line (see Curry *et al.* 1971). Though the events which had first caused this line had been superseded, it continued to affect sedimentation in the Channel.

The uplift of the western part of the province which caused the widespread erosion was followed by depression, for by Eocene times renewed transgression from the west towards the Start–Cotentin line had begun. These Eocene sediments were influenced by the Atlantic and contrast with those which predominate east of the line; one cause of the contrast is discussed by Wright & Murray (1972).

There is no widespread complete succession of Eocene sediments in the Western Province, instead the higher Eocene sediments are of more limited extent, possibly due to uplift and erosion. The succeeding Oligocene sediments, though very rare, are thought to have been deposited in freshwater conditions, thus further indicating a period of emergence. The succeeding Miocene sediments are undoubtedly marine and though they did not reach as far into the Channel as the Eocene sediments, they are once again a consequence of a marine transgression. There is further evidence for the repeated vertical movements of the outer edge of the continent. A sample dredged from a depth of 1000 m in the canyon system of the approaches to the Channel contained Eocene limestone with a relatively shallow water fauna together with early Miocene limestone which, on faunal evidence, was deposited in water perhaps as deep as 1000 m.

In contrast with those of the Western Province, the geological successions of the Central and Eastern Provinces have strong affinities with those on the adjacent land areas. The principal geological structures are strongly related to the structures of the Western Province and are along lines defined early in the Channel's history. As has been noted above, the magnetic evidence from the Central Province show that the movements on these structures have not always been in the same sense, and it seems likely that such movements controlled sedimentation locally. The structural contrast between the Central and Eastern Province is marked – this contrast is due to the Bembridge–St Valéry line, which appears to have protected the Eastern Province from the structures developed early in the Channel's history. It is for this reason that the geological picture of the Eastern Province coincides so neatly with that of the adjacent land areas. This province has remained a relatively stable area with some evidence of pre-Upper

Cretaceous movements as well as some gentle post-Eocene movements. There is no clue as to when sedimentation in this area began and evidence from deep bore holes must be awaited. The possibility of Coal Measure strata beneath this part of the Channel cannot be neglected for it seems to be part of an old and relatively stable part of the continent. That this may be so is emphasized by the recognition that the Bembridge–St Valéry line is part of an important structure which can be traced to the Massif Central of France (see figure 8). After balancing the mid-Channel downturn, the Bembridge–St Valéry line divides and crosses the French coast

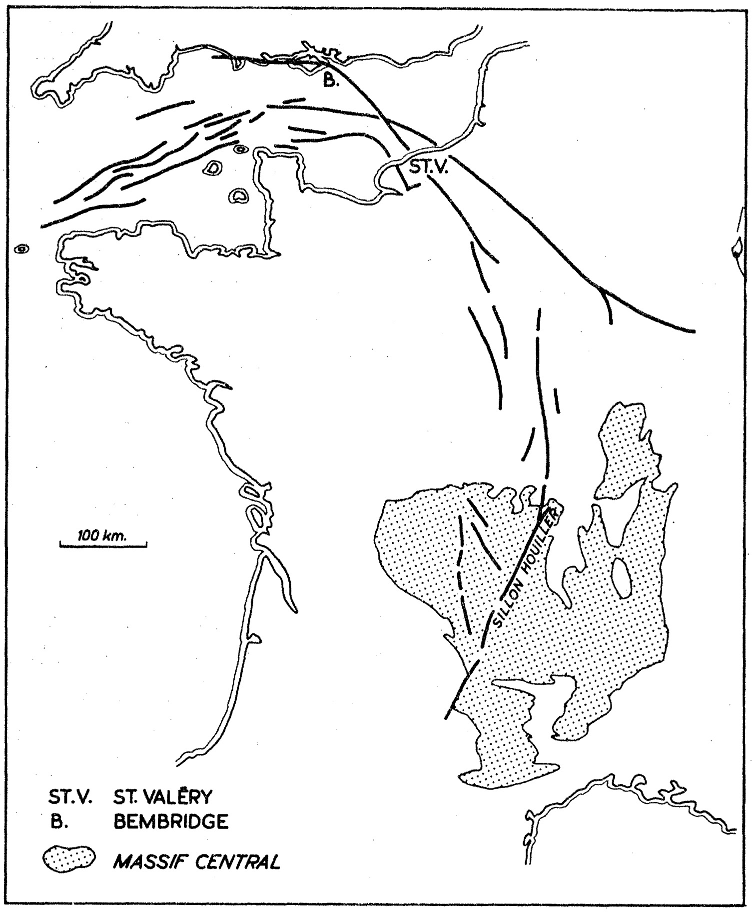

Figure 8. The principal tectonic structures of the Channel and their relation with the Sillon Houiller of the Massif Central.

as two relatively minor structures. The more easterly structure increases in intensity and develops into the Pays-de-Bray anticline while the direct Bembridge–St Valéry line continues first southeastwards then southwards as surface faults, as subsurface faults, recognized from isopachyte maps based on borehole evidence, and as a distinct magnetic anomaly until it reaches the Massif Central where it becomes the Sillon Houiller. This major structure separates the northwest trending structures of the Massif Central from those which trend northeastwards, that is, it is the bisectrix of the Hercynian structures of France, and as such, is one of the major structures of Europe.

If the history of the Channel is summarized briefly, it will be seen that it owes its origin, tectonic pattern and development to two sets of forces – on the one hand those of a developing

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Atlantic ocean crust, on the other events affecting continental northwest Europe. The early part of the history is related to a possible development of ocean crust along what is now the line of the Channel, this development might have been deflected southeastwards into the European continent. Though this development was effectively stopped by the change in direction of opening of the Atlantic consequent upon the development of the Bay of Biscay and the new northwesterly trend, lines of weakness once developed have continued to be active. With the new Atlantic development, the Western Province came under the influence of vertical movements of the periphery of the continent which caused a series of transgressions and regressions. As the Alpine orogeny proceeded, the area of the Channel was subject to pressures which caused vertical movements on old lines of weakness and the post-Eocene folding is a surface expression of movements between crustal blocks. Some movement still continues on these lines of weakness. Throughout much of this time the Eastern Province continued to remain relatively stable. Igneous activity is believed to have been on a significant scale in the Western Province during Permian, Jurassic and Lower Cretaceous times and it seems that a combination of the extrusion of basic lavas and crustal thinning on the one hand and buoyancy related to granite bodies found in Cornubia and Armorica have been responsible for the continued developments of the western English Channel Basin. Deposition in the area of the Central Province was partially controlled by the movement of blocks while in the Eastern Province sedimentation was controlled by warping on a regional scale.

The ideas put forward in this paper owe much to interchanges with colleagues and co-workers extending over a long period of time. In this connexion the authors would like especially to acknowledge many fruitful discussions with Mr D. Hamilton of the University of Bristol and to pay tribute to the inspiring leadership for many years of the late Professor W. F. Whittard, F.R.S., also of Bristol.

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Discussion

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Pour montrer l'importance des failles dans la Manche, vous avez mesuré leur rejet d'après la nature des terrains en contact de part et d'autre du l'accident. Or les failles ont joué à plusieurs reprises, et leur rejet réel observé au niveau du socle est parfois beaucoup plus important que celui qui apparaît à l'affleurement. Cette remarque vaut en particulier pour l'accident Aurigny–Ouessant, que vous avez peut-être sous-estimé.

Dr A. J. Smith replied that he readily agreed that the map did not show the true implication of the Ouessant–Alderney line since it was based only on the most recent movements as determined from studies of the surface geology. As had been made clear in the paper – the Ouessant–Alderney feature is a major feature with a basement downthrow of possibly several kilometres on its north side.

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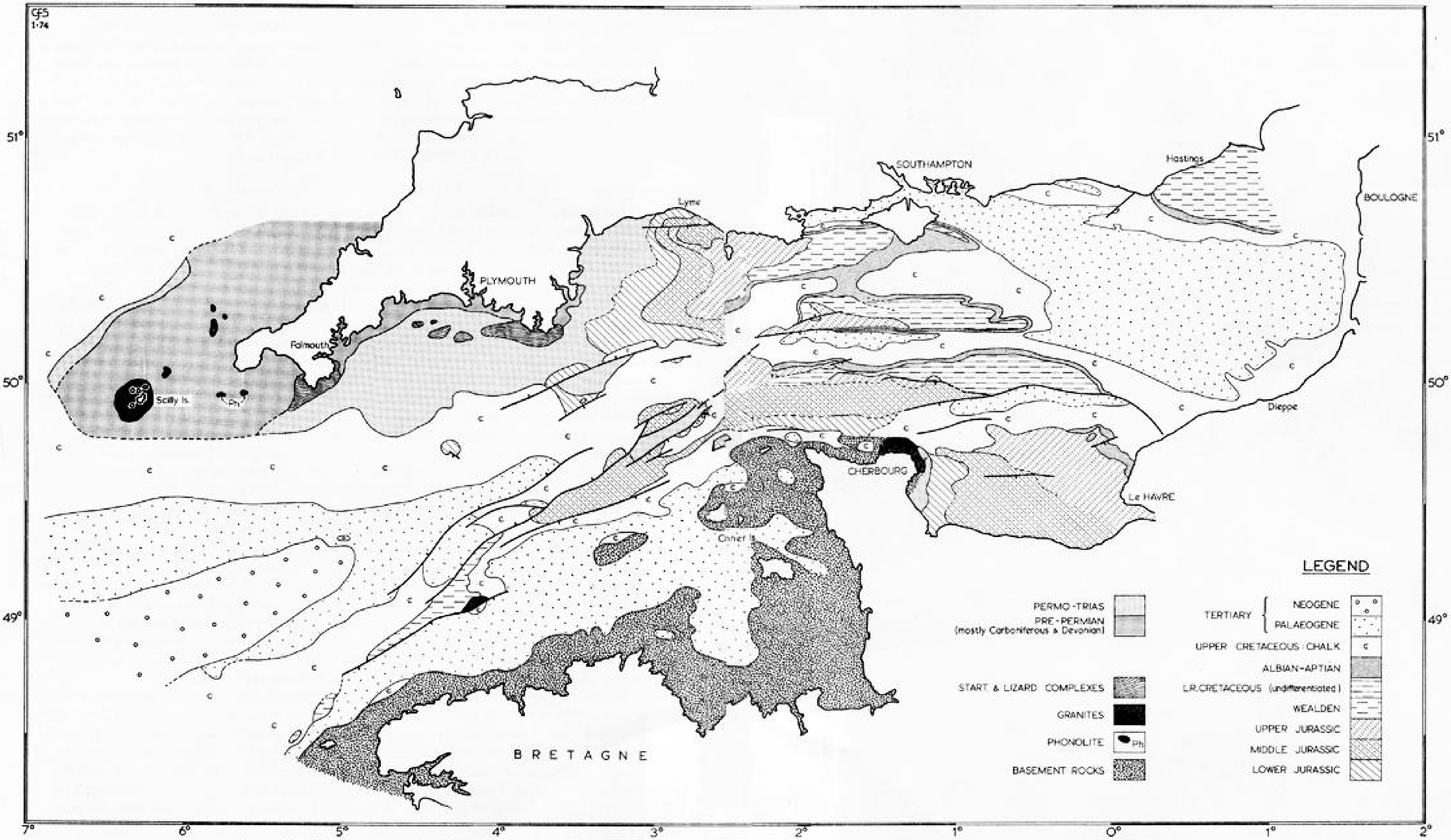

FIGURE 2. Geological map of the Channel.

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