Basins and swells and the evolution of an epeiric sea (Pliensbachian–Bajocian of Great Britain)

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SUMMARY

During Pliensbachian–Bajocian times northern Europe, including Britain, was covered by an epeiric sea. Sediments formed include clays, sandstones, limestones and ironstones, usually cyclically arranged; different facies were developed synchronously in different areas. There is very little evidence, by way of slumps or turbidites, that redeposition processes were active. The sequence clay, sandstone, limestone/ironstone is here interpreted as representative of a shallowing. Thus, at any one time, despite differing bathymetric zones, bottom slopes were apparently subdued enough to ensure that sediment displacement did not generally take place.

To reconcile the concept of Jurassic 'basins' and 'swells' with the subdued bottom slopes of the north European epeiric sea, we suggest that these structural elements were characterized by great and negligible subsidence respectively, but that sedimentation was always rapid enough to maintain a roughly level sea floor. We relate the Mendip, London Platform and Dorset coast 'swells' to early Jurassic positive fault motions in the basement. The Market Weighton 'swell' is ascribed to relative buoyant rise of a salt pillow or granitic body whose movement was probably triggered by the same motions. These, presumably extensional, tectonics were probably the driving force behind the formation of the whole north European epeiric sea and must be related, in turn, to the opening of the oceanic central Atlantic and Alpine–Mediterranean Tethys.

THE TERM 'EPEIRIC' was used by Shaw (1964, p. 4) to describe seas that spread over the central parts of continents. The vast areal extent of ancient epeiric seas, their shallow depths and subdued bottom slopes were particularly stressed. Irwin (1965) presented a 'general theory of epeiric clear water sedimentation' and suggested various models that dealt with the hydraulic energy zones that would characterize such marine areas, proposing a hierarchy of simple facies belts. Both of these works were largely theoretical, and actual examples were only briefly mentioned (Ordovician, Devonian, Pennsylvanian and upper Cretaceous of North America).

Pliensbachian–Bajocian facies in England and their bathymetric hierarchy

Description

In southern England shallow marine facies of Pliensbachian to Bajocian age (Fig. 1) are represented by cyclically arranged clays, sandstones, limestones and ironstones. The clays are dominantly illitic and typified by a fauna of protobranch, lucinoid and thin-shelled pectinid bivalves, ammonites and belemnites. Apart from the ammonites and belemnites, this fauna compares favourably with that

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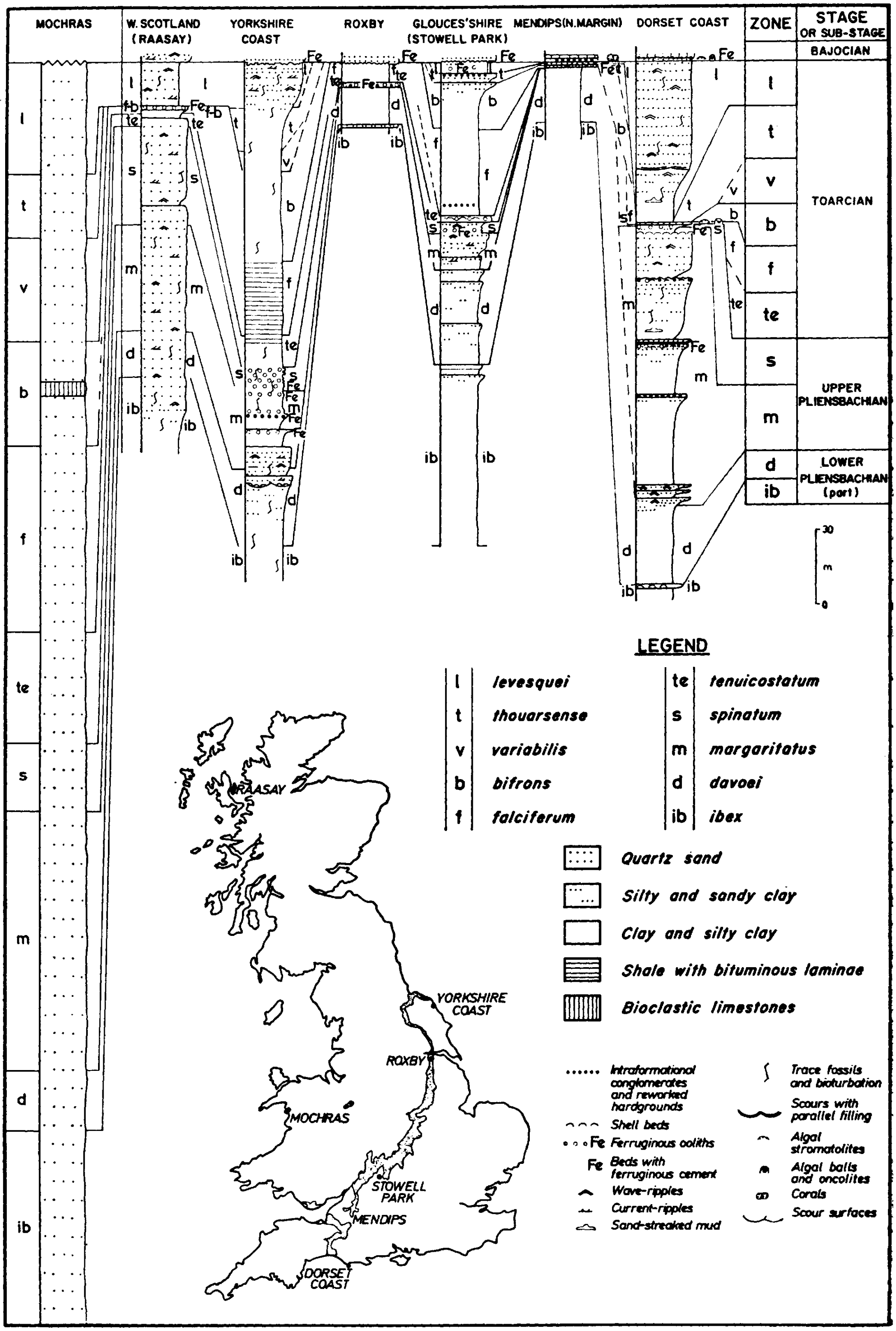

MOCHRAS
W. SCOTLAND (RAASAY)
YORKSHIRE COAST
ROXBY
GLOUCES'SHIRE (STOWELL PARK)
MENDIPS (N. MARGIN)
DORSET COAST
ZONE
STAGE OR SUB-STAGE
BAJOCIAN
TOARCIAN
UPPER PLIENSBACHIAN
LOWER PLIENSBACHIAN (part)
l
t
v
b
f
te
s
m
d
ib
Fe
30
m
0
LEGEND
l levesquei
t thouarsense
v variabilis
b bifrons
f falciferum
te tenuicostatum
s spinatum
m margaritatus
d davoei
ib ibex
Quartz sand
Silty and sandy clay
Clay and silty clay
Shale with bituminous laminae
Bioclastic limestones
Intraformational conglomerates and reworked hardgrounds
Shell beds
Fe Ferruginous ooliths
Fe Beds with ferruginous cement
Wave-ripples
Current-ripples
Sand-streaked mud
Trace fossils and bioturbation
Scours with parallel filling
Algal stromatolites
Algal balls and oncolites
Corals
Scour surfaces
RAASAY
YORKSHIRE COAST
ROXBY
MOCHRAS
STOWELL PARK
MENDIPS
DORSET COAST

of modern shelf-mud assemblages. Detailed descriptions of the faunas are given by Howarth (1957), Palmer (1966a, b) and Hallam (1967). Clays usually pass upwards into quartzitic sands with wave-induced cross-lamination containing a more diverse assemblage of infaunal and epifaunal suspension-feeders than the clays. The assemblage of faunas and structures indicates a shallow neritic environment (Howarth 1957, Davies 1967, 1969, Sellwood *et al.* 1970).

The limestones are generally biomicrites and biosparites, sometimes ferruginous and often contain stromatolites and oncolites (Sellwood *et al.* 1970, Gatrall *et al.* 1972). Limonitic ooliths and intraclasts of limestone may be present. Diverse benthonic faunas generally indicate shallow turbulent conditions (Richardson 1928–30, Hallam 1967, Sellwood *et al.* 1970). Unlike the clastics, the limestones are usually stratigraphically condensed.

Ironstones may grade into limestones, clays or sandstones. Chamosite, siderite and limonite constitute the most important minerals and can be present as either ooids or matrix (Whitehead *et al.* 1952). Other components of the matrix include micritic calcite, illite, kaolinite and subordinate quartz. Chamositic ironstones are often cross-bedded and contain abundant and diverse shallow-marine faunas of suspension-feeders. The mineralogy of these ironstones is predominantly diagenetic in origin (Hallam 1966, 1967, Berner 1970, Knox 1970, Catt *et al.* 1971) and ironstones share with limestones the distinction of being stratigraphically condensed. These condensed beds correspond to the "Dachbank" limestones recognized in the German Lias by Klüpfel (1917) who attributed them to subaerial exposure. On the Dorset coast three types of condensed sequence may be recognized: (1) ferruginous limestones, often stromatolitic and typified by the middle Bajocian "Snuff Box" beds; (2) intraformational sandstone conglomerates (reworked hardgrounds) typified by the Pliensbachian Margaritatus Stone; and (3) ferruginous sandy shell beds typified by the Pliensbachian Thorncombiensis Bed and the Marlstone.

Bathymetric hierarchy

There are several variables controlling the deposition of mud as opposed to sands in shelf seas; these include the density of suspended matter, depth of water, and the influence of tidal currents and waves (McCave 1971). In the simplest model wave activity is assumed to be the major factor controlling deposition of mud, this being laid down only below the level of wave effectiveness. Thus, in the modern Celtic Sea, mud generally occurs at depths below 80–90 m; sand is present in shallower zones. In the modern Tyrrhenian Sea, the lower limit of

FIG. 1

Correlation and facies of Pliensbachian to lower Bajocian rocks in Britain illustrating the occurrence of cyclic successions and the coeval development of expanded and condensed sequences. Zonal scheme follows Arkell (1956) and Dean *et al.* (1961). Sections are based on Green & Melville (1956), Hemingway *et al.* (1969), Howarth (1956), O'Sullivan *et al.* (1972) and references cited in the text. Roxby is near Market Weighton, and the Mendips section is taken at Timsbury Sleight.

wave action lies at even shallower depths (6 m) and marks the transition from sands to silty muds (Reineck & Singh 1971). We thus interpret the transition of clay to sand in British Pliensbachian–Bajocian facies as a shallowing sequence.

Certain of the ironstones and limestones contain stromatolites and other algal traces which suggest deposition in photic zones, which may have been fairly shallow in turbid-water environments. But on these grounds alone it is impossible to assign these facies to a place in the depth hierarchy; their fauna and flora are probably substrate controlled. The presence of oncolites and ferruginous ooliths might suggest wave influence, and the paucity of sand shows that clastics were deposited but rarely. This, however, could be related as much to lack of subsidence as topographic control. Lime mud apparently *was* laid down to form the micritic limestones, although this may have resulted from submarine cementation and algal trapping of calcareous fines (see below). Although we intuitively suspect that limestones and ironstones are the shallowest-water deposits of the cyclic sequences, from the absence of clay we can only assign them to a depositional depth comparable with that of the sandstones.

'Basins' and 'swells'

Recognition that both stratigraphically condensed and stratigraphically expanded facies occur coevally in the lower Jurassic of Britain (Fig. 1) led first to the concept of axes of uplift (Arkell 1933, p. 59) and later to that of 'Schwellen' or 'swells' (Hallam 1958). How these swells were envisaged was not made clear. Hallam later (1966) referred to "offshore shoals." If the condensed sequences were deposited on "off-shore shoals," then clearly the more expanded clay-rich sections were laid down in basins; but we regard this as a simplification.

Cyclicity and 'swells'

The Dorset coast provides the most spectacular example of the cyclic arrangement of Pliensbachian–Bajocian facies (Fig. 1); however, the same pattern may be picked out elsewhere although, to the north, the limestone member may be omitted. Examples occur in Gloucestershire, Somerset, Yorkshire and Raasay (Fig. 1). What perhaps is remarkable is that the cyclicity persists, even when the relatively thick successions are traced into the highly attenuated sequences of Market Weighton and Radstock in the Mendips. At this latter locality highly condensed (2–3 m) iron-shot ammonite-bearing limestones are overlain by thick (38 m) blue clays, both of early Pliensbachian age (Tutcher & Trueman 1925). The upper Pliensbachian is apparently missing; the Toarcian is represented by a thin (*c.* 1 m) ammonite-bearing calcarenite containing limonite ooliths and an overlying thicker (*c.* 2 m) sand to clay sequence. Above this, conglomeratic ferruginous limestones of Bajocian age occur; these contain corals, thick-shelled bivalves and brachiopods and are thus similar to coeval facies on the Dorset coast.

Thus, in any one area condensed sequences were formed at discrete intervals, and were separated by times of more expanded sedimentation. Thus, if we invoke the concept of 'swells' these positive areas must have come and gone, being punctuated by episodes of 'basinal' conditions.

Time spans of 'swells'

If a condensed limestone or ironstone is taken as a manifestation of a 'swell,' then the lifespan of these features varied considerably (Fig. 1). Some condensed sequences on the Dorset coast (e.g. the Junction Bed) comprise several zones (*c*. 6 m.y.); others only parts of a zone (e.g. the Margaritatus Stone, say 0·01 m.y.). Nevertheless, the presence of any sedimentary section at all shows that the area was undergoing net subsidence, albeit discontinuously.

Better candidates as persistent positive areas are the London Platform, Market Weighton, and the Mendips, where Pliensbachian–Bajocian successions are very thin or absent. The London Platform and the Mendips remained generally positive during the early Jurassic but the presence of more extensive post-Bajocian sections (Arkell 1933, pp. 320, 323, 478) shows that they were characterized by a later history of subsidence. Market Weighton is unique, in that it continued as a positive feature throughout the whole of the Jurassic and much of the Cretaceous (Arkell 1933, p. 62, Kent 1955, Jeans 1973).

Expanded sequences and 'basins'

Expanded sequences always occur between condensed sequences, even in the most attenuated successions. Nevertheless, with respect to the highly reduced Pliensbachian–Bajocian successions of the London Platform, the Mendips and Market Weighton, all other sequences are expanded. The only sequence that lacks all evidence of even temporary 'swell' conditions, however—as manifested by ironstones, ferruginous limestones, intraformational conglomerates—is that of the Mochras Borehole in Cardigan Bay (Fig. 1). This comprises a thick (1305 m Lias) series of clays, siltstones and silty mudstones with some calcareous levels. Fossils include ammonites, belemnites, brachiopods, bivalves, crinoids and abundant plant remains. Particularly significant is the presence of slump bedding in calcareous mudstones of *spinatum* age (O'Sullivan *et al.* 1972). Even more significant perhaps is the complete absence of slumps or turbidites in Pliensbachian–Toarcian clay facies anywhere else in Britain.

Summary:

1. Clay, sandstone and ironstone/limestone were deposited in different depths of water; and the sequence of clay to sand or limestone/ironstone represents a shallowing.
2. 'Basinal' clay sequences were formed even in highly attenuated sections like the Mendips and the edge of Market Weighton (Fig. 1).
3. In all of the Pliensbachian–Bajocian successions of Britain, turbidites are lacking. Slumping has only been recorded at two levels in the Mochras Borehole.
4. On the Mendips and the London Platform only thin successions accumulated throughout the early Jurassic; later sections were much thicker. Market Weighton, however, remained as an essential non-accumulating area throughout much of the Jurassic and Cretaceous.

5. In any one area, 'swells'—as manifested by condensed ironstone/limestone—were active only at discrete intervals and behaved 'basinally' in the intervening times (Fig. 1).
6. Regions of 'swell' conditions, whether long-lived or short-lived, passed laterally into regions of 'basinal' conditions (Fig. 1).
7. Times of 'swell' or 'basin' formation were not synchronous over the whole of the British area (Fig. 1).

From 1–3 we may conclude that although topographic irregularities did exist on the floor of this epeiric sea—to produce different facies areas at any one time—they were subdued enough to prohibit development of turbidites, and soft-sediment slumping did not generally take place. This means that a pronounced basin-swell topography was not present, and that in this British part of the European epeiric sea sediment supply was always great enough to ensure that pronounced bottom slopes were never obtained.

We may conclude from 4–7 that eustatic rise and fall of sea level was not the only, or indeed the most, important factor governing changes in water depth and that intermittent subsidence, even of such highly positive areas as the Mendips and Market Weighton, must have taken place, such subsidence varying both in time and space.

In the following section we outline models to explain the genesis of various British Jurassic 'swells' and show how they have controlled the development of characteristic facies.

Models for the formation of 'swells'

Cyclic 'swells' of the Dorset coast

To explain the genesis of condensed limestone/ironstone successions cyclically arranged between clays and sands (Fig. 2), let us assume that clay is being deposited on a laterally extensive sea floor below the level of wave effectiveness.

FIG. 2. Models to illustrate the development of cyclic 'swells.'

I. Starting point is a basin whose sea-floor is below limits of wave-effectiveness. Assume rapid clay and silty clay deposition exceeds rate of subsidence.

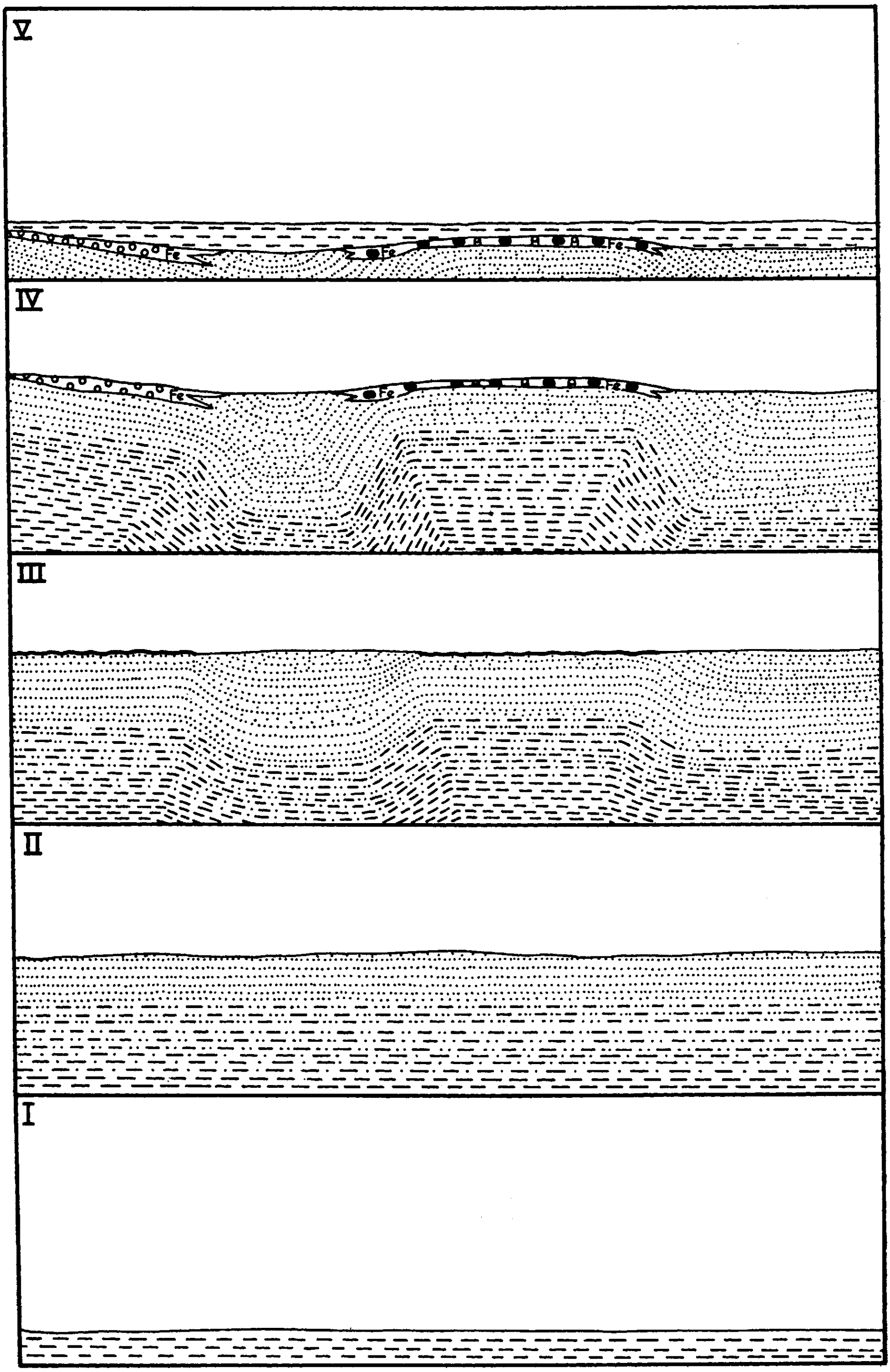
II. Sea-floor accretes towards zone of increasing wave-effectiveness. Silty and rippled sands deposited. Sediment supply exceeds normal rate of slow subsidence.

III. Subsidence ceases in areas above temporarily stabilized basement. Here, sedimentation continues to equilibration level after which erosion surfaces are formed. Surrounding areas of continued subsidence provide clastic traps.

IV. Precipitation and trapping of carbonates and iron oxide–hydroxides produces stabilized substrates in shallow water. Hardgrounds ("Dachbanks") are thus developed. These condensed sequences are flanked by continually subsiding clastic traps. Slight up-warping may accentuate condensed sequences.

V. Finally, the whole region undergoes renewed rapid subsidence taking sea-floor below limits of wave-effectiveness. Sea-floor is rapidly inundated with clay.

Legend as in Fig. 1.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If rate of deposition exceeds rate of subsidence the sea floor will accrete vertically into shallower zones of more vigorous water movement so that clays are kept in suspension; silts and sands will now be introduced into the region and, where the hydrodynamic regime is favourable, they will be deposited.

Assume now that subsidence ceases over a certain area; sedimentation will only continue up to equilibrium level where a balance is struck with erosion, and after this no net deposition will take place. Assume furthermore that in neighbouring areas subsidence continues unabated, then these areas will act as clastic traps for clays, silts and sands, denying access of these grains to the less subsident region. Thus in the stable area a stratigraphically condensed sequence will result, formed partly by reduced input of sediment and partly by abundant erosional reworking (cf. Jenkyns 1971). The resulting non-depositional environment may be favourable for the precipitation of high-magnesian and/or aragonitic cements (Bathurst 1971, p. 371–81, Milliman & Müller 1973). This will produce a hard substrate which can be colonized by crinoids, boring organisms and stromatolitic algae. Deposition of fine-grained carbonate derived from nannofossils, plus macerated skeletal calcite and aragonite, will be aided by the trapping activities of algal mucilage; the affinity of blue-green algae for fine material is well documented (e.g. Black 1933). Once deposited, cohesion of the fine material may render it difficult to erode. Deposition of iron minerals such as goethite and possibly chamosite would also be favoured in this setting (Hallam 1966, Gatrall *et al.* 1972).

Assume that after considerable lengths of time (several zones or parts of zones) the stable area undergoes rapid subsidence, plunging the sea floor below the level of wave effectiveness. Clay deposition recommences, and the cycle begins anew.

Clearly this mechanism is dependent on intermittent differential movement within the basement (here considered as the pre-Permian floor, following Kent 1949, Bott & Watts 1970, McIver 1972). There was, however, no transmission of these movements to the sea floor in bold topographic terms because high rates of sedimentation more than compensated for rates of subsidence. Lack of competence of the sedimentary pile—that is, an inability to produce an upstanding block on the sea floor—may possibly have been a contributory feature. We conclude that the control for these transient cyclic 'swells' was movement along faults in the basement.

London Platform and Mendips

Since the sedimentary successions that occur on the London Platform and on the Mendips are similar in kind, if not in thickness, to those of the Dorset coast we suggest that these areas were also relatively positive blocks whose behaviour was governed by circumscribed faults that moved intermittently. In the case of the Mendips and London Platform, however, there is the important difference that, during early Jurassic times, the basement blocks existed as emerged landmasses that were gradually transgressed by the sea (Arkell 1933, p. 128, Sellwood 1972). Geophysical investigations around the margins of the Mendips have revealed steep gravity gradients which may be interpreted as evidence of basement faults (Fig. 3), (Brooks *in* Green & Welch 1965).

Market Weighton

Many explanations of a purely tectonic nature have been proposed in the past for the Market Weighton structure (Arkell 1933, p. 62, Kent 1955, Hallam 1958) and more recently Jeans (1973) reaffirmed the view of fault control with posthumous movements of basement faults continuing into the Cretaceous. However, the Market Weighton 'swell' is so different from other areas in terms of its longevity that we believe its origin to be dissimilar. In this part of Britain the pre-Permian floor lies in excess of 1 km below the surface (Kent 1949). The Bouguer Anomaly Map (I.G.S. 1965, Sheets 7 & 8) reveals a striking circular gravity low (−27 mgals) centred near Market Weighton. Kent (in discussion of Jeans 1973) admitted that the cause of the Market Weighton structure remained enigmatic, but that the phasing of its movements showed a close analogy to halokinetics structures in the North Sea, where salt domes and salt pillows are known to have controlled Jurassic sedimentation (Brunstrom & Walmsley 1969, Christian 1969). Market Weighton lies at the edge of the North Sea Zechstein basin and it is palaeogeographically reasonable to assume significant salt deposits in this area. Kent (1955) showed that Permian salt was present in a borehole situated on the flanks of the gravity low at Market Weighton, but it was not anomalously thick. Nevertheless, some kind of salt build-up could explain the presence of the gravity low, and natural buoyancy of the evaporite body when compared to surrounding country rocks could easily have led to a non-subsident area over Market Weighton during Jurassic and Cretaceous time.

An alternative possibility, suggested to us by Professor Bott, is that the gravity low is caused by a granite, presumably of Caledonian or greater age. Like a salt body, the relatively low density of this kind of igneous rock could have rendered

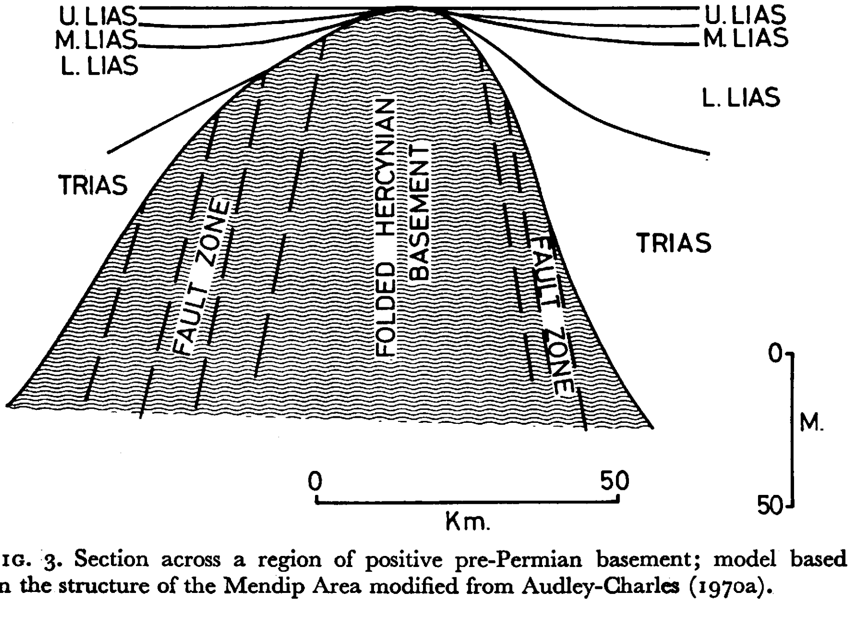

FIG. 3. Section across a region of positive pre-Permian basement; model based on the structure of the Mendip Area modified from Audley-Charles (1970a).

it buoyant relative to the surrounding basement from which it was probably uncoupled by faults. The role of granites in affecting Carboniferous sedimentation by producing so-called stable blocks is well established (Bott 1967, 1974) and there seems no reason why these igneous bodies should not have played a similar role in Mesozoic time.

Whether the Market Weighton 'swell' is salt- or granite-controlled, it seems very probable that differential movement of the less dense body was triggered by early Jurassic fault movements.

Palaeogeography of the north European epeiric sea

Up to 1970 published palaeogeographic maps for the early and middle Jurassic differed little from those constructed by Arkell (1933, pp. 595, 597) and Wills (1951). The early Jurassic reconstructions of these authors were dominated to the west by a 'North Atlantis' continent which encompassed most of Wales, Ireland and the Irish and Celtic Seas with its eastern edge passing through Cornubia. Present-day upland areas were assumed to have been sediment sources and consequently Pennine Islands and Lake District Islands were postulated even though sedimentary evidence was often lacking. The discovery of a thick basinal sequence of lower Jurassic sediments at Llanbedr (Mochras Farm), Merionethshire (Woodland 1971) casts an immediate doubt on the validity of the Welsh landmass; and the increasing volume of off-shore information from W. Britain (Kent 1969) reinforces the view that 'North Atlantis' must be considered largely a myth. Some sediment may have been derived from the Greenland–Laurentian platform (see palaeogeography in Fig. 4) but the main source of clastics deposited in the north European epeiric basin was probably Fennoscandia. Along the flanks of the Fenno–Scandinavian shield, lower Jurassic sediments contain fragments of gneiss (e.g. on Bornholm); generally, however, the sediments are extremely mature and indicate either Palaeozoic sedimentary sources or extremely severe weathering of the igneous/metamorphic terrains. In view of the local survival of recognizable gneissic fragments, it seems more probable that upper Palaeozoic sediments are the likely sources and that much of this cover was eroded during the Mesozoic.

Smaller source areas of sediment also existed (Fig. 4). The lower Jurassic stratigraphical record around these land-masses usually indicates the former presence of limited sources of clastics, apparently derived from upper Palaeozoic rocks. The geological evolution of these emerged areas is well known in terms of their regressive and transgressive histories (Arkell 1933, Hallam 1961, Sellwood 1972). On the Armorican Massif, in Normandy, the Pliensbachian rests with a coarse basal conglomerate upon the Ordovician (Rioult 1958). These gravels, with their well rounded and oyster-encrusted pebbles of Ordovician sandstone pass up over a mere 1·5 m into condensed biosparites and biomicrites. The complete restriction of the clastics to the basal gravel suggests that the Armorican Island was topographically subdued and supported only minor rivers with low fluvial discharge. The characteristics of the Armorican Island probably applied in a general way to the other island areas and helps to explain the singularly local influence that these areas had on sedimentation in the whole of the epeiric basin.

Origin of the north European epeiric sea

It is assumed in the above models that movement along basement faults during early Jurassic time controlled depositional patterns. The only onshore fracture zone which can be directly demonstrated as active during the Lias, by its effect on sediment thickness, is the Peak Fault on the Yorkshire coast (Arkell 1933, p. 180, Hemingway 1974). Infra-Liassic folding has, however, been documented both locally (Tutcher & Trueman 1925, Whittaker 1972, Chowns *in* Hemingway 1974) and regionally (Arkell 1933). Perhaps the most graphic manifestation of

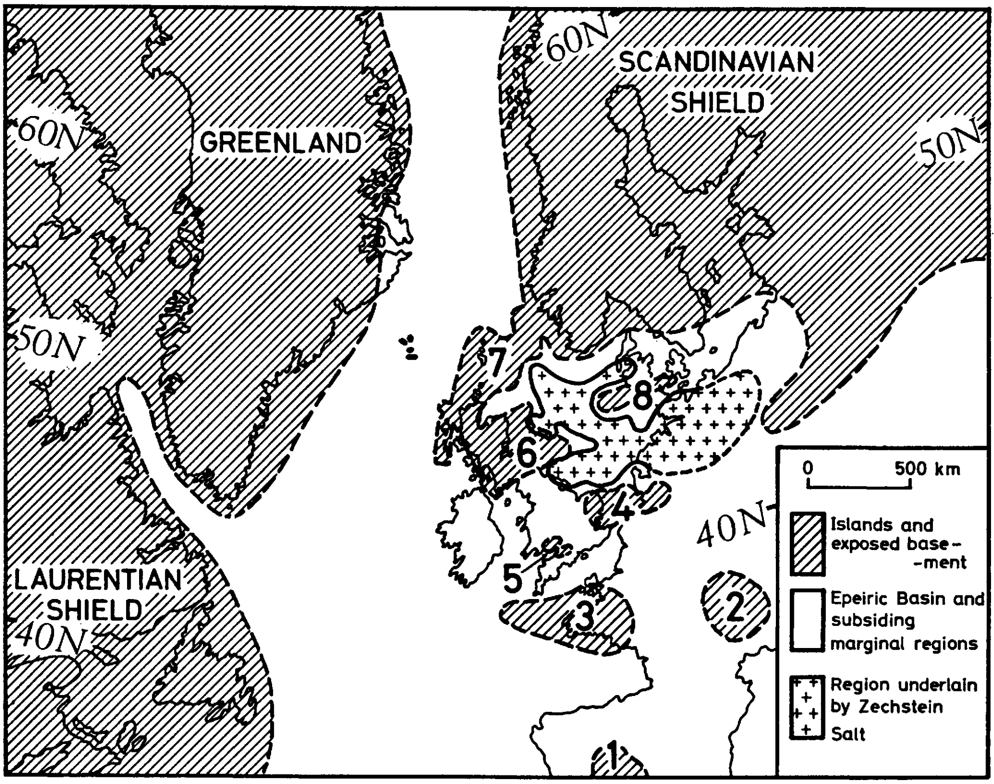

FIG. 4. Distribution of positive and negative regions within and around the epeiric basin of northern Europe during the late early Jurassic. Drawn from data of Armstrong 1972, Hallam 1971a, b, Cazenove and Co. 1972, McIver 1972, Rosenkrantz 1934, Sellwood 1972, Sorgenfrei 1969, Surlyk *et al.* 1973, Vann 1974. Palaeolatitudes from Van der Voo & French (1974).

1 = Spanish Meseta;
2 = Massif Central;
3 = Armorican Massif;
4 = London–Brabant Massif (London Platform)
5 = Mendip–Glamorgan Archipelago;
6 = Mid-North Sea High;
7 = Grampian–Shetland Platform
8 = Ringkøbing–Fyn High.

tectonism is that of neptunian dykes in the Mendips that bear witness to fracturing of Carboniferous Limestones and subsequent filling by Liassic and younger sediments (Moore 1867). Epeirogenic movements also took place within the Jurassic as a whole both on the mainland (Arkell 1933, Hallam 1969) and in the North Sea (Armstrong 1972).

The north margin of the epeiric sea was probably fault-controlled (Sellwood 1972). In Bornholm, Denmark, very coarse, locally derived slump-conglomerates containing granitic and gneissic materials are interbedded with lower–middle Jurassic coal measures (Gry *et al.* 1969); these conglomerates were almost certainly derived as a result of syn-depositional tectonism along a nearby fault zone. In the Helvetic nappes of the Alps, the Pre-Alps and the southern Sub-Alpine chains—domains formerly situated near the southern margin of the epeiric sea—Liassic fault movements are documented by breccias, stratigraphical discordances and abrupt changes in sedimentary thickness (Trümpy 1960, Plancherel & Weidmann 1972, Coadou & Beaudoin 1973). Fault movements continued during the middle and late Jurassic in the Helvetic zone and southern Sub-Alpine chains (Trümpy 1960, Coadou & Beaudoin 1973).

Horst–graben topography has been suggested as an important factor in controlling the sedimentation of the British Triassic (Audley-Charles 1970a, b); thus this tectonic regime presumably continued into the Jurassic, but with the difference that environments were now marine. Exploration in the North Sea and western European shelf has revealed the presence of horst and graben structures that apparently formed during the Jurassic: many of the troughs contain thick sedimentary sections of this age (Kent 1967, 1969, Naylor *et al.* 1974, Howitt 1974). Some of these troughs meet in trilete junctions (e.g. Moray Firth Trough, northern North Sea Trough, Forties–Ekofisk Trough). The Forties–Ekofisk Trough, for example, connects with the Netherlands Trough System and the Lower Rhine Graben.

From the above it seems likely that the formation of the north European epeiric basin (i.e. the overall subsidence) was directly related to fault movements in the basement (Armstrong 1972, cf. Shelton 1968). The role of eustatic rise in sea level is difficult to assess, but we suspect it is minor. Hallam (1969) has suggested a secular rise in sea level throughout the Lias; whereas Rona (1973) recognized a progressive regression associated with inferred slow rates of sea-floor spreading during the early and middle Jurassic. Both Hallam and Rona agree on a minor regressive phase towards the end of the Lias that continued into the middle Jurassic (Sellwood & Hallam 1974). Hallam's (1969) plots of continental areas overstepped by Jurassic sediments perhaps provide the more convincing evidence but bearing in mind the inevitable subsidence of newly created continental edges, it seems likely that any eustatic change was of modest order. There is no convincing evidence for major synchronous phases of shallowing or deepening that can be recognized on a global scale.

In parts of the Alps and in southern Europe there is evidence of block-faulting and volcanism through the middle-late Triassic to early Jurassic (Bernoulli & Jenkyns 1974). Pronounced bottom relief during early Jurassic time is witnessed by the abundance of slumps, turbidites and slope breccias (e.g. Bernoulli 1964, 1971, Bosellini 1967, Bernoulli & Jenkyns 1970, Castellarin 1972). This fault-block topography was produced by the dissection and differential subsidence of the carbonate platforms and fringing reefs that were installed on the southern continental margin of the nascent Tethyan Ocean (Bernoulli & Jenkyns 1974). A vertical displacement of approximately 4 km has been estimated for a Liassic fault in the Southern Alps (Bernoulli 1964). The major phase of block-faulting in Alpine and southern Europe took place during the Pliensbachian–Toarcian, a time which correlates with the initiation of sea-floor spreading in the Alpine–Mediterranean Tethys (Bernoulli & Jenkyns 1974) and with that in the central Atlantic as deduced from magnetic anomalies and deep-sea drilling data (Pitman & Talwani 1972). On the southern margin of Tethys, sediment supply was minimal and pelagic conditions prevailed, ensuring longevity of bottom slopes. In the North Sea the formation of Jurassic troughs has been similarly related by Naylor *et al.* (1974) and Sellwood & Hallam (1974) to rifting associated with the break-up of the Laurasian supercontinent. In this context they regard the northern North Sea Trough as the 'failed' arm of a trilete system centred east of the Moray Firth. Thus it seems that the whole north European epeiric basin owes its origin to the extensional tectonics that characterize regions marginal to new oceans (e.g. Dewey & Bird 1970, Hutchinson & Engels, 1970, 1972, Bott 1971). We can regard this basin as related to the formation of the Tethyan and central Atlantic Oceans.

Arkell (1956, p. 632) saw the Jurassic of the Old World as a time of tectonic 'quiet.' Clearly this was not so. In early to middle Jurassic times at least we may now point to abundant evidence of disturbance, disruption and collapse—effects that necessarily witness the formation of oceans and the dispersal of continents.

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