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THE ENGLISH CHANNEL: A RESPONSE TO GEOLOGICAL EVENTS AFTER THE VARISCAN OROGENY[1)]

(13 Figs.)

Kanał La Manche: wynik procesów postwaryscyjskich

(13 fig.)

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Abstract: The geology of the English Channel contrasts with that of the other seas around the British Isles. The structural evolution is thought to have begun with late Variscan events and the proximity to the Variscan Front, the northern limit of major movements, has influenced the style of the structural evolution. Listric faults are thought to be common, possibly related to deeper planes of decollement. The movements continued through the Mesozoic and Cenozoic giving the geology of the Channel floor much variety. There has been little subsidence since the late Palaeogene, while late Pleistocene erosional events, perhaps of a catastrophic nature, were especially influential forming its more easterly parts.

Key words: Variscan orogeny, Variscan Front, Mesozoic, Cenozoic, English Channel.

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Treść: Budowa geologiczna Kanału La Manche kontrastuje z budową den mórz otaczających Wyspy Brytyjskie. Ewolucja strukturalna tego obszaru rozpoczęła się w późnym cyklu waryscyjskim. Zasięg frontu waryscyjskiego wpłynął na styl ewolucji strukturalnej. Często występujące połogie uskoki są prawdopodobnie związane z głębszymi odkłuciami. Ruchy tektoniczne kontynuowały się w mezozoiku i kenozoiku, wpływając na znaczne zróżnicowanie budowy dna Kanału. Począwszy od późnego paleogenu zaznaczyły się słabe ruchy obniżające, natomiast w późnym plejstocenie miała miejsce silna erozja, szczególnie wyraźna we wschodniej części obszaru.

INTRODUCTION

The development of the British Isles as islands on the northwestern part of the European continent owes as much to prolonged tectonic evolution as to the contemporary high stand of sea level.

[1)] The paper was presented at the scientific conference „Two hundred years of geological sciences at the Jagellonian University".

Each of the seas surrounding the British Isles (Fig. 1) has a long structural history but no history is common to them all. That of the North Sea, the largest of the adjacent continental shelf seas, is now well known because of intensive exploration for and exploitation of hydrocarbons. Its geological history may be briefly summarised as follows: structural lines, which were related to Caledonian events became emphasised on the closure of the Lower Palaeozoic Iapetus Ocean which

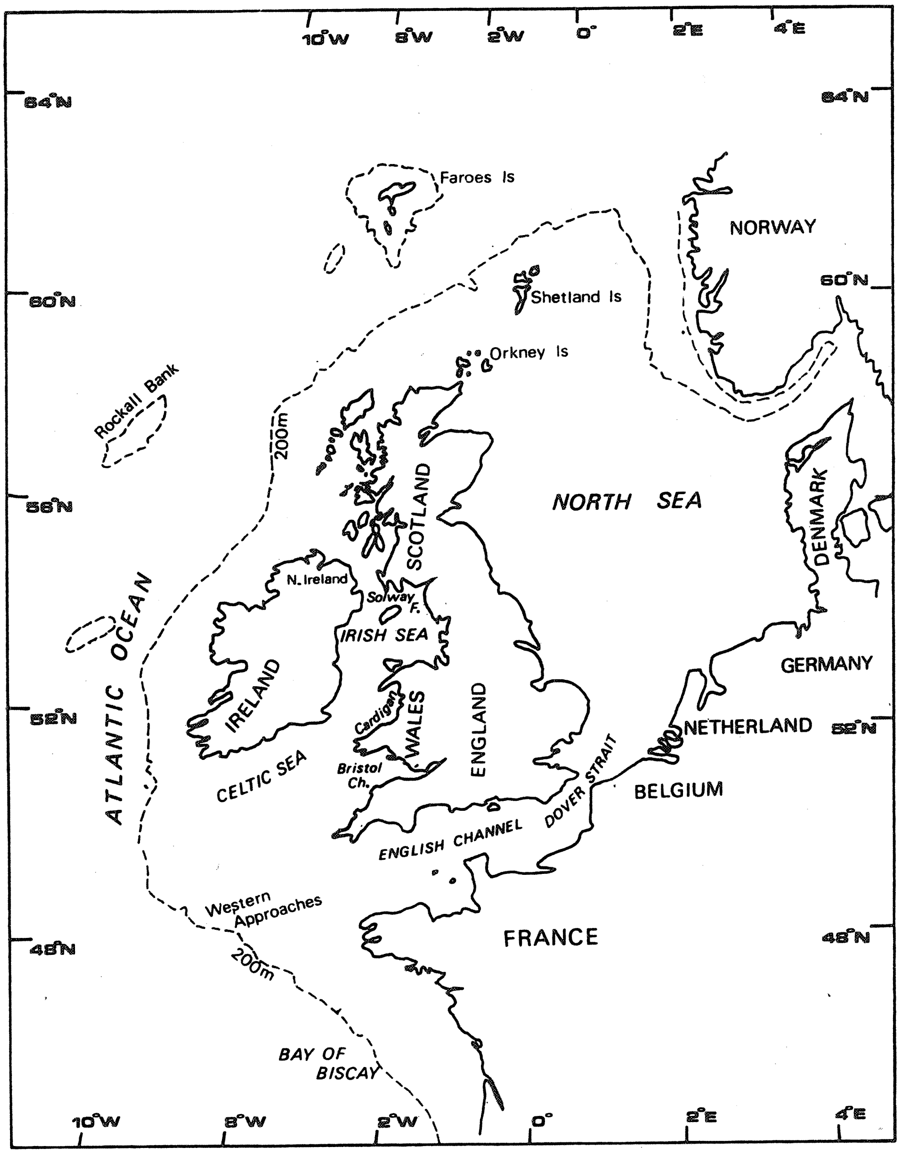


Fig. 1. Map of shelf seas around the British Isles
Fig. 1. Mapa mórz szelfowych wokół Wysp Brytyjskich

was accompanied by the collision of the bordering continents; Devonian and Carboniferous sediments were deposited in subsiding basins which were not subject to major tectonism in the Variscan orogeny; subsidence and rifting occurred in the Permo-Triassic; contemporaneous volcanism accompanied extensional tectonism in the Jurassic; movements, including inversion tectonics continued in the late Jurassic and early Cretaceous (the Cimmerian phase); a broad degree of uniformity followed in the late Cretaceous and prolonged subsidence occurred throughout the Tertiary and Quaternary (see Ziegler, 1982).

The geological histories of the seas which separate Britain and Ireland are revealed in a number of separate geological basins which contain sediments much younger than those usually found on the adjacent land. Nearly all are fault bounded and while they may have been depressions in post-Caledonian times, their real separate histories begin after the Variscan orogeny. Permo-Triassic sedimentation in fault bounded basins characterises the early histories of the Solway Firth, Irish Sea and Celtic Sea Basins as well as the West of Scotland Basins. Throughout the Jurassic much of the bordering land – Scotland, northern England, Wales, south-west England and Ireland – was uplifted and marine and non-marine sediments were deposited in the basins. The basins were usually linked and though local successions differ many regional similarities prevail. There were earth movements in the late Jurassic and Cretaceous and after a general retreat of the sea in the Lower Cretaceous and the subsequent Cenomanian transgression, Upper Cretaceous Chalk was widespread. In some basins post-Cretaceous erosion removed evidence of the Chalk. Tertiary subsidence continued and in Cardigan Bay, Neogene sediments are preserved faulted against Cambrian strata. The outer margin of the continental shelf, beyond Ireland and the Western Isles of Scotland, is less well known. Lower Paleozoic successions can be predicted because of pre-Atlantic Ocean connections with North America. Evidence for Permo-Triassic sediments exists but the areas are particularly characterised by events related to the opening of the Atlantic Ocean and subsequent ocean-continent margin effects superimposed on older lineaments. The marginal slope shows the continental crust thinning oceanwards with major slump-like features related to crustal extension. Naylor and Shannon (1982) discuss the outer continental shelf and western seas in detail.

The geology of the sea area south and southwest of England has yet another history. Whereas the North Sea basin continued to subside throughout the Quaternary thus presenting apparently tectonically undeformed Pleistocene and even Holocene sediments over the greater part of the sea floor, the sea floor south of England gives every impression of having been, and even currently being, affected by recent tectonism. It reflects the influence of structural events which extend beyond its present area and contains evidence of a major geomorphic event in recent times. This southern sea is comprised of the English Channel from the Dover Strait in the east and the Western Approaches to the English Channel which extend to the continental margin with the Atlantic Ocean in the west. It is this sea which is the subject of this paper.

THE ENGLISH CHANNEL

Its present dimensions are the product of contemporary global sea-level accompanied by vigorous erosion of the coast particularly in the central and eastern areas where Mesozoic and early Cenozoic strata are observed to be eroded at rates exceeding one metre per year (see Table I). The solid geology of the sea floor is well known (Smith & Curry, 1975 for a comprehensive review) by direct sampling and shallow geophysical surveys conducted by British and French geologists (Fig. 2).

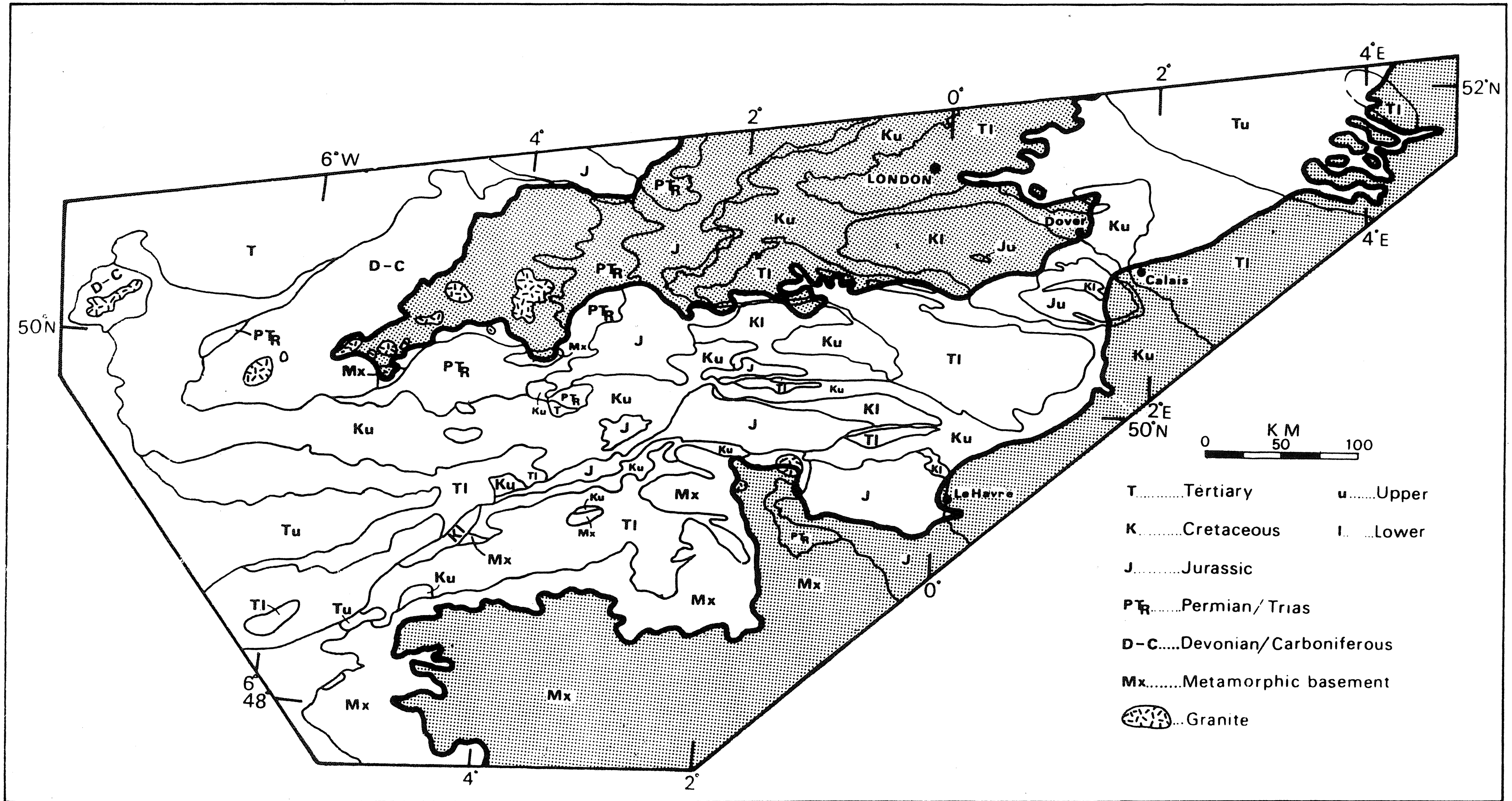


Fig. 2. Map of solid geology of the English Channel

Fig. 2. Mapa geologiczna odkryta Kanału La Manche

Table – Tabela 1

Speed of cliff retreat based on observations of the south coast of England

Prędkość cofania się klifu na podstawie obserwacji południowego wybrzeża Anglii

	per year	per 10,000 yrs
Tertiary Clays	1.0 – 2.0 m	10 – 20 km
Chalk	0.3 – 0.5 m	3 – 5 km
Hastings Sands	1.0 m	10 km

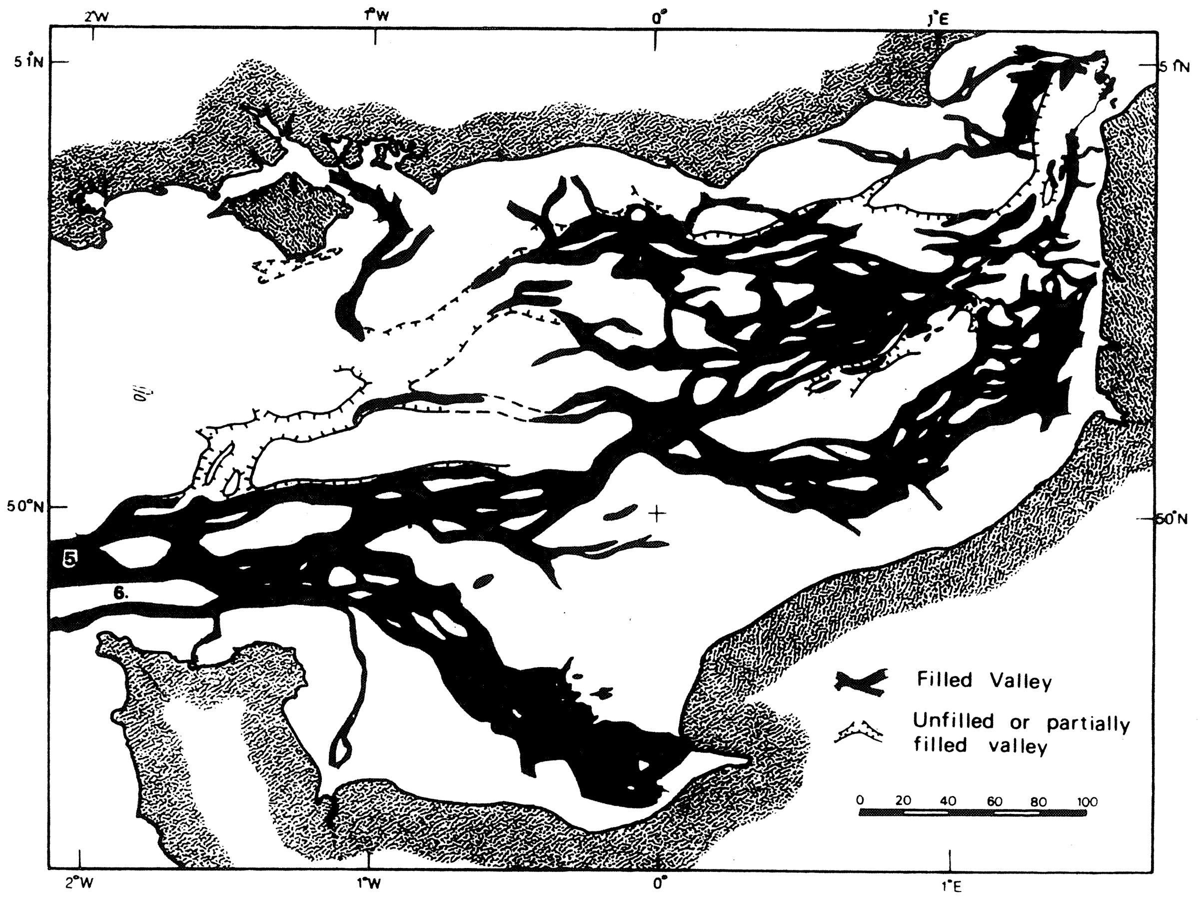
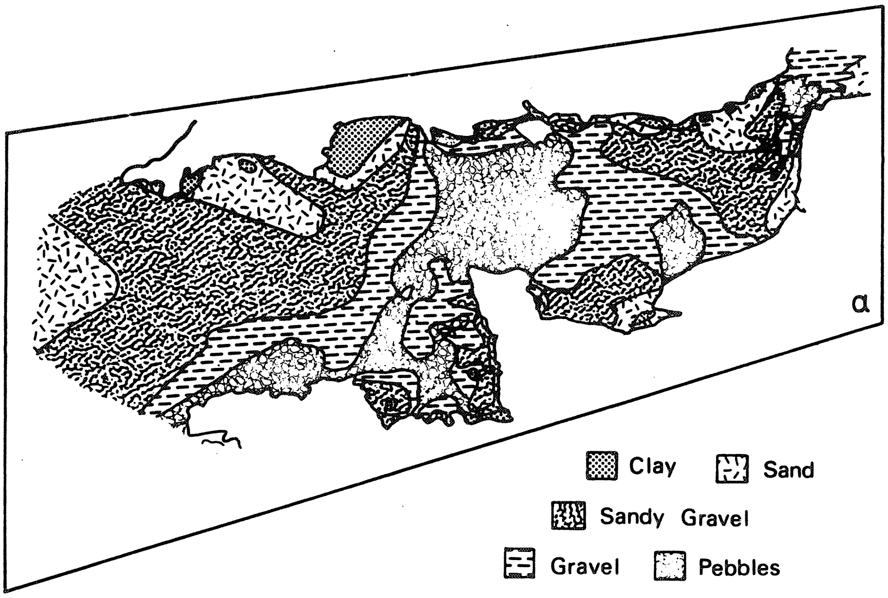


Fig. 3. Paleovalley system on the floor of the eastern English Channel

Fig. 3. System kopalnych dolin na dnie wschodniej części Kanału La Manche

Though the present sea floor is relatively flat, sloping sharply only near the coastline, with a gentle inclination overall from about – 30 m near the Dover Strait to about – 180 m at the shelf break in the west (a total distance exceeding 700 km), it contains in its central and eastern parts a complex system of infilled paleovalleys (Fig. 3) (Auffret *et al.*, 1980, 1982). These are believed to be of late Quaternary age (Smith, in preparation). Covering the solid geology and the palaeovalley sediment system is a relatively thin veneer (often less than 300 mm) of recent, unconsolidated sediment which is subject to movement by tides and storms (Fig. 4a and 4b). This sediment has two principal components: the insoluble residues of the Mesozoic strata, essentially



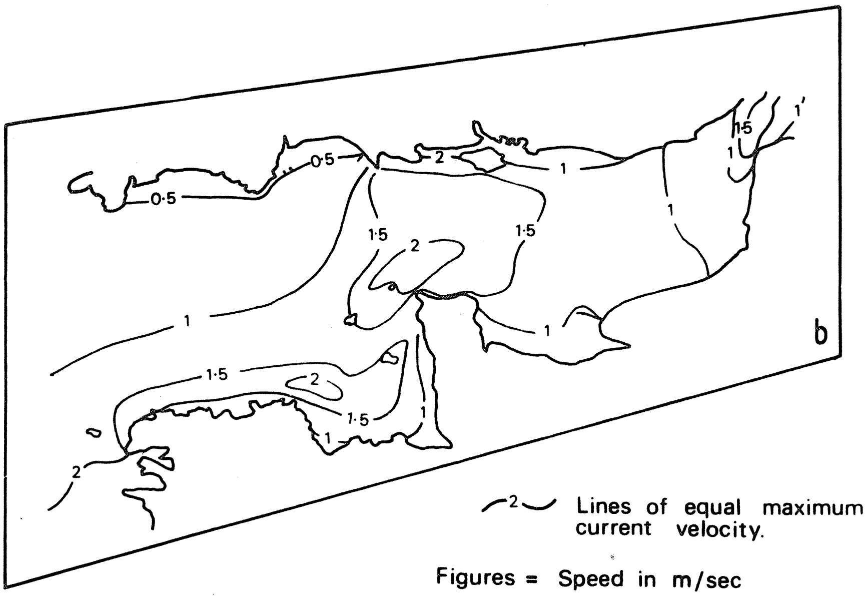


Fig. 4.a. Grain size distribution of sea floor sediments in the English Channel

b. Strength of tidally induced currents in the English Channel

Fig. 4.a. Uziarnienie osadów dennych Kanału La Manche

b. Siła prądów wzbudzanych przez pływy w Kanale La Manche

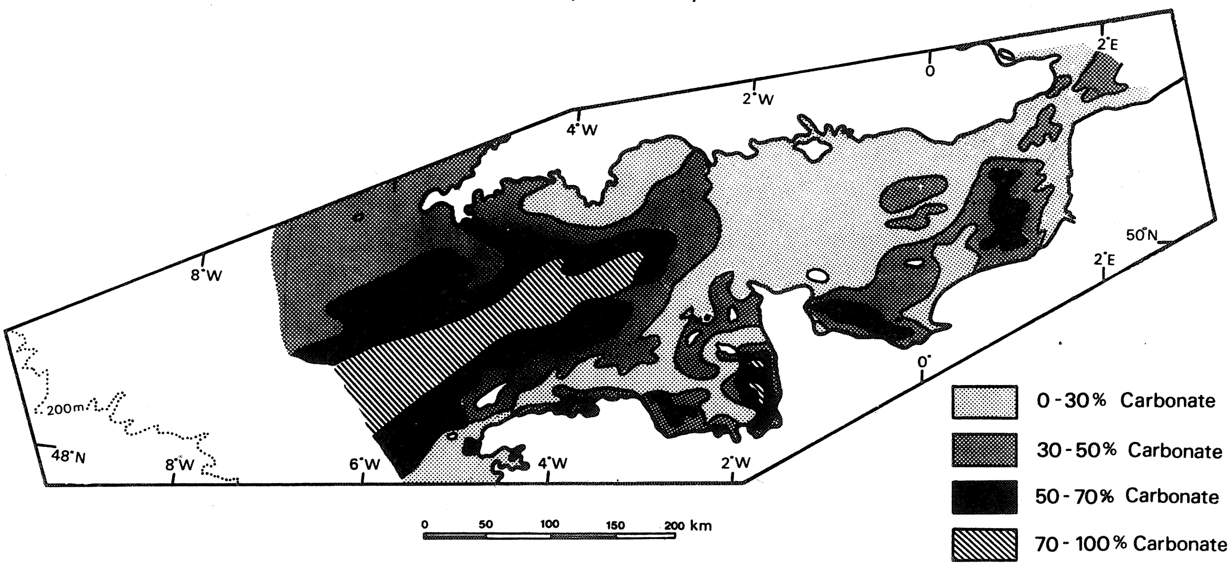


Fig. 5. Sediment type distribution of sea floor sediments in the English Channel (based on Larsonneur *et al.*, 1979)

Fig. 5. Typy osadów dennych Kanału La Manche (według Larsonneur *et al.*, 1979)

chert and clays, and the products of organic activity which gives rise to a high calcium carbonate content, particularly in the west (Fig. 5) (Larsonneur *et al.*, 1979). The sediments do not reflect the underlying solid geology or the palaeovalley system in any way. Only in the extreme west are there substantial (>20 m) and extensive thicknesses of late Quaternary sediments (Evans *et al.* 1981).

THE STRATIGRAPHY OF THE ENGLISH CHANNEL

The present distribution of geological strata on the floor of the English Channel exhibits, in contrast with the North Sea, a relatively complex outcrop pattern. While the latter continued to subside throughout the Cenozoic, and particularly during the Quaternary, the former shows no evidence of extensive sedimentation in the Neogene in its central and eastern provinces (see inset in Fig. 8 for the extent of these provinces). Extensive Neogene (Miocene) deposits occur in the western province and at numerous but isolated localities in the land areas surrounding the central and eastern provinces. As will be argued later in this paper, the English Channel is thought to be, at least in part, an area of neotectonic activity of a compressional nature.

The oldest rocks exposed in the English Channel and its Western Approaches are the seaward extensions of the old Armorican massif of Brittany (see Fig. 2 and Fig. 6 for localities mentioned in text). These rocks, many of Precambrian age, outcrop on the seafloor and as islands (the Channel Island) for a considerable

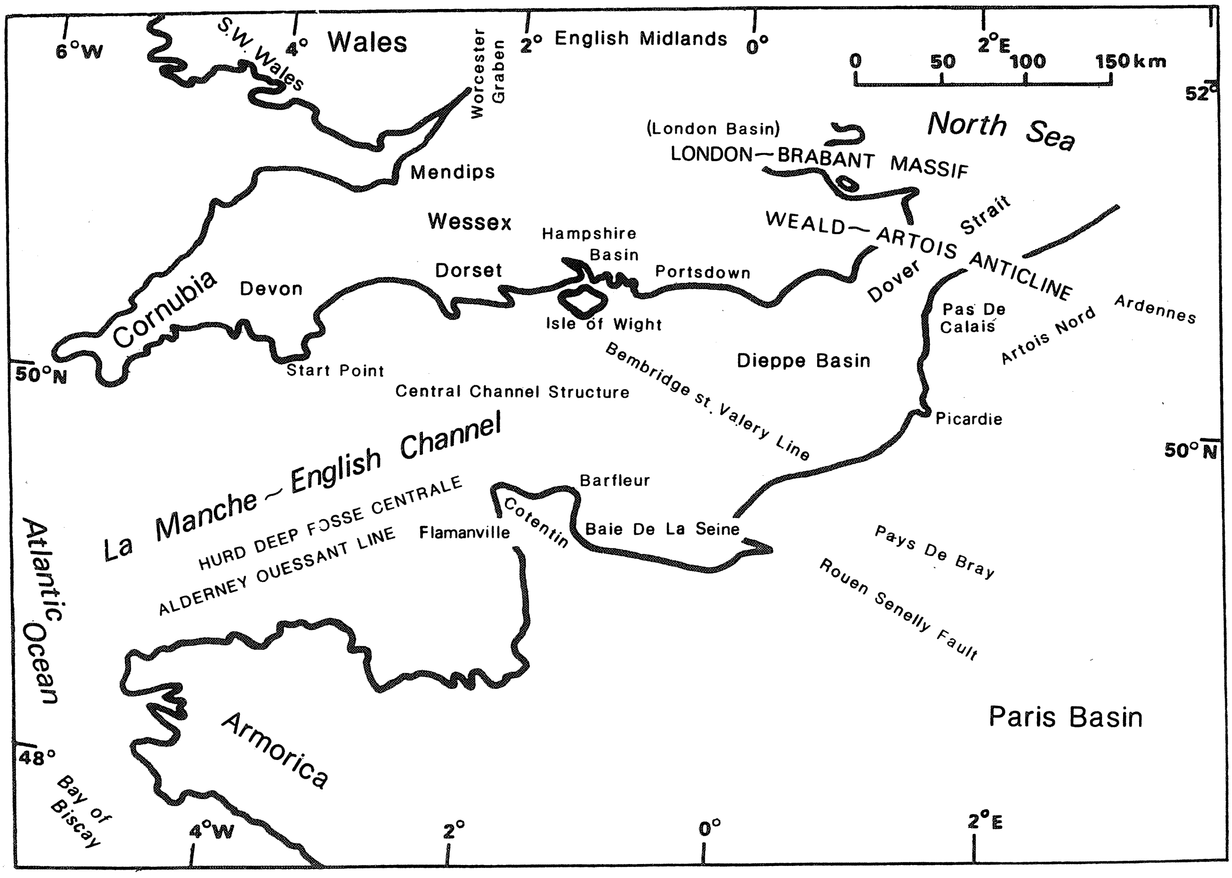


Fig. 6. Location of place names mentioned in the text

Fig. 6. Usytuowanie miejscowości wymienionych w tekście

distance. Off southwest England, younger, Palaeozoic, rocks outcrop off the Cornubian peninsula on the sea floor and as islands and shoals. The first strata of an essentially Channel development are Permo-Triassic strata which rest unconformably on and, perhaps, in part faulted against, the Devono-Carboniferous strata off Cornubia. These outcrops are confined to parts of the western province and the very western part of the central province. The sediments are similar to the Permo-Triassic deposits found on the mainland of Britain and the North Sea: essentially the products of clastic sedimentation under arid conditions. No evidence for evaporite deposits has yet been published, though oil company records may contain such information. Estimates of thickness vary but a thickening towards the axis of the Channel is generally implied.

The succeeding Jurassic rocks have only a limited exposure in the more eastern parts of the western province. More extensive outcrops occur in the central province and yet more outcrops occur at the eastern part of the eastern province. The character of these sediments closely resembles that of the Jurassic successions known in the adjacent land areas. Jurassic deposits may, however, be more extensive beneath the younger successions of the western province though the type of sediment there may differ from that of the exposed Jurassic further east since this western area may have been affected by events related to the creation of the North Atlantic. The Cretaceous successions are more widespread. Lower Cretaceous sediments are found near the Alderney – Ouessant tectonic line (see later in the discussion of the structural geology of the Channel). These clastic deposits may be only a part of more extensive deposits of the same age in this province. Lower Cretaceous deposits in the central and eastern provinces resemble those of the adjacent land

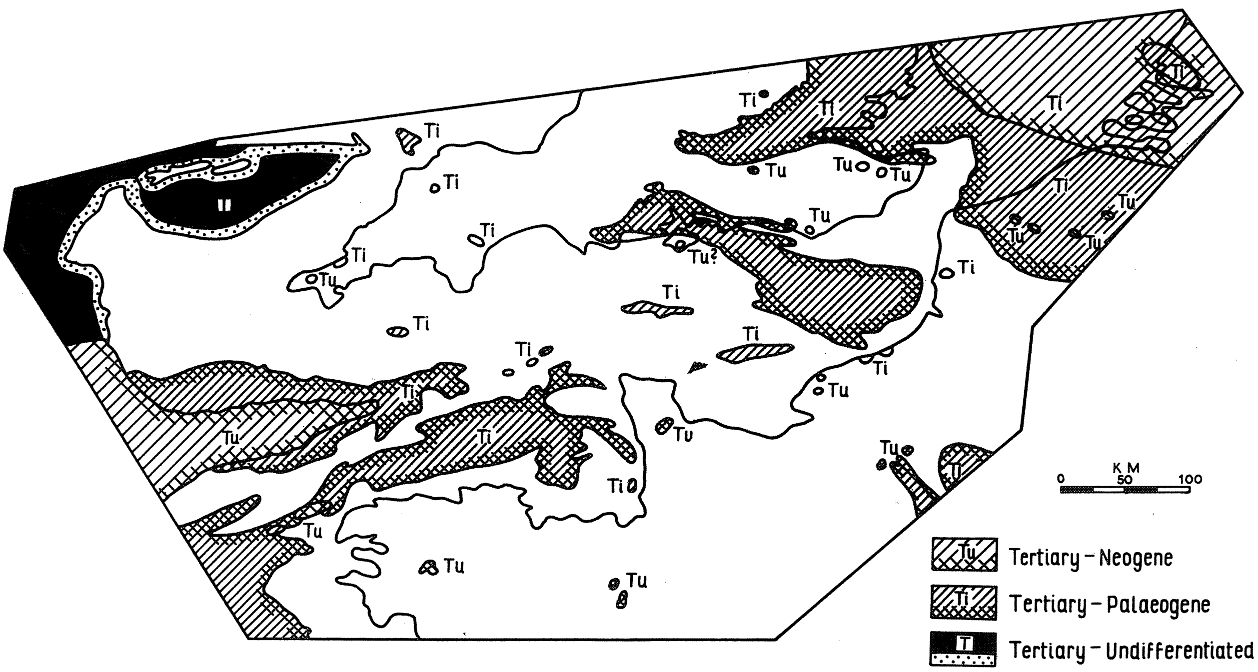


Fig. 7. Distribution of Palaeogene and Neogene deposits in southern England, the Channel and northern France

Fig. 7. Rozmieszczenie osadów paleogeńskich i neogeńskich w południowej Anglii, w obrębie Kanału La Manche oraz północnej Francji

areas. The Upper Cretaceous, represented by Chalk, has the most extensive outcrop in the region and rests unconformably on earlier strata. All the zones are represented and can be compared directly with the Chalk succession of southern England and northern France. In the western province the Palaeogene commences with the Danian, a zone not known on land in this part of Europe. The deposits of this zone are overstepped by extensive early Eocene marine deposits in the western province. A fuller succession of Eocene and early Oligocene sediments occurs in the central and eastern provinces. These deposits, ranging from marine to non--marine and now separated in outcrop due to earth-movements, were once part of the extensive Anglo-Paris Basin – Belgian deposits with which they can be correlated. (Curry & Smith, 1975). Neogene deposits on the floor of the present Channel are found only in the western province where there is an extensive outcrop of Miocene *Globigerina* silts. Miocene and Pliocene marine and non-marine sediments are, however, found in small and widely separated outcrops on the land areas bordering the Channel (Fig. 7).

THE STRUCTURAL GEOLOGY OF THE ENGLISH CHANNEL

In their paper of 1975, Smith and Curry found it convenient to distinguish three provinces in the Channel and its Western Approaches. Each province has its distinctive structural character and the differences between provinces, as will be discussed later, reflect responses to contrasting tectonic settings. The western province is characterised by a graben-like structure which began development in Permian, or possibly late Carboniferous times, though the latter suggestion cannot be substantiated. The trend of the bounding faults is W.S.W. (see Fig. 8) and movements have continued to occur on these faults into historic times on the southernmost set of faults – the Alderney – Ouessant line. It is this set which has had the maximum vertical movement, as much as 2 km in the eastern part of this western province and increasing westwards. The surface expression of this line in the youngest strata shows a series of nearly parallel faults. In the north the present day expression of the faults is less intense and a tilted-graben structure, with maximum downthrow nearer to the southern margin, is envisaged. Movements continued, it is supposed through the Trias, but the Permian and Trias have not been separated here. The Jurassic sediments exposed in the western province do not show evidence of contemporary movements, but thicker Mesozoic sediments are inferred from geophysical evidence further west (Avedik, 1975a, 1975b). Lower Cretaceous sediments, where exposed in the western province, are non-marine. It is known that the North Atlantic and Bay of Biscay were developing west of the Channel at these times and northwest aligned faulting associated with rifting in that direction must have influenced sedimentation patterns. Northwest aligned faults are significant in southwest England and, less obviously, in northwest France. These, however, have a long history commencing in the Variscan orogeny and continuing into the Cenozoic, furthermore most of these faults, for at least part of their history, were dextral wrench faults. Faults in this direction have not been

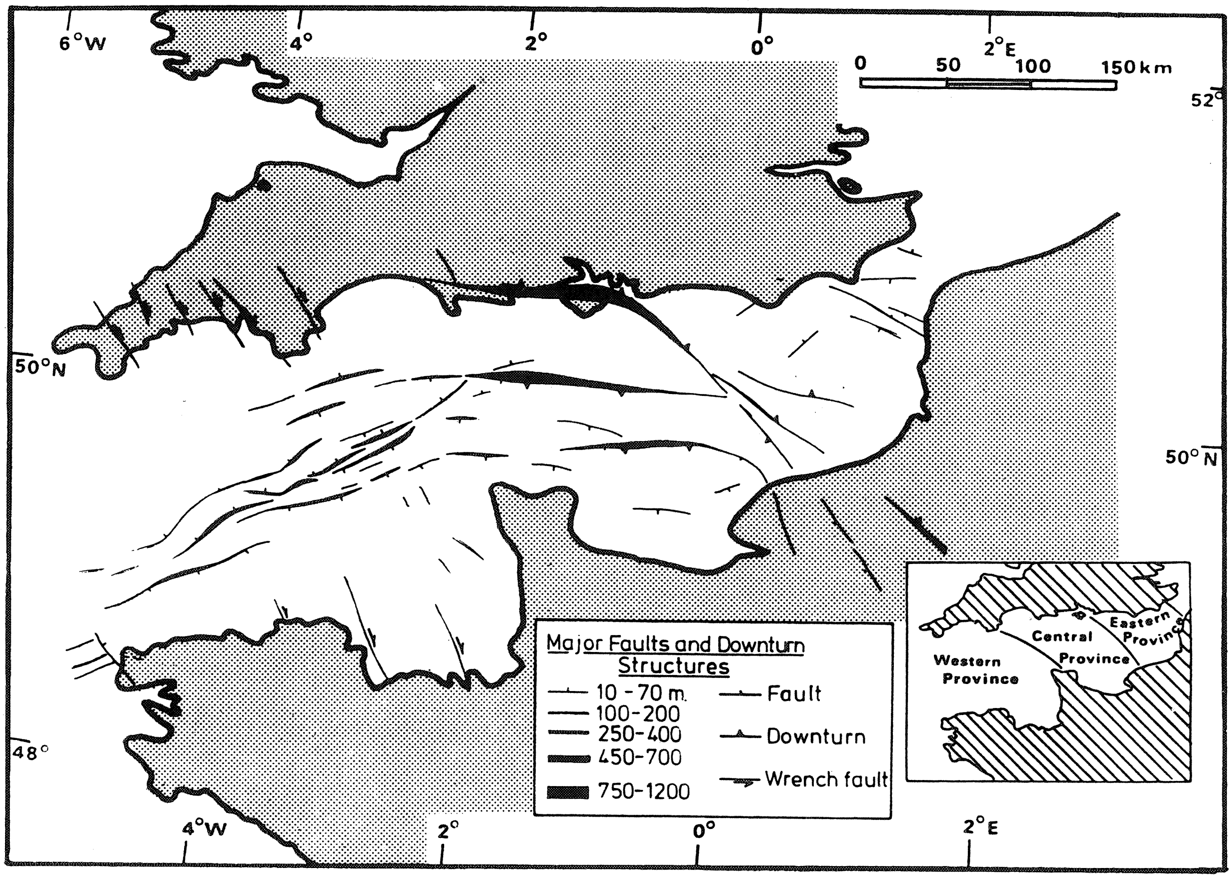


Fig. 8. Structural map of the English Channel (after Smith and Curry, 1975) with inset showing provinces described in the text

Fig. 8. Mapa strukturalna Kanału La Manche (wg Smith i Curry, 1975) oraz szkic obrazujący rozmieszczenie opisywanych prowincji

detected affecting the youngest strata of the western province but geophysical evidence implies some deeper structural features with this alignment (Avedik, *loc. cit.* & Avedik *et al.*, 1982). After mid-Cretaceous times, the western province was subject to warping rather than to rifting. The present outcrop of the Cenomanian and subsequent zones of the Chalk shows a basin-like structure widening westwards. It seems entirely likely, however, that the outcrop represents a remnant of a much wider distribution. The Danian sediments of the Palaeogene occupy a much smaller area and these and the earlier Chalk were subject to erosion before a general transgression in the early Eocene. The deposits of this age were also subject to erosion – indeed it is unlikely that deposition continued throughout the Eocene – before the marine transgression of the early Miocene. There are indications that the vertical movements, which accompanied these warpings, were more intense towards the westernmost part of the province (Curry *et al.* 1972). Some vertical movements along old W.S.W. lines continued intermittently throughout these times.

The boundary between the western and central provinces is regarded as a broad ridge-like feature between Start Point and the Cotentin Peninsula. It may have influenced sedimentation in the Permo-Trias (Laming, 1966) and it certainly caused a thinning in later successions (Lefort, 1975). Its origin may be structural though

Bacon (1975) suggested, on gravimetric evidence, the presence of a granite or granite-like mass hereabouts. Some of the WSW aligned faults cross the boundary feature but a change in the tectonic style is clearly seen at the boundary (Figs 8, 9).

The structural geology of the central province shows a predominantly west-east alignment, though in detail the structural features are usually slightly curved rather than straight. Further the structural regime extends northwards

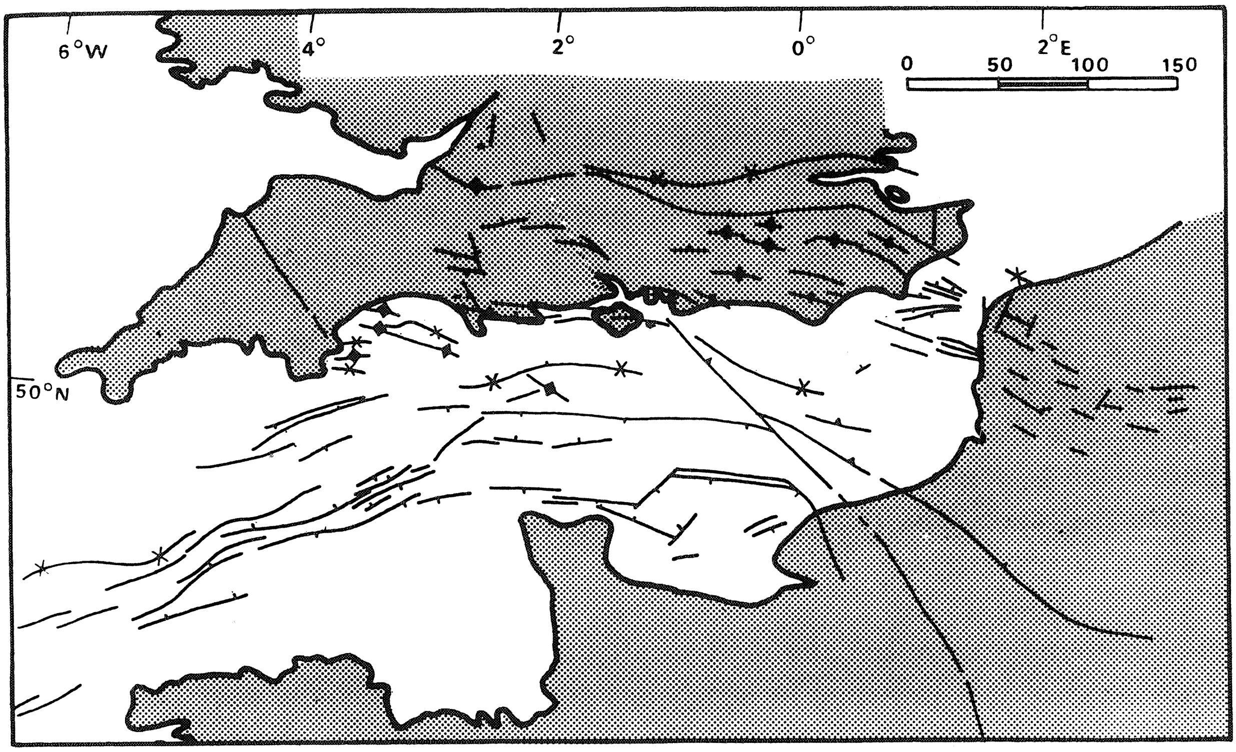


Fig. 9. Mesozoic and Cenozoic structures

Fig. 9. Struktury mezozoiczne i kenozoiczne

into the Wessex region of southern England. At or near the English coast there is a line of north-facing asymmetrical anticlines or monoclines of a range of dimensions (Donovan & Stride, 1961; House, 1961; Ridd, 1973; Melville & Freshney, 1982; Stoneley, 1982) and several of these exhibit at least two episodes of movement. Northwards the structures are less intense. To the south there is a broad syncline and to the south of that there is a major south-facing structure shown in part as a monocline and in part as a faulted structure (Fig. 8) (Smith & Curry, 1975; IGS 1977). This Mid-Channel structure, like the north-facing Isle of Wight monocline, brings strata of widely different ages into close juxtaposition and the amount of vertical movement as measured from strata presently exposed on the sea floor may exceed one kilometre. South is an asymmetrical syncline and at the northern part of the Baie de la Seine there is yet another southfacing steep sided structure. The total movement is less, about half a kilometre, but the surface expression appears to be two nearly parallel but arcuate, concave southwards, faults (Larsonneur *et al.*, 1975). In this central province of the Channel the strata, in general terms, thicken eastwards. There may, however, be local differences in thickness related to more local tectonism. Though the strata sampled in the area strongly resemble those of the adjacent land areas, there is evidence of changes accompanying late Jurassic/early Cretaceous (Cimmarian) inversions of movement (Kent, 1975). The significance of these structures is discussed later in this paper.

At the eastern end of the structures they swing into a southeasterly direction; this is particularly marked east of the Isle of Wight. Traced southeastwards the northeast-facing structure balances the Mid-Channel structure. Further southeastwards the structure links with the several minor structures which reach to the Palaeozoic surface (Héritier & Villemin, 1971) of France and the prominent magnetic anomaly which crosses the Paris Basin (Corpel *et al.*, 1972). The W – E structure in the north of the Baie de la Seine also turns southeast and is parallel to the major structure. Other structures, including the asymmetric and northeast-facing Pays de Bray anticline are aligned in a southeasterly direction. The structure from the eastern end of the Isle of Wight to the French coast (the Bembridge-St Valery line of Curry and Smith, 1975) is taken as the boundary between the central and eastern provinces of the Channel.

The structural style of the e a s t e r n p r o v i n c e is dominated by a broad syncline, the Hampshire-Dieppe Basin, and northeastwards, a much faulted anticline which is part of the Weald – Artois anticlinorium of southeast England and northeast France. The Hampshire – Dieppe Basin reveals a succession of Tertiary strata which can be correlated with strata of similar age in England and France (Curry & Smith, 1975). The syncline is essentially flat-floored, it widens eastwards and its boundaries reflect the shift in alignment of structures from southeasterly in the west of this province to nearly easterly in the east. Only near the margins of the Basin do the dips increase. The structure thus limits the present outcrop of the Tertiary strata to the floor of the Channel with only isolated outcrops on the cliff tops of France and extensions north of the Portsdown anticline and into the Hampshire Basin of southern England. Northeastwards, towards the Dover Strait, the Channel narrows. Jurassic strata are exposed in the core of the Wealden – Artois anticlinorium and there is much strike-faulting. The Channel is at its narrowest near the lower boundary of the north-dipping Chalk on the northern limb of the anticline. Beyond this narrow point, the Channel widens into the North Sea and the structural style changes into one of continued subsidence throughout the Cenozoic to the present.

THE STRUCTURAL EVOLUTION OF THE CHANNEL

The site of the present Channel may coincide, in the opinion of some, with a west-east aligned Caledonian feature (see Ziegler, 1982 for general account and Lefort, 1977). The term "feature" is necessarily vague since it may have been a broad cuvette resembling the southeast extension of the Caledonian sea from the present North Sea into Poland, or it may have been the site of a Caledonian subduction zone (Lefort, 1977). What is clear, however, is that it is sited between the exposed Variscan and pre-Variscan complex of the Armorican massif with its south eastward extension and the concealed ancient London – Brabant massif (Fig. 10) which

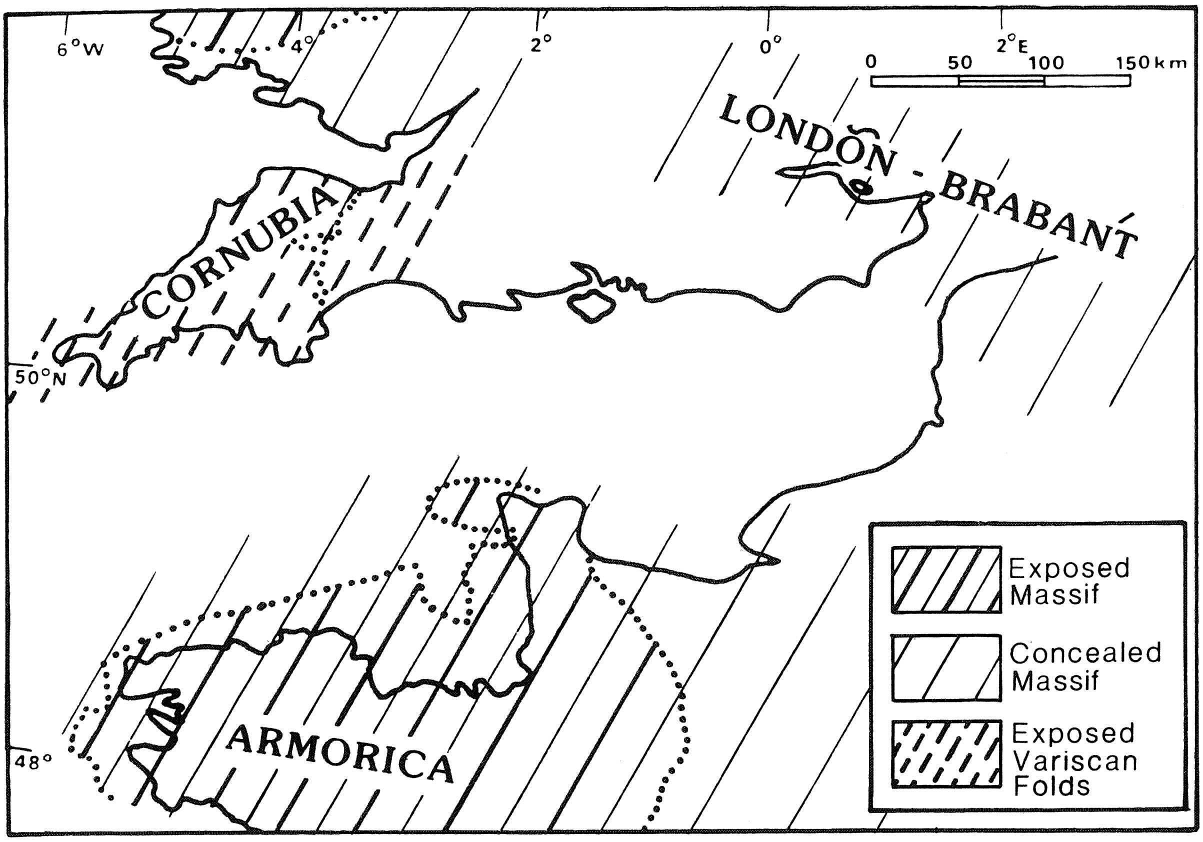


Fig. 10. Exposed and hidden extent of the Armorican and London – Brabant massifs together with exposed Variscan folded areas

Fig. 10. Zasięg masywów armorykańskiego i londyńsko-brabanckiego wraz z obszarami fałdowań waryscyjskich

approaches to within less than half a kilometre of the surface near London (Wallace, 1982 & Fig. 11) and is exposed as Cambrian and possibly Precambrian at Charnwood further north. What, however, is less clear is the pre-Variscan positions of these two areas. Some authors have argued for a major separation measured in thousands of kilometres (Scotese *et al.*, 1979) or at least many hundreds of kilometres apart (Cocks & Fortey, 1982) and that movements towards each other may have been as much oblique as at right angles.

Certainly the Variscan orogeny affected the older rocks of Armorica and folded and faulted the Upper Palaeozoic sediments and volcanics of Cornubia. The present-day Channel is generally regarded to be on the site of the two external zones of the Variscan fold belt – the Rheno-Hercynian Zone and the Saxo-Turingian Zone (Fig. 12) (Autrun *et al.*, 1980). The northern limit of Variscan events, the Variscan Front, can be drawn from southwest Wales, eastwards to the Mendips, across southern England (passing south of London), turning ESE across into northeast France and Belgium before swinging eastwards again (Fig. 12). Though Variscan structures are exposed in southwest England and south Wales, they are hidden beneath Mesozoic and later strata until they re-emerge in the Ardennes. The precise position of the Front remains in doubt and its position and form are particularly vague north of the central province of the English Channel.

The Variscan structures of southwest England have recently been re-evaluated

(Isaac *et al.*, 1982; Shackleton *et al.*, 1982) and many geologists now favour thin--skinned tectonics with a shallow, southward inclined, plane of decollement from southwest Wales southwards. Shackleton *et al.*, (*loc. cit.*) proposed crustal shortening of 150 km and thus imply that the late Variscan granite batholiths of Cornubia and Devon have been translated northwards. Such a model would, in turn, imply that the western province of the Channel is situated above a major thrust and that Armorica may be allochthonous. It would further be reasonable to suggest, as

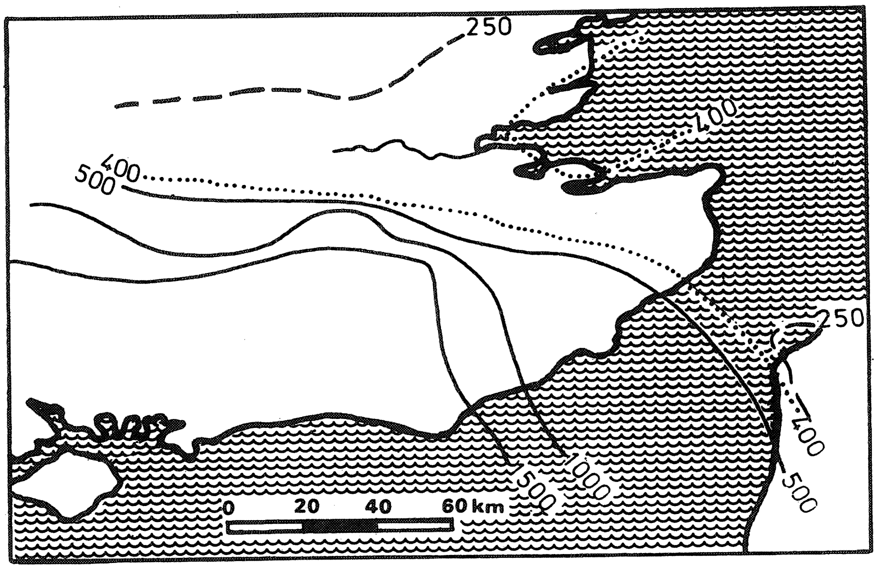


Fig. 11. Isopachytes to the surface of the London Platform (after Wallace, 1982)

Fig. 11. Izopachyty powierzchni platformy londyńskiej (wg Wallace'a, 1982)

Leeder (1982) has done, that the western province began as a very late Variscan response to extensional tectonics after the main compressional phase. Smith and Curry (1975) suggested rifting in the Permian, possibly accompanied by basic igneous activity and that the rifting was on a line of possible development of the Atlantic Ocean. Events, however, in southern Europe led to the rotation and translation of Iberia thus causing the creation of the Bay of Biscay. This, in turn, led to a northwesterly alignment of the Atlantic Ocean/English Channel margin. This change in direction probably commenced in late Triassic/early Jurassic times and the upwarping of the new margin of the continent was a source of sediment. Many faults in southwest England and northwest France are aligned NW–SE. They had a Variscan origin, they parallel Variscan mineral lineations (Durrance & Laming, 1982) and many link into late Variscan thrusts, but were moved, probably dextrally in Mesozoic and even Cenozoic times. Throughout the development of the province the Alderney–Ouessant line remained active, making an abrupt northern boundary to the Armorican massif. During the late Mesozoic and Cenozoic the transgressions and regressions came from the west and the broad, shallow basin, partly fault controlled, between the more bouyant peninsulas of Cornubia and Armorica permitted the sedimentation and preservation of the Chalk, Eocene and Miocene successions. The widespread unconformities testify to continued structural evolution throughout the Mesozoic and Cenozoic with the total thickness north of

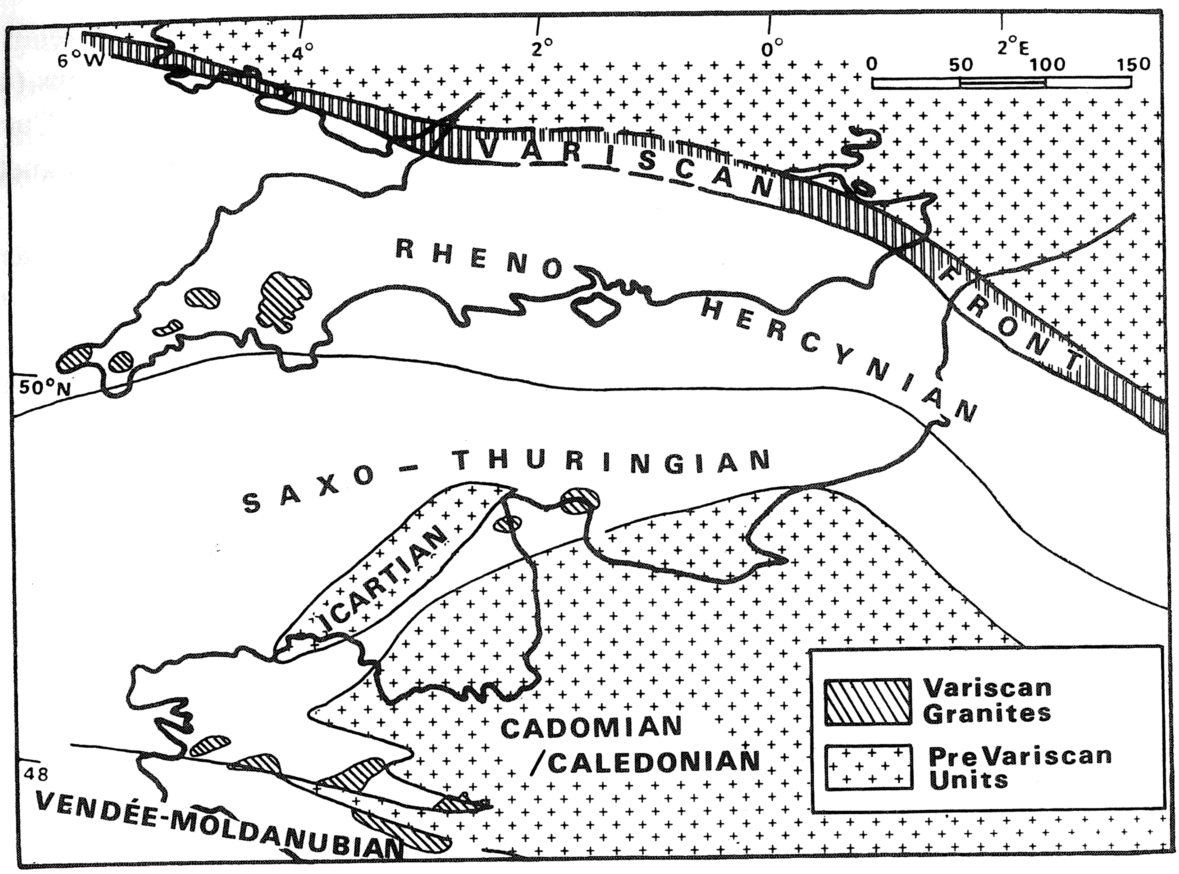


Fig. 12. Variscan fold belts and Caledonian and pre-Caledonian areas

Fig. 12. Strefy fałdowań waryscyjskich, kaledońskich i prekaledońskich

the Aldernery – Ouessant line exceeding 2 km in the east and exceeding 4 km in the west of the province.

The significance of the boundary of the western and the central provinces becomes clearer – it influenced sedimentation from Permian (Laming, *loc. cit.*), through Cretaceous (Lefort, *loc. cit.*) and Tertiary times (Curry *et al. loc. cit.*). The line of the boundary parallels Variscan faults and the Flammaville and Barfleur granites of the Cotentin peninsula are of similar age and composition to the granites of Cornubia and Devon. Furthermore, Neogene deposits are elevated on the Cotentin peninsula and there is even evidence of marine Pleistocene deposits much uplifted here (Larsonneur pers. comm.). All factors point to a long lived tectonic feature, possibly with dextral movements.

The central province has, as has been stated, a different tectonic style. There is evidence of local variations in thickness of the Permo-Trias hereabouts (Stoneley, 1982) and it is generally agreed that inversions in subsidence (i.e. areas previously subsiding are uplifted and eroded while previous highs became basins) have occurred (Kent, 1975), local unconformities occur and nearly everywhere the Upper Cretaceous rests unconformably on Lower Cretaceous and earlier strata. Tertiary deposits now occur in elongate outcrops as a result of Palaeogene movements. While local differences in thickness of formations occur (Curry & Smith, 1975), they were once part of much more extensive deposits themselves reaching the London and Paris Basins.

As stated earlier the tectonic displacements, as measured from the relative movements of strata now exposed on the sea floor, are of major proportions (see above and Figs 8 & 9). The deep geology can only be inferred: Smith and Curry (1975) suggested vertical movements of crustal blocks, however, while magnetic anomalies parallel, in general terms, the main structures, actual coincidences of anomaly and structure are very rare. Though the mapped faults in the central province and to the north are nearly always vertical or near vertical, it has long been known that the faults become less steep at relatively shallow depth (Taitt & Kent, 1939). This fact, together with the lack of coincidence between magnetic anomalies and surface structures implies listric faulting in this province. The exact nature of these faults at depth is not known but an interpretation is given in Fig. 13. This implies an association with low angle thrusting with surface faults being either north-facing or south-facing depending upon "sticking". The ages of the

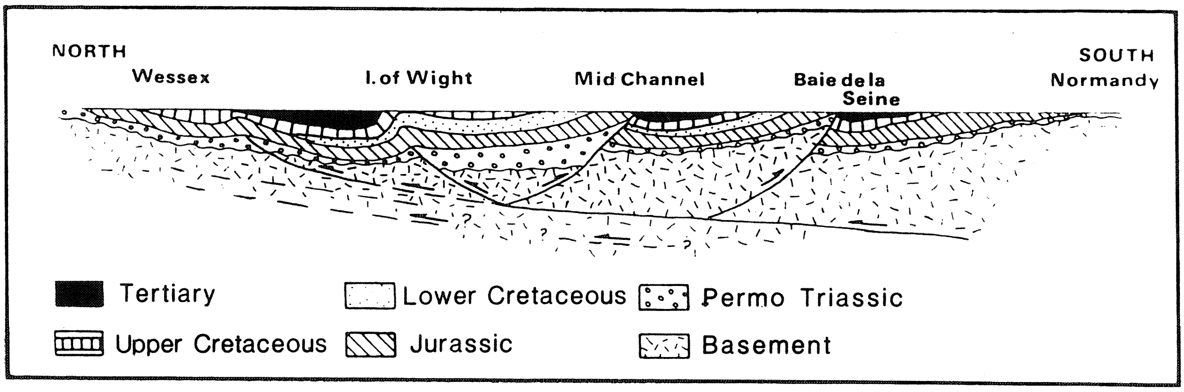


Fig. 13. Hypothetical cross section of the English Channel from Wessex to the Baie de la Seine
Fig. 13. Hipotetyczny przekrój przez Kanał La Manche między Wessex a Baine de la Seine

faults vary across the Channel and the complexity increases northwards (Stoneley, 1982). This style of tectonics would help explain the tectonic reversals of the Jurassic/Cretaceous episode and the reactivation of faults along old lines (House, 1961; Ridd, 1973). Though the last obvious movements are of Oligocene age, the possibility of still later movements is strong and there is increasing evidence of movements continuing into the present.

The Bembridge – St Valery line separates the central from the eastern province. This structure links into tectonic and magnetic features and could be an eastern limiting structure to the inferred listric faults of the central province. Again this is perhaps an old structure and it could be the site of a major wrench movement (Colbeaux, 1974). The link into Variscan or early post-Variscan movements seems strong.

The structures of the eastern province increase in intensity northwards and northeastwards (towards the Weald and Artois anticlinoria and the London – Brabant massif). Only the Portsdown anticline, near the south coast of England, and the Pays de Bray anticline, in northern France, contradict this statement and both of these structures have a long history. Few faults affect the Dieppe Tertiary Basin; all have small displacements and are of limited length.

The complex nature of the Weaiden anticline can be ascribed to listric faults, the steepening and intensification of the structures towards the north being related to the shallowing of the London – Brabant massif (Lake, 1975; Smalley & Westbrook, 1982). After mid-Cretaceous times there had been inversion of movements. Geological evidence suggests a total uplift of 1.2 km and two specific times of uplift have been recognised: about 250 m in the late Eocene and 200 m in early Pliocene times. The timing of the greater amount of uplift remains unclear and though late Oligocene/early Miocene times seems most likely, late Pliocene and Pleistocene movements cannot be dismissed. In northern France, in the Pas de Calais/Nord regions, the Weald – Artois anticline closes and the Upper Cretaceous – Cenozoic boundary parallels, approximately, the hidden coalfields of northern France and Belgium. To the south the rivers of northern France parallel the structural trends which fan from ESE in the north to SE in the south. The depth to the London – Brabant basement is about a third of a kilometre near Calais and deepens to more than a kilometre beneath Picardie. The deep geology is complex with much thrusting of Carboniferous strata and evidence of Caledonian as well as Variscan movements (Bouroz, 1960). There has been speculation (Shephard--Thorn *et al.*, 1972) that a sub-Channel N – S fault parallels the coast of Picardie but the evidence is not unequivocal.

The generally accepted date for the last movements is late Palaeogene with peneplanation by the Miocene. However, late Miocene/Pliocene sediments are much elevated in the area of northern France, southern Belgium and southeast England though they pass below present sea-level beneath eastern England and northern Belgium suggesting Pliocene movements. Smith (in press) however argues for more recent movement – including late and very late Pleistocene times (see also below).

CONCLUSIONS

It is suggested that the history of the present day Channel is strongly linked to Variscan and later events. Each province of the Channel reflects in its distinctive structural history a response to these events. In particular, the distance from the Variscan Front, the northern limit of the Variscan events, is an important factor in the type of structure which developed. The western province is developed on the site of post-Variscan rifting and is margined by Variscan and older blocks which may be allochthonous. The subsequent history was related to the origin of the Bay of Biscay and Atlantic Ocean accompanied by reactivation of established faults: something which continues to the present. The central province, it is suggested, is a response through listric structures to movements on a relatively high plane of decollement which again may have begun as a late-Variscan event. The special character of this province may also be linked to the N – S graben structure of the English Midlands (the Worcester Graben) which causes the Variscan Front to be poorly defined hereabouts. The marked boundary with the eastern province may be linked with the graben development in the English Midlands.

The eastern province is closer to the Variscan front and only in its western part did it form a natural depression in post Miocene times – all the existing and older drainage patterns of southeast England and northern France trend towards this depression. The narrowing Channel towards the Dover Strait reflects the approach to the Variscan Front. However, in late Pleistocene times this area was, it is argued by this author, the site of a catastrophic geomorphic event. At a time when the northern access of the North Sea was blocked by extensive glaciers, a lake developed in the southern North Sea between the icefront and the ridge of the Weald – Artois anticlinorium which blocked the southern connection to the Atlantic. Overtopping of this ridge by melt waters caused a plunge pool to be created and modified and further extended the lower reaches in mid-Channel, of the river systems of southern England and northern France. This event resembled in size and intensity the great Missoula – Spokane Flood of northwest USA which created the channelled scablands of that area (Bretz, 1969). (A more detailed description of this event in the Channel's history is in the course of preparation but readers may compare the published maps of the scablands with Figure 3 of this paper). This short lived but intensive event created the Dover Strait and gave the shape of the eastern province of the Channel. In so doing it gave the last piece to complete the picture of the evolution of the Channel.

The Channel is not simply a piece of submerged continent – it has a history linked to the structural evolution of Europe with the added feature of a major geomorphic event of a proportion larger than anything hitherto imagined in Europe.

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REFERENCES – WYKAZ LITERATURY

Auffret J. P., Alduc D., Larsonneur C., Smith A. J. 1980. Cartographie de réseau des paleovallées et de l'épaisseur des formations superficiales meubles de la Manche orientale. *Ann. l'Inst. Océan.*, 56: 21–35.

Autrun A., Breton J. P., Chantriane J., Chiron J. C., Gros Y., Roger P. 1980. Carte téctonique de la France (1:1,000,000) and Introduction a la carte téctonique de la France. *Mém. Bur. Rech. Geol. Min.* 110: 1–52.

Avedik F. 1975a. Seismic structure of the Western Approaches and the South Armorican continental shelf and its geological interpretation. (in:) *A.W. Woodland* (ed.), *Petroleum and the Continental Shelf of NW Europe*, p. 29–44, Academic Press.

Avedik F. 1975b. Seismic reflection survey in the Western Approaches to the English Channel: preliminary results. *Phil. Trans. R. Soc. London, A 279:* 29–39, London.

Avedik F., Camus A. L., Ginzburg A., Montadert L., Roberts D. G., Whitmarsh R. B. 1982. A seismic refraction and reflexion study of the continent-ocean transition beneath the north Biscay margin. *Phil. Trans. R. Soc. London, A 305:* 5–25, London.

B a c o n M. 1975. A gravity survey of the Western English Channel between Lyme Bay and St. Brieuc Bay. *Phil. Trans. R. Soc. London, A 279:* 69 – 78, London.

B o u r o z A. 1960. La structure du Paléozoique du Nord de la France au sud de la Grande Faille du Midi. *Ann. Soc. Géol. N.* 80: 101 – 113.

B r e t z J.H. 1969. The Lake Missoula floods and the channeled scabland. *Jour. Geol.* 77: 505 – 543.

C o c k s L. R. M., F o r t e y R. A. 1982. Faunal evidence for oceanic separation in the Palaeozoic of Britain. *J. Geol. Soc. London,* 139: 465 – 478, London.

C o l b e a u x J.P. 1974. Mise en évidence d'une zone cisaillement Nord Artois. *C. R. Lebd. Seanc. Acad. Sci. D 278*: 1159 – 1161, Paris.

C o r p e l J., O g i e r M., W e b e r C. 1972. Carte Magnetique de la France: 1: 1,000,000 (Feuille Nord) et notice explicative. *Bur. Rech. Géol. Min.,*. Paris.

C u r r y D., H a m i l t o n D., S m i t h A. J. 1971. The geological evolution of the western English Cannel basin and its relation to the nearby continental margin. (in:) *Delaney S. M.* (ed.), *The geology of the east Atlantic continental margin, pt. 2 : Europe. Rept. Inst. Geol. Sci.* 70, 14: 129 – 142.

C u r r y D., S m i t h A. J. 1975. New discoveries concerning the geology of the central and eastern parts of the English Channel. *Phil. Trans. R. Soc. London, A 279:* 233 – 242, London.

D o n o v a n D. T., S t r i d e A. H. 1961. An acoustic survey of the sea floor south of Dorset and its geological interpretation. *Phil. Trans. R. Soc. London, B 244*: 299 – 330, London.

D u r r a n c e E. M., L a m i n g D. J. C. 1982. The Geology of Devon. *University of Exeter,* 347 p.

E v a n s C. D. R., L o t t G. K., W a r r i n g t o n G. 1981. The Zephyr (1977) Wells, Southwestern Approaches and western English Channel. *Rep. Inst. Geol. Sci.,* 81, 8: 1 – 44.

H é r i t i e r F., V i l l e m i n J. 1971. Mise en évidence de la téctonique profonde du Bassin de Paris par l'éxploration pétroliére. *Bull. Bur. Rech. Géol. Min.,* Sec. 1, 2: 11 – 30, Paris.

H o u s e M. R. 1961. The structure of the Weymouth anticline. *Proc. Geol. Assoc. London* 72: 222 – 238.

I. G. S. 1977. Wight Sheet, scale 1: 250 000. *Inst. Geol. Sci.,* London.

I s a a c K. P., T u r n e r P. J., S t e w a r t I. J. 1982. The evolution of the Hercynides of central SW England. *J. Geol. Soc. London,* 139: 521 – 531, London.

K e n t P. E. 1975. Tectonic development of Great Britain and the sourrounding seas (in:) *A.W. Woodland* (ed.), *Petroleum and the Continental Shelf of NW Europe.* Academic Press, p. 3 – 28, London.

L a k e R. D. 1975. The structure of the Weald – a review. *Proc. Geol. Assoc. London,* 86: 549 – 558, London.

L a m i n g D. J. C. 1966. Imbrications, palaeo-currents and other sedimentary features in the Lower New Red Sandstone of south Devonshire. *Jour. Sedim. Petrol.* 36: 940 – 959.

L a r s o n n e u r C., A u f f r e t J. – P., S m i t h A. J. 1982. La Manche orientale: Carte des paleovallées et des bancs sableux. *Bur. Rech. Géol. Min.,* 1: 500 000 Map and text 8 pp., Paris.

L a r s o n n e u r C., H o r n R., A u f f r e t J. – P. 1975. Géologie de la partie méridionale de la Manche central. *Phil. Trans. R. Soc. London,* A 279, London.

L a r s o n n e u r C., V a s l e t D., A u f f r e t J. P. 1979. Les sediments superficiel de la Manche. *Bur. Rech. Géol. Min.* 1: 5 000 000 Map and text 15 pp., Paris.

L e e d e r M. R. I. 1982. Upper Palaeozoic basins of the British Isles – Caledonide inheritance versus Hercynian plate margin processes. *J. Geol. Soc. London,* 139: 479 – 491, London.

L e f o r t J.-P. 1975. Le controle du socle dans l'évolution de la sedimentation en Manche occidentale aprés le Paléozoique. *Phil. Trans. R. Soc. London,* A 279: 137 – 144, London.

L e f o r t J. – P. 1977. Possible „Caledonian" subduction under the Domnonean domain, North Armorican area. *Geology,* 5: 523 – 526.

M e l v i l l e R. V., F r e s h n e y E. C. 1982. The Hampshire Basin and adjoining areas. *Inst. Geol. Sci., O.H.M.S.,* p. 146, London.

N a y l o r D., S h a n n o n P. M. 1982. The geology of offshore Ireland and West Britain. Graham and Trotman, p. 161, London.

R i d d M. F. 1973. The Sutton Poyntz, Poxwell and Chaldon Herring anticlines: a reinterpretation. *Proc. Geol. Assoc. London,* 84: 1 – 8, London.

S c o t e s e C., B a m b a c h R. K., B a r t o n C., V a n d e r V o o R., Z i e g l e r A. 1979. Paleozoic base maps. *J. Geol. Chicago,* 87: 217 – 278.

S h a c k l e t o n R. M., R i e s A. C., C o w a r d M. P. 1982. An interpretation of the Variscan structures in SW England. *J. Geol. Soc. London,* 139: 533–541, London.

S h e p h a r d - T h o r n E. R., L a k e R. D., A t i t u l l a h E. A. 1972. Basement control of structures in the Mesozoic rocks in the Strait of Dover region, and its reflection in certain features of the present land and submarine topography. *Phil. Trans. R. Soc. London,* A 272: 99–113, London.

S m a l l e y S., W e s t b r o o k G. K. 1982. Geophysical evidence concerning the southern boundary of the London Platform beneath the Hog's Back, Surrey. *J. Geol. Soc. London,* 139: 543–554, London.

S m i t h A.J. (in preparation). A catastrophic origin for the palaeovalley system of the eastern English Channel.

S m i t h A.J., C u r r y D. 1975. The structure and geological evolution of the English Channel. *Phil. Trans. R. Soc. London,* A 279: 3–20, London.

S t o n e l e y R. 1982. The structural development of the Wessex Basin. *J. Geol. Soc. London,* 139: 543–554, London.

T a i t t A. H., K e n t P. E. 1939. Notes on an examination of the Poxwell anticline, Dorset. *Geol., Mag.,* 76: 173–181.

W a l l a c e P. 1982. The subsurface Variscides of Southern England and their continuation into continental Europe (in:) *P.L. Hancock* (ed.), *The Variscan fold belt in the British Isles,* p. 198–208.

Z i e g l e r P. A. 1982. Geological Atlas of Western and Central Europe. *Shell Internationale Petroleum Maatschappij B. V.,* The Hague, p. 130.