PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME TWO
PART TWO

Edited by
E. B. SELWOOD

REDRUTH, NOVEMBER 1969

THE USSHER SOCIETY

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The following papers were also read :

Par Beach exploration. By A. D. Francis.

Chemical analysis of the dolerites and associated rocks of the middle Teign valley. By J. A. Chesher.

CONFERENCE OF THE USSHER SOCIETY HELD AT TREBETHERICK, NORTH CORNWALL, JANUARY, 1969

CHAIRMAN'S REPORT

Geological Research in South-West England, 1969

The eighth Conference of the Society was held in the St. Moritz Hotel, Trebertherick on the 8th and 9th of January. Dr. J. M. Hancock of King's College, London, gave the invitation address *Transgression of the Cretaceous sea in South-West England.* On Tuesday, 7th January Professor M. R. House and the Rev. B. B. Clarke led an excursion to the Trebetherick area, and the meeting ended with a visit on Friday, 10th January to the Boscastle area under the direction of Dr. E. C. Freshney.

Membership of the Society and attendance at the conference have been well maintained. The total membership at the end of February, 1969 was 139, and some 65 members, the largest number ever, attended the conference. In anticipation of the production of an up to date version of the map *(Proc. Ussher Soc.,* Vol. 1. pt. 4, Contribution 100) showing geological research being undertaken in 1965, just over 100 members have given details of their research interests. Of the replies, 80% were from people actively working on geological and geomorphological problems in the South-West; 64% were from University staff and associated research workers. Details of individual research topics are set out on the accompanying map, and the dominance of stratigraphical and geomorphological topics is not surprising; but there is an encouraging growth of interest in applied aspects of geology. The most important differences between the 1965 and 1969 maps are the direct and indirect contributions of the South-West Unit of the Institute of Geological Sciences. In the 1963 Chairman's Report *(Proc. Ussher Soc.,* 1. pt.2), commencement of the primary survey on 6-inch maps of the Okehampton 1-inch Sheet 324 is recorded; both map and memoir have now been published. Work is complete on Boscastle Sheet 322 and the contiguous Tintagel area, Holsworthy Sheet 323 and Bude Sheet 308. In addition mapping is continuing in the

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Chumleigh Sheet 309, the Bideford Sheet 292 and the Weston-super-Mare Sheet 279. A particularly interesting contribution is the seven entries on the map recording the collaborative effort of the Department of Geology at Exeter University and the Institute of Geological Sciences in the revision of the Teignmouth Sheet 339.

Notably absent this year was the friendly figure of Ken Hosking who is now Professor of Applied Geology in the University of Malaya. He will be remembered particularly for his encyclopaedic knowledge of South-West England mining and mineral deposits and his enthusiastic presentation of the results of geochemical prospecting in the region.

On a personal note, during the past I have become increasingly aware that thin-section studies are an essential adjunct to field observations in structural geology, that a slaty cleavage is not an infallible indicator of the first phase of tectonic deformation, and that fold shape must be treated with the same caution. Much of the old work remains to be redone, although the main structural framework is now known in some detail.

The 1970 Conference is to be held for the second time at Bristol University by the kind invitation of Professor D. L. Dineley.

W. R. Dearman, July, 1969.

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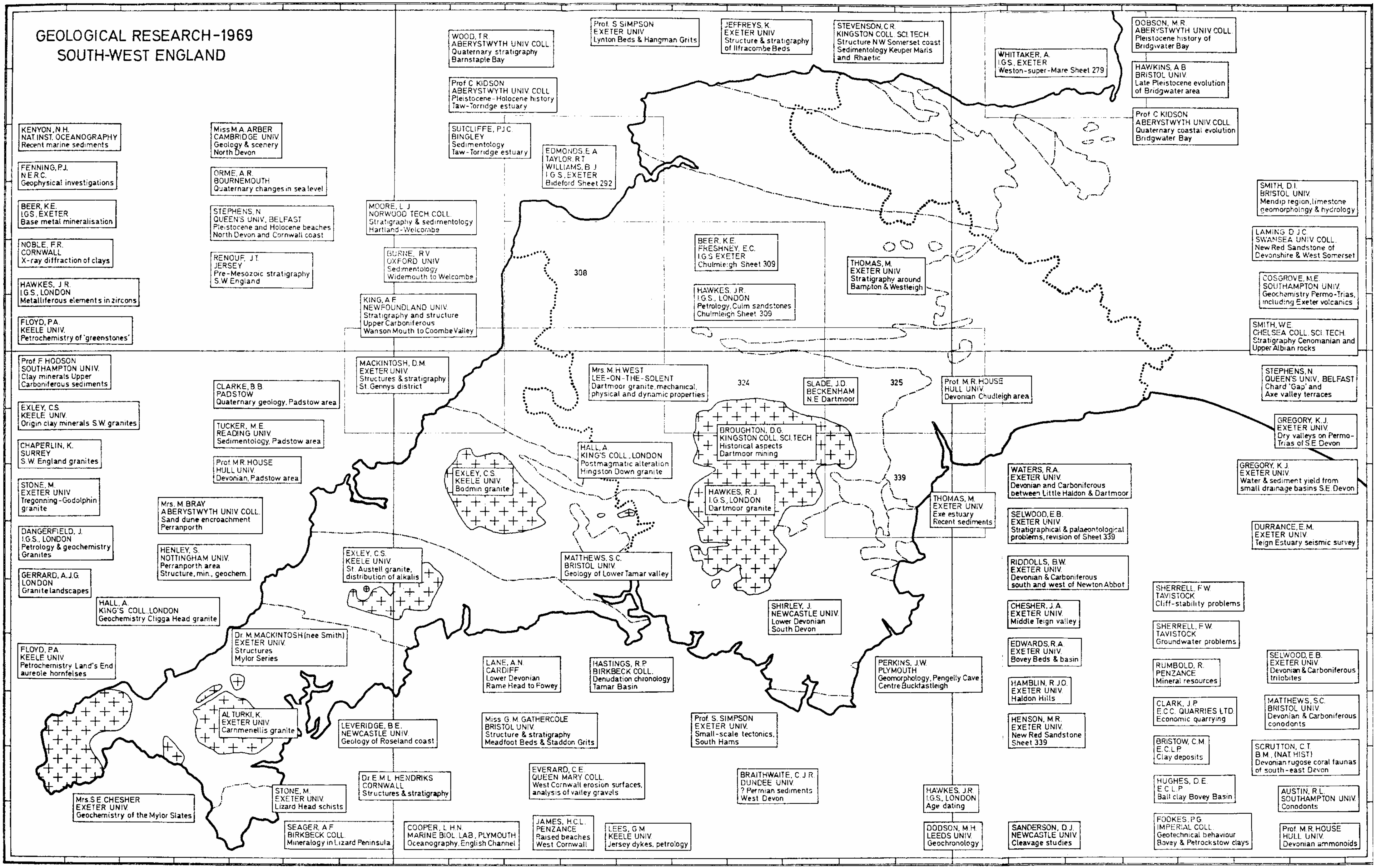
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TRANSGRESSION OF THE CRETACEOUS SEA IN SOUTH-WEST ENGLAND

by J. M. Hancock

Abstract. There was a repeated south-westward advance of sedimentation during the Cretaceous from a basin region in Wessex on to the Cornubian massif, and the incoming of the basin facies was often earlier in north Dorset than in south Dorset. By the Upper Senonian the whole of Devon and Cornwall was probably submerged. The heavy minerals in the Cenomanian indicate that the Dartmoor granite was not exposed or was not undergoing appreciable erosion.

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1. Introduction

Cretaceous sediments in north-west Europe are entirely in shelf to fresh-water facies. During the Lower Cretaceous, sedimentation was confined to subsiding basins; following the ideas of Barrell (1917) one supposes that the thicker sediments occur where subsidence was greater. During the Upper Cretaceous many of these basins continued to subside but, at the same time, sea-level rose, apparently on a world-wide scale - the Cenomanian transgression of Suess. This transgression started during the Upper Albian, and continued in jerks until the late Campanian; then, in the Maestrichtian, there is evidence of a fall in sea-level. The Upper Cretaceous rise in sea-level submerged ancient massifs in many parts of the world. In the late Campanian the only parts of the British Isles standing out of the sea were the highlands of Scotland and possibly the northern mountains of Wales.

In South-West England one has both the ancient massif of Cornubia and the subsiding basin of Wessex centred in the Isle of Wight. In this region sediments deposited near the margin of the basin, and over the massif, are preserved from all stages up to early Turonian; thereafter the evidence is scanty. The region is particularly valuable for showing the lateral transition from basin to massif during the Albian and Cenomanian - two of the stages during which considerable transgressions occurred.

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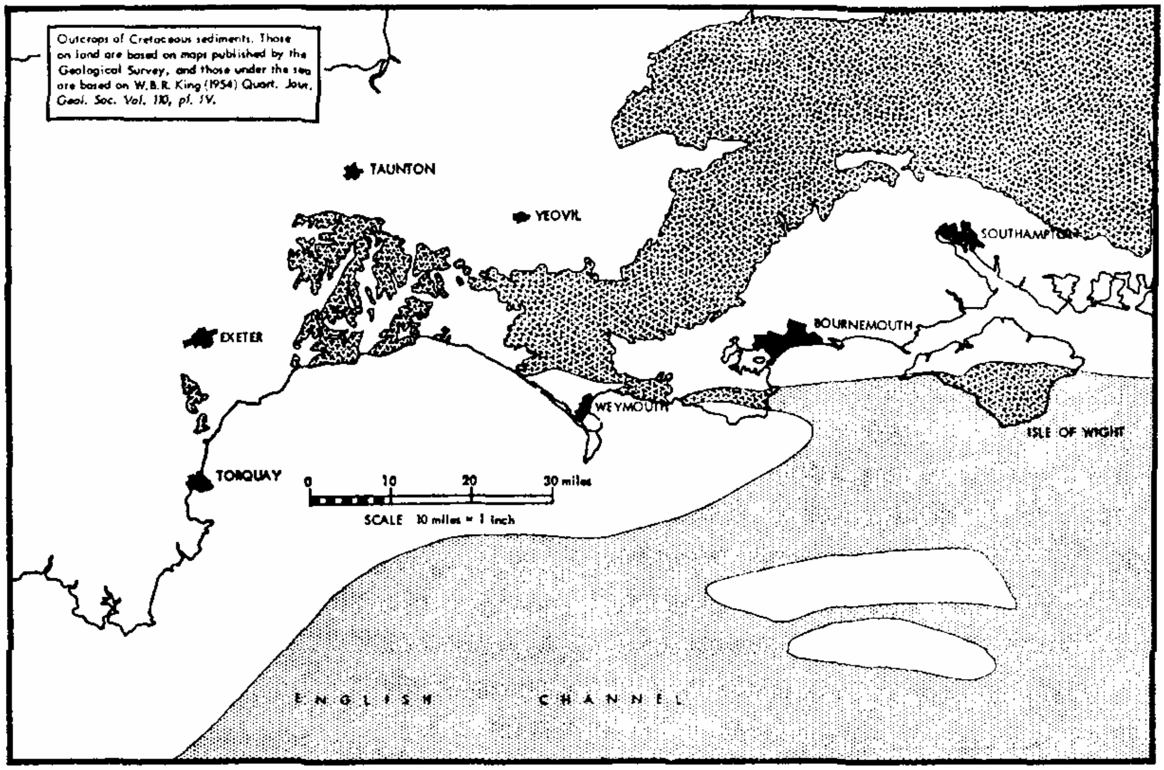

FIGURE 1. Outcrops of Cretaceous sediments. Those on land are based on maps published by the Geological Survey, and those under the sea are based on W.B.R. King (1954) *Q.Jl geol.Soc.Lond.,* Vol. 110, pl. IV.

2. General Features of the Cretaceous Sediments

(a) The Wessex basin sediments are characterised by :

(i) Thickness. The pre-Turonian Cretaceous sediments in the Isle of Wight are about 900 m thick. In the marginal area of Lulworth Cove the equivalent succession is only 225 m; in south-east Devon it is as little as 48.6 m (Whitecliff, near Seaton).

(ii) Fuller representation. The Wealden (590 m in the Isle of Wight, Arreton bore; Falcon & Kent 1960) thins to nothing just north of Weymouth. The Lower Greensand (120-240 m in the Isle of Wight) dies out at Lulworth Cove. These disappearances are not merely differential erosion association with the pre-Albian earth movements of the Weymouth district : the Wealden especially shows appropriate facies changes from being dominantly argillaceous in the Isle of Wight to a succession which includes coarse-grained, tourmaline-rich, sands at Lulworth Cove.

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(iii) Glauconitic Marl. At the base of the Chalk there is a grey glauconitic marl, which sometimes rests without a marked break on the underlying Upper Greensand.

(b) The succession over the massif is characterised by:

(i) Little sediment earlier than Upper Albian.

(ii) The Chalk basement bed always resting abruptly on a marked erosion surface.

(iii) The Chalk basement beds being largely free of both clay and glauconite.

(iv) The base of the Chalk, although of various ages, is probably never older than the *Turrilites acutus* assemblage-horizon of the *Acanthoceras rhotomagense* Zone (Middle Cenomanian). However, in several areas there are earlier Cenomanian sediments in other facies e.g. Wilmington Sands, Cenomanian Limestone of the Devon coast.

3. The Advance of the Sea out of the Wessex Basin

(a) Wealden

During the Wealden sedimentation was confined to the basin and almost entirely fresh-water; only in the top beds of the Weald Shales of the Isle of Wight are marine fossils such as *Ostrea distorta* found. Most of the succession is sandy and the material shows unmistakably its Cornubian origin: the sands near Swanage are rich in tourmaline; the coarse sands around Lulworth are speckled black with tourmaline. The westerly coarsening and thinning is extraordinarily rapid (fig. 2), and the formation does not extend beyond Friar Waddon, 8 km north-north-west of Weymouth (Wilson and others 1958).

There are a few metres of silty clay mapped as Wealden at Dinton, west of Salisbury.

(b) Aptian - Lower Albian

There is almost no palaeontological control on the dating of the Lower Greensand west of the Isle of Wight except at the horizon of the Forbesi Zone in the Lower Aptian. This zone is represented

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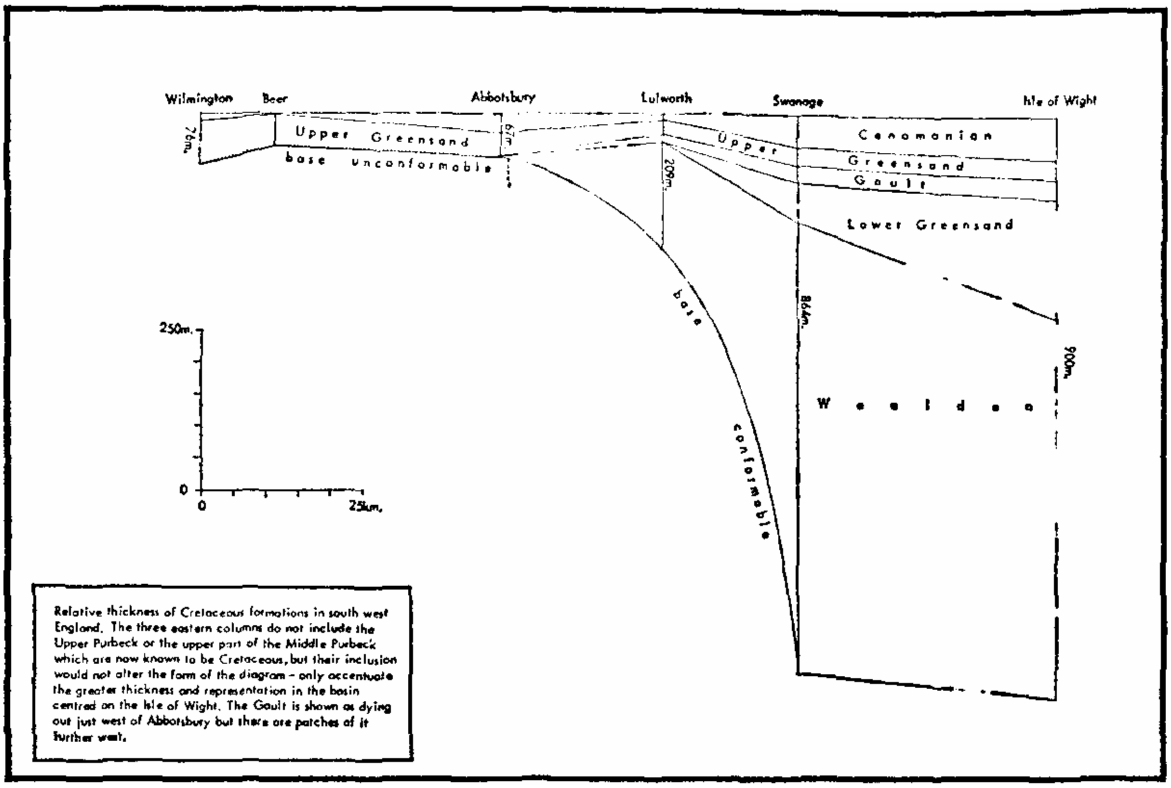

FIGURE 2. Relative thicknesses of Cretaceous formations in South-West England. The three eastern columns do not include the Upper Purbeck or the upper part of the Middle Purbeck which are now known to be Cretaceous, but their inclusion would not alter the form of the diagram - only accentuate the greater thickness and representation in the basin centred on the Isle of Wight. The Gault is shown as dying out just west of Abbotsbury but there are patches of it further west.

by the Punfield Marine Band at Swanage, a thin fossiliferous ironstone in Worbarrow Bay and on the east side of Lulworth Cove, becoming less marine as it is traced westwards (Casey 1961: 516-7). There is no reason to doubt that the main mass of the Lower Greensand belongs somewhere in the Aptian-Lower Albian. Its western limit at Lulworth Cove is probably set by the erosion on pre-Middle Albian uplift in the Weymouth region. Nevertheless, the farther westerly extent of the Wealden is probably a fair reflection of original distribution.

In Wiltshire the sandy basement beds of the Gault at Dinton (13 km west of Salisbury) and Dilton Marsh (3 km south-west of Westbury) belong to the lower part of the Mammillatum Zone in the Lower Albian (Casey 1956, 1961), equivalent to the bulk of the Carstone of the Isle of Wight.

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In north Dorset the sands around Bedchester give little clue regarding their former extent to the west and north-west. They could be close to their original limits of deposition. Casey (1961: 565) suggests that they also may belong to the Mammillatum Zone.

(c) Middle Albian

With the Middle Albian we have a palaeontological control although the sections are so poor and the gaps between them so great that one cannot be dogmatic. Much of our knowledge of this substage comes from the work of Hugh Owen, and I am indebted to him for graciously allowing me to use some of his unpublished work.

At Punfield Cove, north-east of Swanage, the Carstone is undated, but the Gault here, and further west in south Dorset, is Middle Albian. The pebble bed at the base of the Gault is probably diachronous, but this cannot be proved. Above the pebble bed the lowest horizon with fossils belongs to the Spathi Subzone at Worbarrow Bay and Osmington (although Wright in Arkell 1947 claimed Benettianus Subzone was present at White Nothe). At Black Ven, immediately north-east of Lyme Regis, Beds 1, 2 and 3 of Lang (1914) belong to the Intermedius Subzone. The same subzone occurs at Charton Goyle about 5 km east of Seaton (Spath 1923-43: 744). The diminutive sandy Gault of Culverhole, 21 km east of Seaton, contains *Inoceramus concentricus* and is probably Middle Albian, as may also be the metre or two of sandy silts called Gault in the railway cutting east of the tunnel at Honiton.

The Eodentatus Subzone at the base of the Dentatus Zone transgresses into north Dorset and forms the base of the Gault resting directly on Kimeridge Clay at Okeford Fitzpaine in the Stour valley, 9 km north-west of Blandford.

During the Middle Albian marine deposition, and probably the sea itself, advanced some 60 km westwards out of the basin and on to the massif.

(d) Upper Albian

(i) Zone of Mortoniceras inflatum. The lower part of the Upper Albian is markedly transgressive, overlapping the Middle Albian everywhere, and overstepping Jurassic and Trias to rest on Permian in the Haldon Hills; at one time it probably extended on to Carboniferous and Devonian. Marine deposition advanced at least 40 km to the west.

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In the basin some of the Gault may extend upwards into the Inflatum Zone but the evidence is poor and there is a considerable thickness of passage beds between Gault and Upper Greensand. A geologist coming from the Weald would probably class most of these as Upper Greensand, whilst someone coming from Devon would regard them as Gault. Jukes-Brown & Hill (1900) quote *A. rostratus (=Mortoniceras)* from the passage beds in the Isle of Wight: this indicates Inflatum Zone, and the upward range of *Hysteroceras* shows that most of the Upper Greensand of the Isle of Wight belongs to this Zone.

In south Wilts the ‘Malmstone’ at the base of the Upper Greensand begins in the Inflatum Zone (Varicosum or Auritus Sub-zone) (Hancock in Mottram and others 1956).

All the western outliers of Upper Greensand begin with the Inflatum Zone: the Haldon Sands are poorly dated but have yielded *Mortoniceras (Deiradoceras)* aff. *devonense* Spath; the Blackdown Sands represent Varicosum and/or Orbignyi Subzones having yielded *Hysteroceras spp.* (e.g. *H. varicosum*), *Prohysteroceras goodhalli, Epihoplites* spp. (e.g. *E. deluci*), *Euhoplites alphalautus* and *Mortoniceras devonense.*

The Foxmould of south-east Devon probably spans the Varicosum and Auritus Subzones having yielded : *Mortoniceras cunningtoni, M. devonense, M. bipunctatum, M. albense, Hystero-ceras varicosum* and *Callihoplites* aff. *auritus.* The bivalve fauna of the Foxmould is also similar to that of the Blackdown Sands (see list by Wood in Smith & Drummond 1963: 342). Tresise (1960) was misled by Spath’s earlier work into thinking that the Blackdown Sands were earlier than the other Upper Greensand of Devon and Dorset: the evidence points to them being contemporaneous with the lower part of the Foxmould. Their lithology differs from the Foxmould; in part because they are probably closer to the original limits of deposition; in part because the removal of the Chalk cover has allowed the calcareous element to be leached out - as Tresise himself has rightly pointed out.

(ii) Zone o f Stoliczkaia dispay. In the Isle of Wight at Compton Bay, Dispar Zone ammonites have been found in a band of large phosphates less than 2 m below the, abundant nodules of the Glauconitic Marl (Wright & Wright 1942). At Punfield, ammonites of this zone are common immediately beneath the Glauconitic Marl,

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but at White Nothe, whence the fauna is well known, it occurs 4.3 m below the Chalk basement bed, probably because the top few metres of the Upper Greensand are Cenomanian.

In north Dorset the Dispar Zone fauna is found immediately beneath the Chalk basement bed at Shillingstone, at Dorsetshire Gap and near Batcombe.

Further west evidence of the Dispar Zone is scant. Spath (1926) assigned the Chert Beds to the Dispar Zone (Substuderi Subzone) but apparently with no evidence; later, Lang found *Mortoniceras* gr. *stoliczkai* in these beds near Charmouth (Wilson and others 1958) confirming Spath's dating. Casey has now recorded (1965: 435) a Dispar Zone *Stoliczkaia* from the Haldon Sands.

(iii) Limits of the Albian sea. The Haldon Sands are sometimes coarse, generally free of glauconite, and contain a fauna which includes corals. They cannot have extended much further in a true westerly direction, but might have once occurred further to the north-west. It is a pity that the scatter of chert pebbles on the New Red Sandstone may only bear witness to a former extent of Eocene gravels. Mention may be made here of the greensands on the east side of the Bovey basin; discovered by Godwin Austen, confirmed by De la Beche (1839), and then overlooked until re-discovered by R. A. Edwards in the last few years.

In a direction north of Dorset, the approach of the Upper Greensand to within 5 km of the Carboniferous Limestone of the Mendips near Frome, can be seen even on small scale maps. Less well known is the outlier of greensand of unknown age in Postlebury Wood which lies higher than the present level of the Carboniferous only 2 km away at Holwell.

(e) Cenomanian

The Chalk basement beds of South-West England have long attracted enthusiastic fossil collectors because of the rich well-preserved phosphatised faunas. But the recognisable horizons represented number perhaps eight, even though some assemblages clearly involve considerable condensation. The faunal horizons preserved are dependent on good preserving conditions, commonly (but luckily not exclusively) immediately preceding normal chalk deposition at any one locality.

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One had hoped that study of the ammonite succession in the ordinary Lower Chalk of south-east England would have provided a continuous ammonite sequence into which the isolated Dorset-Devon assemblages could be fitted. The detailed work of W. J. Kennedy has shown that this is not entirely possible because even in the Lower Chalk the ammonite faunas are usually limited to discrete horizons with considerable gaps between: at many levels there has been dissolution on the sea floor of their aragonitic shells. Moreover, there is no *a priori* reason why faunal assemblage horizons recognisable in the Lower Chalk sequence should be represented in the Chalk basement beds of the south-west.

Kennedy's assemblage horizons are listed in Table I and fitted into a zonal scheme worked out by C. W. Wright (*in litt.*) and followed by Hancock (1959). Kennedy has applied his horizons to Wessex (in press) but for many purposes it will be sufficient to use a three-fold division of the stage.

(i) Lower Cenomanian. In the Isle of Wight and north-east Dorset the Mantelli Zone is represented by Glauconitic Marl and some of the Lower Chalk. Passing westwards from this region the Mantelli Zone quickly disappears. In north Dorset there is lower Mantelli Zone well represented at Shillingstone in the Stour gap (Hancock in Mottram *et al.* 1956). At Dorsetshire Gap, 4½ km east of Alton Pancras, there is a highly condensed Chalk basement bed resting on Dispar Zone Upper Greensand; the Chalk basement bed contains strongly phosphatised ammonites of the Mantelli Zone (probably lower part) mixed with lightly phosphatised ammonites of the *Turrilites costatus* assemblage of the Middle Cenomanian. Kennedy has also found a similar succession at Buckland Newton.

When the Mantelli Zone is next seen near Maiden Newton it is represented by a hard creamy calcareous sandstone in the Eggardon Grit at the top of the Upper Greensand, and the Chalk basement bed is Middle Cenomanian (Jukes-Browne and Hill 1900, p.174; Welch in Vernon Wilson *et al.* 1958). From Toller Fratrum, west of Maiden Newton, to Horn Hill, north of Beaminster (Smith and Drummond 1963, p.348), a remanie pebble bed of Mantelli Zone age lies between the Eggardon Grit and the Chalk basement bed.

Further west the Mantelli Zone part of the Eggardon Grit becomes more sandy but the evidence is poor until one gets right over to Chardstock in Devon where it is plain sand overlain by

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TABLE 1. Cephalopod zonation of the Cenomanian stage in Southern England.

STAGES		ZONES	FAUNAL HORIZONS	OCCURENCES OF PHOSPHATISED FAUNA
TURONIAN		**Mammites nodosoides**		
C E N O M A N I A N	Upper	**Actinocamax plenus**	**Metoicoceras gourdoni**	
			Metoucoceras geslinianum	
		Calycoceras naviculare	**(clear subdivisions not yet recognised)**	Bed C of Devon coast
	Middle	**Acanthoceras rhotomageese**	**Acanthoceras jukes-brownei**	Furley near Membury
			Turrilites acutus	Snowdon Hill, Chard
			Turrilites costatus	Buckland Newton
	Lower	**Mantetliceras mantelli**		
			Mantelliceras dixoni	
			Mantelliceras saxbii	upper phosphate bed } Gore
			Hypoturrilites carcitanensis	lower phosphate bed } Cliff
ALBIAN		**Stoliczkaia dispar**		

The work of W. J. Kennedy has emphasised that even in the Lower Chalk the horizons at which ammonites are found depend on preservation of the ammonites. The gap at the top of the Mantelli Zone happens to be particularly obvious; there may be other faunal horizons to be discovered in both the Mantelli and Rhotomagense Zones.

limestone (Smith and Drummond 1963: 346; Kennedy in press). Around Wilmington in Devon the Mantelli Zone sands (Wilmington Sands) reach 11 m, and are lithologically part of the Upper Greensand; there is sometimes (e.g. Hutchins Pit) a lower Mantelli Zone bed, with green coated pebbles marking the base, which yields the richest unphosphatised Cenomanian fauna in Wessex (Smith 1957b: 152; Kennedy in press).

On the south coast the changes are similar but not identical. Although at Compton Bay in the Isle of Wight the Glauconitic Marl fauna is basal Cenomanian, that at Punfield Cove, near Swanage (33 km from Compton Bay) is already much younger, yielding an indigenous Middle Cenomanian fauna and a sparse phosphatised Mantelli Zone fauna. For some distance west of Purbeck, Mantelli Zone ammonites only occur within lenticles at the bottom of the Middle Cenomanian Chalk basement bed, as at Sutton Poyntz (some 6 km north-east of Weymouth). At the same locality the Mantelli Zone calcareous sandstone of the Eggardon Grit makes its appearance. Derived Mantelli Zone ammonites preserved as calcareous grit moulds occur in the Middle Cenomanian Chalk basement bed at Bincombe. Bed A on the Devon coast is really a more calcareous development of the top part of the Eggardon Grit, but Bed A usually yields a better fauna which belongs to the Upper Mantelli Zone.

(ii) Middle and Upper Cenomanian. In Wiltshire, north-east Dorset and the Isle of Wight the Rhotomagense Zone is represented by chalk (see Kennedy 1969 for details). In north Dorset the Chalk basement bed becomes Middle Cenomanian by Dorsetshire Gap *(Turrilites costatus* assemblage). Over the whole of north-west Dorset (e.g. Evershot, Maiden Newton) the Chalk basement beds along to the higher *Turrilites acutus* assemblage of the Rhotomagense Zone. This is also the horizon of the common phosphatised fauna at Snowdon Hill, near Chard, but the indigenous fauna only 150-300 mm above the base belong to the *Acanthoceras jukes-brownei* assemblage (Kennedy in press), a fauna better known in its phosphatised state in the basement bed at Furley, near Membury in Devon.

On the south coast the westward younging of the Chalk basement bed is rapid: already Rhotomagense Zone at Punfield (probably *Turrilites costatus* assemblage), at Lulworth Cove it belongs to the *Acanthoceras jukes-brownei* assemblage horizon. At Ringstead and Bincombe it is possibly even younger. At Chilcombe

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Hill, some 15 km west of Dorchester, Welch records a fauna suggesting Upper Cenomanian (Naviculare Zone) (Vernon Wilson *et al.* 1958: 170) and this has recently been confirmed by Kennedy at a locality nearby at Askerswell (Kennedy in press). Thus the Cenomanian succession south-west of Maiden Newton ties in with Bed C resting on Bed A as at Rousden between Seaton and Lyme Regis, although Bed C in Devon includes later phosphatised ammonites.

In the coastal sections in south Devon the whole of the Cenomanian is rarely more than a few metres thick, but it can be divided into three divisions called by Jukes-Browne and Hill (1903) A, B, and C. The rapid lateral changes in the preservation of these divisions have been recorded in detail by Smith (1957a, 1961a, 1965). As mentioned earlier, Bed A belongs to the upper Mantelli Zone. Bed B belong to the lower part of the Rhotomagense Zone although a few top Mantelli Zone fossils can also be found in it. Bed C is a much condensed bed whose bottom phosphatised fauna spans the bulk of the Naviculare Zone, and whose indigenous fauna belongs to the Plenus Zone.

It will be noticed that the above account does not mention the Lower Chalk in the more westerly districts. This is partly because the fossil-rich Chalk basement beds are more attractive to collectors, partly because the Lower Chalk is really poor in fossils. At a few localities in Dorset (e.g. Lulworth Cove) there is evidence that the Lower Chalk above the basement bed belongs to the Naviculare Zone. On the Devon coast, the first chalky sediment - the matrix of Bed C - is Plenus Zone. Inland in Devon, at Wilmington, there is a similar situation with a Plenus Zone matrix to the basement bed and ordinary chalk begins with Turonian. At Furley, roughly half way between Wilmington and Chard, the chalk above the basement bed has generally been assumed to be Lower Chalk (Naviculare Zone) e.g. Jukes-Brown & Hill (1903: 121). My report of an Upper Cenomanian *Schloenbachia* from this chalk (Smith and Drummond 1963: 346) must be questioned : re-examination shows that it might be an early Turonian compressed *Collignoniceras,* in which case the most westerly Cenomanian chalk in the British Isles would be that of Snowdon Hill, Chard, where there is evidence of the Naviculare Zone.

(iii) Limits of the Cenomanian sea. In spite of the detail known about the Cenomanian, we do not know how far west it extended.

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The facies of the Mantelli Zone in Devon looks regressive compared with the underlying Albian. E. M. Durrance and R. J. O. Hamblin (personal communication) believe there may be Cenomanian in the Haldon Sands, the upper part of which has rarely been examined by fossil collectors.

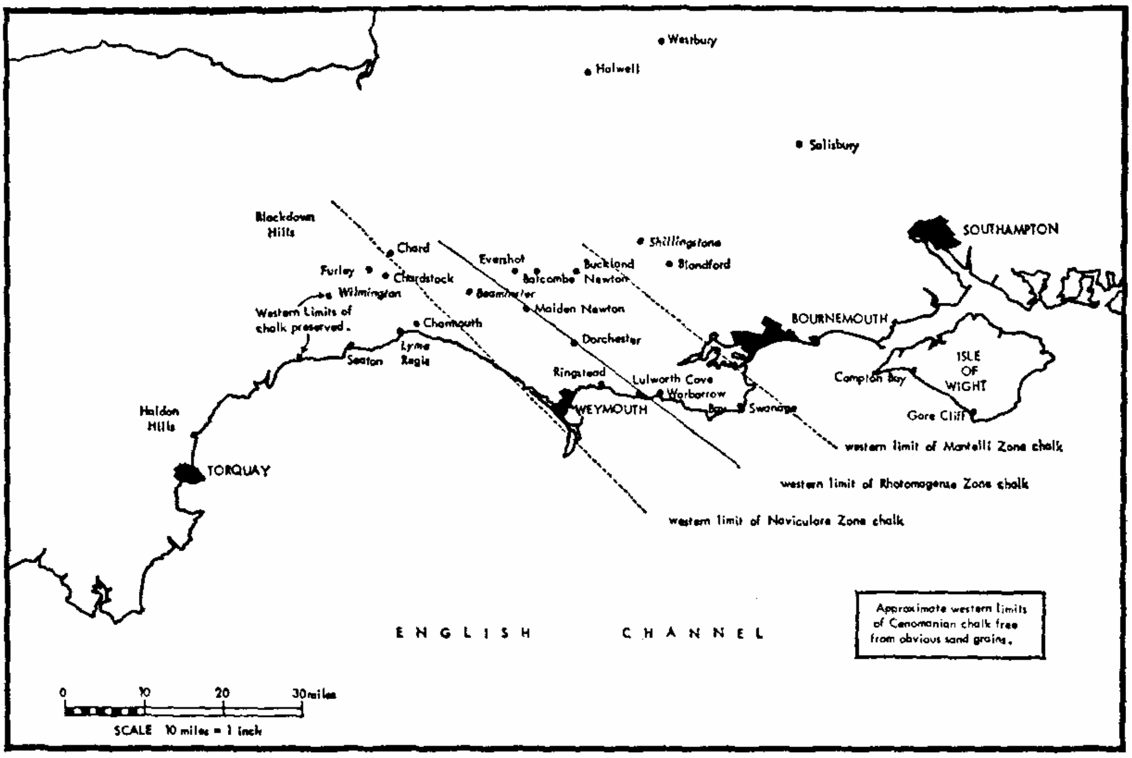

FIGURE 3. Approximate western limits of Cenomanian chalk free from obvious sand grains.

(f) *Turonian*

The stratigraphy of the British Turonian has been little studied but the top and bottom are generally clear. The only districts in South-West England on which any detailed work has been done are the Dorset and Devon coasts (Rowe 1901, 1903; Wright in Arkell 1947).

Nowhere does the Turonian show a chalk basement bed facies, even at those localities where it rests directly on Lower Cenomanian (Berry Cliff, Hooken Cliff, Haven Cliff) or Albian (Charton Cliff) owing to late Cenomanian earth movements; nowhere is it preserved resting on pre-Cretaceous rocks. The local variations in facies that do occur (e.g. Beerstone) can, however, be related to lines of uplift (Smith 1957a, 1961a, 1965 and Ager in discussion of Smith 1961a). These facies variations are purely local, and although most interesting are only a minor aspect of South-West England as a whole.

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(g) The incoming of Chalk deposition

The change from sandy sediments of the Upper Greensand to coccolith limestone or marl with the Chalk always involves a break in deposition, or some period of very slow deposition. As sea-level rose and the belt of sand deposition moved away further on to the massif, for a time no sand arrived at the locality, but conditions were not yet suitable to form chalk: possibly the water was too shallow (less than 60 m) to receive a full crop of coccoliths and Glauconitic Marl was formed; in other areas the bottom currents may have been too strong to allow coccoliths or clay to settle, giving a chalk basement bed deficient in both clay and glauconite but with a higher proportion of the coarser particles of chalk. Whatever the explanation, the antipathy of sand and chalk is widespread and where the two do occur together the sequence is always condensed: at Furley where there is about a metre of sandy, faintly glauconitic chalk, Kennedy has found that it embraces parts of Lower, Middle and Upper Cenomanian. Similar condensation occurs in Northern Ireland. In both regions the deposition rate was about 0.1 - 0.01 of that in the open sea.

(h) Western limits of the Turonian and Senonian Seas

The absence of any sediments younger than the Albian resting directly on pre-Cretaceous rocks, does not prevent an estimate of the extent of the sea during the Turonian and Senonian. The gravels (presumed Eocene) on the Haldon Hills contain fossils preserved in flint representing Planus to Marsupites Zones and possibly the Lata Zone beneath (Jukes-Browne and Hill 1904: 133). Even more useful are the flint gravels at Orleigh Court near Buckland Brewer in north Devon. Rogers and Simpson (1937) found that they contained fossils that range from the Planus Zone in the Upper Turonian to the Mucronata Zone at the top of the Senonian. The perfect preservation of the fossils in flint shows that the gravels represent a residual of ordinary chalk facies even though the present deposit is post-Eocene and possibly represents a former beach deposit (Balchin 1964). One can calculate thus: Haldon Hills - present height of base of gravels is 180-244 m; thickness of Lata to Marsupites Zone over a massif such as north Norfolk is 168 m; the depth of the chalk sea was probably 200-300 m; total 550-720 m. Orleigh Court - present height of base of gravels is 122 m; thickness of Planus to Mucronata Zone in north Norfolk is 320 m; with 200-300 m of chalk sea this gives

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a total of 640-740 m. Both sets of figures suggest that the whole of Cornubia was submerged by the Senonian sea, provided there has been no appreciable lowering of Dartmoor during the Cainozoic. All such calculations have obvious possible sources of error and discussion of them in detail would be laborious and dull. It is more useful to note that even if the highest part of Dartmoor (today 625 m) stood out as an island, there can be little doubt that the bulk of Devon and Cornwall was under the sea.

4. Contemporary Earth Movements

Intra-Cretaceous earth movements (sometimes called 'Pre-Albian') are well known in the Weymouth district where the faulting and periclinal structures have been described in detail by Arkell (1947) and considered further by House (1961). Movements of probably similar age in the Vale of Wardour, west of Salisbury, are more gentle (Mottram 1961). At outcrop in south Dorset the structures die out rapidly eastwards, and are absent at Lulworth and Swanage. Underground, they turn up again in the Wessex basin : at Fordingbridge, Gault rests directly on lower Kimeridge Clay (Falcon and Kent 1960: 48), cutting out the equivalent of 1,200 m of sediment in east Dorset. It is now known that such pre-Albian movements are also extensive in the Paris basin.

Movements before, during and after the Cenomanian in the Beer district have been described by Smith (1957a, 1961a). The vertical scale is small, probably never more than 5m. Late Albian- early Cenomanian movements have also been traced across a NW-SE 'Mid-Dorset Swell' by Drummond (Smith and Drummond 1963) although the details have been modified by Kennedy (in the press).

The seismic work of E. M. Durrance and R. J. O. Hamblin has shown that there are marked local thickness variations in the Haldon Sands which they suggest may result from preservation in Cenomanian down-folds.

5. Heavy Minerals in the Cenomanian

There are two distinct regions of heavy minerals in the Cenomanian (Table 2 and fig. 4). Each region is remarkably clear-cut considering that under marine conditions one commonly gets a uniform distribution over a great area (e.g. Lower Greensand of England) because material from all sources is thoroughly mixed by submarine currents. Just how clear-cut is brought out by Table 3 which gives the closest numerical approaches between the two regions.

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TABLE 2. Percentages of Non-Opaque Heavy Minerals (mainly Cenomanian with a few Albian and Turonian for comparison).

	South-west region						North-east region					France		Albian		
	Great Haldon, Albian	Wilmington	Furley	Beer Stone (Turonian)	Haven Cliff	Bincombe	Shillingstone	Melbury Beacon	Dead Maid, Mere	Punfield, Swanage	Gore Cliff, I.O.W.	Cap de La Heve	Vimoutiers	Punfield (Albian)	S. of St Alban's Hd	S. of Seaton
Zircon	2	5	15	3	6	20	56	46	48	60	55	22	26	50	27	37
Tourmaline	94	84	78	94	87	68	23	28	26	8	18	70	61	31	60	56
Rutlie	2	1	2	1	3	5	9	12	9	12	13	1	2	8	2	2
Monazite		<1	x					s	s			s				
Sphene					s		<1	s	s		1	<1	s			?
Cassiterite										s						
Topaz	<1	2	s	s	1	x				2		,1	y		x	<1
Flourite				s												
Andalusite	<1	3	2		x					s		s	y	2		s
Garnet		<1		s			6	6	7	8	6	<1	y	4	3	<1
Staurolite	<1	2	s	s	1	s	2	4	2	2	1	2	2	s	5	2
Kyanite			x			s	2	1	4	2	4			x		?
Sillimanite				s			s	s		x				s		
Chloritoid											x					
Anatase	s			s	1	1				s	s	<1	<1	s		
Brookite						1	s	1			s	<1	<1	3	2	<1
Corundum										s						
No. of grains counted	512	260	129	434	187	150	259	195	185	179	168	583	920+	159	223	545

s = single grain seen in traverse
x = occurs, but not seen in traverse counted
y = not counted

For localities see Figure 4

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TABLE 3. Closest numerical approaches between the heavy mineral contents of the Chalk basement beds in the south-west and north-east regions.

Mineral	south-west region	north-east region
Zircon	20% (Bincombe)	46% (Melbury)
(zoned Zircon)	20% (Bincombe)	14% (Gore Cliff)
Tourmaline	68 %(Bincombe)	28 %(Melbury)
Rutile	5% (Bincombe)	9% (Shillingstone and Dead Maid)
Topaz	Occurs at all localities	Occurs at Punfield rare at Cheddington.
Andalusite	Occurs at all localities in Devon and Somerset, but not seen in Dorset.	Rare at Cheddington, but otherwise only one grain found (Punfield)
Garnet	1 % (Wilmington)	6% (Shillingstone, Melbury, Gore Cliff)
Staurolite	Ranges overlap, but more prominent in north-east.	
Kyanite	In Devon only seen at Furley. In Dorset single grains at Bincombe and White Nothe.	Occurs at all localities but is rare at Cheddington and Batcombe.

The south-west region includes the south-east Devon area which has been studied in detail by Smith (1961b). His figures and mine are in agreement, and his paper should be referred to for descriptions of the minerals.

(a) Interpretation

The sand of the south-west region is derived from Devon and Cornwall. The sand of the north-east region is derived from a broad variety of sources but probably all English and includes some material from the south-west.

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(i) *South-west region.* The heavy minerals of the top sandstones of the Albian and of the Cenomanian are similar, as noted by Smith (1961b: 322). Such differences as there are can be explained by the coarser grade of the sand in the Cenomanian (see fig. 3 in Smith 1961b): zircon occurs in small crystals and hence is more abundant in the top Albian; topaz occurs in large crystals and is more abundant in the Cenomanian. The minerals alone cannot indicate if the sand in the Cenomanian is from re-working of the Upper Greensand or merely of the same provenance; stratigraphy points to the latter.

The whole assemblage is from Devon and Cornwall. The only mineral that might seem difficult to account for is the staurolite, although the quantity is usually less than one per cent (up to 2.3% by myself, 4.2% in Bed A by Smith). The only known primary source is the Lizard (Tilley 1937) which is far too small, and there were no other extensions in the English Channel as postulated by Smith. The only known source is the New Red Sandstone and much of this would have been covered by Upper Greensand. However, the New Red Sandstone of the Crediton valley and its former extension would have been available, and is known to contain staurolite (Hutchins 1963: 123-which he found difficult to explain). The grains in the Cenomanian are always stout, and one grain at Wilmington had outgrowths which were themselves slightly rounded: these both indicate derivation from a sediment.

The following features suggest that the main granite of Dartmoor was not a major source of sediment:

(i) Only one fifth of the zircons are zoned; these few could be from New Red Sandstone. (But there are much higher proportions of zoned zircons in both the Haldon Sands and the Turonian Beer Stone).

(ii) The scarcity of biotite-but this may partly have gone to form the small quantity of glauconite.

(iii) The scarcity of monazite.

(iv) The flood of tourmaline compared with zircon; although one must allow for the large quantities of tourmaline in the aureole of the granite.

(v) The low proportion of euhedral zircons (maximum 7% of zircons at Bincombe) suggests that there was no primary source at hand (Table 2; compare 17% at Cap de La Heve).

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(vi) More than 90% of the assemblage belongs to the stable three minerals: zircon, tourmaline and rutile.

On the other hand, the following features suggest that the Cornish granites were being eroded:

(i) Up to three-quarters of the zircons are unzoned.

(ii) Topaz is widespread (St. Austell granite).

(iii) Pleochroic andulusite is widespread (Bodmin Moor and Carnmenellis granites).

No tests have yet been done to see if the tourmaline in the Cenomanian is dominantly aureole-type in terms of trace elements (Power 1966); blue or bi-coloured tourmaline is never more than a small minority (see table Ha in Smith 1961).

The scarcity or absence of Dartmoor granite detritus could mean that the granite was not exposed, and that the granite surface now seen is still close to the original roof. This fits with the suggestion of Dangerfield and Hawkes (1969) that the distribution of the marginal, big-feldspar facies of the granite would indicate that erosion has only penetrated 50-200 m into the mass (Brammall and Harwood 1932: 223, seem to have thought otherwise). At the same time Dangerfield & Hawkes have produced convincing evidence that there are pebbles of Dartmoor granite and micro-granite of several facies in the Permian St. Cyres Beds of the Crediton valley. Some of the granite must have been exposed and undergoing erosion during the Permian.

These two opposite lines of evidence can only be reconciled in two ways: it is just possible that the granite was covered again by further New Red Sandstone (this was suggested to me by the late P. F. Hutchins from his study of the minerals in the Crediton valley New Red Sandstone); alternatively, the drainage pattern did not provide appreciable erosion of the Dartmoor granite during the Mesozoic.

This conclusion that the Dartmoor granite was not a major source of sediment during the Upper Cretaceous disagrees with most previous workers: Smith (1961b) concluded that the granite contributed to the late Albian and early Cenomanian sediments; Groves (1931) considered that it was being actively eroded during the Wealden; Cosgrove & Salter (1966) from the kaolinite content of the sediments, suggested that the earliest unroofing would have been during the deposition of the White Lias (Upper Trias).

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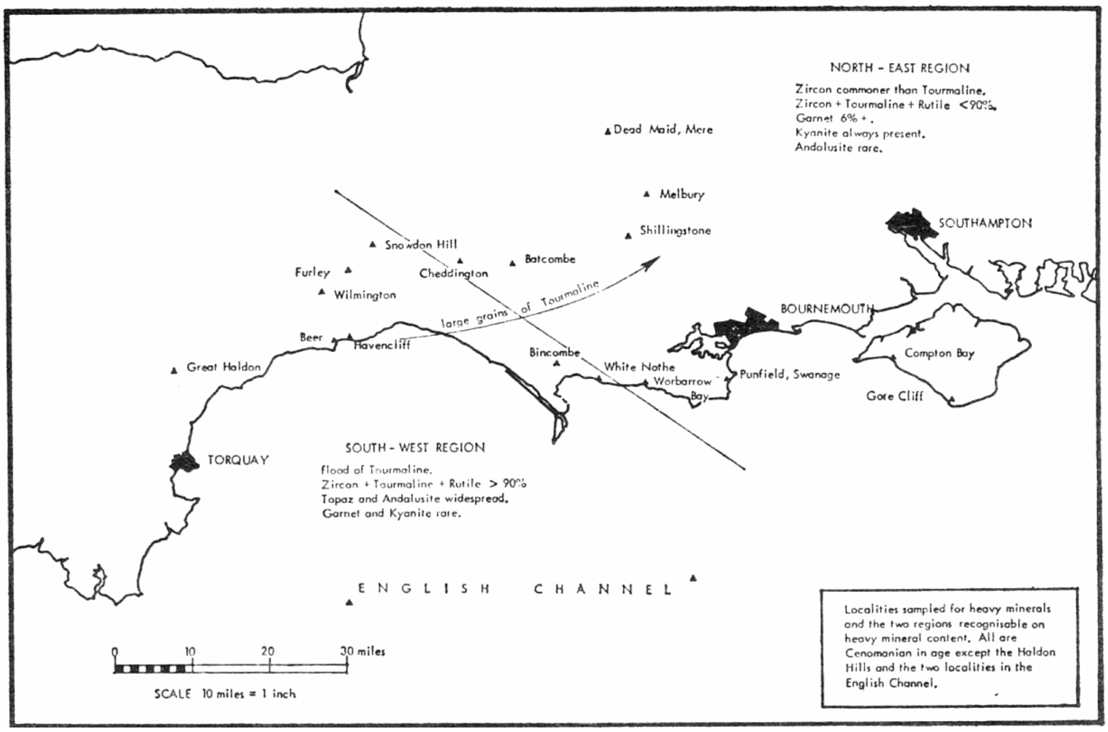

FIGURE 4. Localities sampled for heavy minerals and the two regions recognisable on heavy mineral content. All are Cenomanian in age except the Haldon Hills and the two localities in the English Channel.

(ii) North-east region. Derivation from the underlying Upper Greensand is negligible in this region except in north-west Dorset where phosphatised pebbles of Upper Greensand may be found 20 cm or more up in the Chalk basement bed. In the Isle of Wight the Glauconitic Marl contains coarser detritus than the Upper Greensand beneath. At Punfield, near Swanage, the differences in mineral content are marked although there is no obvious difference in grade or sorting.

The assemblage of the north-east region still contains some minerals with a probable Devon-Cornwall origin, e.g. (i) some of the well-zoned zircons, (ii) very large grains of tourmaline, (iii) topas, andalusite and cassiterite at Punfield, and (iv) some of the staurolite. But the general tenor of the assemblage is of more normal proportions than that in the south-west region. The sweep of earlier sediments in England to the north and north-west of the region could easily have maintained the supply of stable minerals; the consistent subsidiary garnet-staurolite-kyanite group seems more difficult to explain but is probably from the same

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sources in the main. (The same metamorphic group is seen in the Lower Greensand.) An English origin should mean that the Glauconitic Marl over the whole of south-east England will yield the same assemblage; certainly the garnet-staurolite-kyanite clan occurs as far away as the Cambridge Greensand.

It has been customary to assign such a metamorphic clan in southern England to a Brittany provenance (e.g. Latter 1926, Worrall 1954, Wood 1957). This custom is made questionable for the Cenomanian by the following:

(i) The main occurrences of staurolite and kyanite in Brittany are in Morbihan and Finistere on the southern side of the massif, and over 300 km from the Isle of Wight.

(ii) There is no equivalent metamorphic assemblage in the Cenomanian of Normandy : at Cap de La Heve (about 280 km from Morbihan) and Vimoutiers (about 240 km from Morbihan) there is less than one per cent garnet. It is necessary to go as far south as the Sarthe to get a rich metamorphic assemblage : in the Sables du Mans the metamorphic minerals are as abundant as zircon plus tourmaline, but this far south one is starting to get the vermicular staurolite that Vatan (1950) considers characteristic of the Massif Central.

(iii) If there was appreciable submarine drifting of sand across the English Channel, one would expect to find some of the closely zoned zircons of the south-west region to have drifted into Normandy, but I could not find any definite examples in the Glauconitic Marl of Cap de La Heve (nor in the Maastrichtian of the Cotentin).

It is not claimed that no material from Armorica reached the north-east region, but it does not seem to have been a major contributor. It is worth recalling that Vatan (1950: 68) reported his vermicular staurolite of the Massif Central in the Lower Greensand of Sandy in Bedfordshire.

Another possibility that needs to be rejected is that the detritus of the north-east region is merely the finer detritus from the south-west. The disproof is that the garnet and kyanite of the north-east region does not appear in the finer grade detritus in the south-west. (Note that the converse does happen : when coarse material occurs in the north-east region, it is accompanied by large grains of

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tourmaline - the mineral whose abundance is so characteristic of the south-west region).

Nor can the two regions reflect a stratigraphic control going with the diachronity of the Chalk basement beds : in each region the mineral assemblage does not change during the time involved. In the south-west it shows the same characters from the top sandstones of the Upper Greensand (probably Dispar Zone of the Albian) to the Lower Turonian. In the north-east the basement beds range from the horizon of *Hypoturrilites carcitanensis* at the base of the Cenomanian to the horizon of *Turrilites acutus* in the middle of the Middle Cenomanian. The boundary between the two mineral regions does not coincide with the 'Mid-Dorset Swell' of Smith and Drummond (1963: 351), but lies well to the west of the swell.

ACKNOWLEDGMENTS. As is usual in a general study, the author is indebted to many people and organisations. All the work on the heavy minerals was done at Cambridge supported by a grant from the Department of Scientific and Industrial Research; the field work in France was subsidised by a grant from the Lake Fund; samples from the English Channel were provided by the late Professor W. B. R. King. In finding exposures in Devon I have been helped by W. E. Smith and his excellent Geologists' Association field meetings.

Numerous geologists have most generously allowed me to include unpublished work of their own. I would particularly mention three names : C. W. Wright to whom I owe the foundation of my knowledge of the ammonite succession; W. J. Kennedy who has applied his detailed ammonite stratigraphy of the Cenomanian to this region; and H. G. Owen who has worked on the subzones of the Middle Albian. Others who have favoured me in this way include : J. Dangerfield, E. M. Durrance, R. A. Edwards, R. J. O. Hamblin and J. R. Hawkes.

Finally, to my good friend Jim Kennedy I am grateful for constructive criticism of the manuscript.

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The Cretaceous structure of Great Haldon (Abstract) : by
E. M. Durrance and R. J. O. Hamblin.

Outcrops of Permian breccia, Cretaceous Greensand and the Haldon Gravels of Eocene and Pleistocene age occur on Great Haldon. The results of a seismic refraction survey of the surfaces between the Haldon Gravels and the Greensand, and the Greensand and the underlying Permian indicate the presence of a period of intra-Cretaceous folding and faulting which accompanied the deposition of the Greensand. Variations in Greensand thickness between a maximum of 84 m and a minimum of 16 m have been recorded underlying a sub-horizontal layer of Eocene Haldon Gravels. This layer consists of flint gravels, derived by *in situ* solution of Senonian Chalk, which are partly a residual deposit and partly the product of penecontemporaneous fluviatile working.

The somewhat abraded and sorted material rests both upon areas of stable residual gravel and upon the Greensand. Fault movement during the formation of the gravels has resulted in depressions in which a thickness of as much as 21 m of fluviatile gravel has accumulated. During the Pleistocene periglacial conditions prevailed throughout the area, producing a major landslip, cryoturbation structures in both the Greensand and the Eocene flint gravels and the formation of gravel solifluxion deposits which now mantle the Greensand outcrop.

The structure of the southern margin of the Bovey Basin (Abstract) :

by C. M. Bristow and D. E. Hughes.

Geological investigations and borehole drilling on the southern margin of the Bovey Basin around Mainbow mine and Ringslade open pit has been carried out in connection with the commercial evaluation of the ball clays. Devonian slate up to 30 m thick was found to be superimposed on Tertiary sediments. A drag fold beneath the slate indicates that the slate has moved eastwards over the Tertiary material. The slate is relatively intact and has not been disaggregated, indicating that hillcreep cannot be responsible for the superimposition. It is argued that a large landslip involving

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a rotational shear cannot be responsible as the movement plane dips into the hill over too large an area. The southern margin of the Bovey Basin is therefore interpreted as a thrust fault of Tertiary age. The thrust plane dips southward at angles varying from 10° to 30°.

It is suggested that this is a rejuvenation of the Hercynian thrust recognised in the Bickington area and further east in the Holne area. The relationship of this thrust fault to the Sticklepath fault may reflect the differing competency of the Dartmoor granite compared with the Palaezoic rocks. Comparison with the southern side of the Wareham Basin suggests a common structural style.

Preliminary results of the mapping of the Bovey Basin (Abstract):

by R. A. Edwards.

In the Bovey Basin, the Bovey Formation is a thick series of clays, lignites and sands of Oligocene age. Its outcrop is margined on the east side by rocks of Upper Greensand facies comprising coarse, pebbly, glauconitic sands of littoral aspect, within which occur fossiliferous chert horizons. Resting directly on the Upper Greensand are the Aller Gravels, a variable set of fluviatile gravels and sands with subordinate silts. They contain abraded flints and Greensand cherts; other constituents, including Culm cherts and aureole rocks, point to northerly derivation. If, as is suspected, the Aller Gravels underlie the Bovey Formation, then they occupy the same stratigraphical interval as the Haldon Gravels, although within this interval they may post-date the Haldon deposits.

The association of the Bovey Basin with the NW - SE Sticklepath - Lustleigh dextral wrench fault zone is well known, and the Upper Greensand and Aller Gravels may owe their present position to down-warping associated with this zone, although some margins of the Basin (especially the south and possibly the west) are partly fault-controlled. Within the Bovey Formation, approximately NW - SE faults show that movements on the Lustleigh trend post-dated or were contemporaneous with deposition of the Bovey Formation.

This contribution has been approved for publication by the Director of the Institute of Geological Sciences.

A new interpretation of the Pleistocene succession in the Bristol Channel area (Abstract) : by D. Q. Bowen.

In recent years the regional Pleistocene succession between Milford Haven and the Isles of Scilly has been interpreted in terms of a succession worked out in north Devon which was dated by comparison with that in south east Ireland. The sequence recognised consisted of Hoxnian (Great Interglacial) raised beach, Saalian and Weichselian head, the former weathered during the Eemian (Last Interglacial), and Saalian glacial drift.

Consistent internal evidence, however, notably from South Wales, shows that the sequence is not so complicated and that the raised beaches and overlying deposits are the product of one temperate and one cold stage respectively.

South of Charlesworth's (Weichselian) South Wales endmoraine (now slightly modified) the succession overlying the coastal raised beaches consists of periglacial slope deposits. These are : (1) head, which contains some previously weathered material, and (2) erratic beds, originally deposited as glacial drift but now lying in a secondary position due to redeposition by solifluction.

Faunal and botanical evidence, together with the relationship of Weichselian moraine to the coastal Pleistocene succession, show that the raised beaches of Wales, Devon and Cornwall are Eemian (Last Interglacial) and their overlying periglacial slope deposits are Weichselian.

Post glacial sea level changes in the Bristol Channel (Abstract) : by A. B. Hawkins.

Submerged peats off Torquay indicate that 10,000 B.P. the High Water Spring Tide was at least -150 ft O.D. The Bristol Channel would then have been largely an area of dry land. During the Boreal period (c.9,500 to 7,500 B.P.), there was a rapid rise in sea level, at the end of which H.W.S.T. was about -50 ft O.D.; implying a rise of at least 1 ft every 15 years (*c*. 20mm/yr.). Older, Late Glacial and Pre-Boreal peats are known from Port Talbot and the Vale of Gordano, but these were formed independently of the sea level at that time.

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During the Atlantic and Sub-Boreal periods, the rate of eustatic rise decreased and coastal peat accumulation became more prolific. It was during these periods that the well-known submerged forest beds were formed. The height of the peats formed at this time bears little relationship to present H.W.S.T., because of the more recent easterly tilting of the British Isles.

At the beginning of the Sub-Atlantic, the height of the H.W.S.T. was about 10 ft lower than the present level. In the eastern Bristol Channel region, early Roman remains have been found up to 14 ft below the present surface, while late Roman remains exist near the surface around the fringes of the estuarine clay deposits. This probably indicates a sudden inundation of the region about 250 A.D., due either to a breakthrough of a coastal barrier, a sudden eustatic rise or a more rapid phase in the easterly tilting of the British Isles. The present rate of sea level rise is about 0.81 ft per century (*c*.2mm / yr.).

THE PROBLEM OF THE NATURE, ORIGIN AND STRATIGRAPHICAL POSITION OF THE TREBETHERICK BOULDER GRAVEL

by B. B. Clarke

Abstract. The small patch of gravel within the head of the Camel estuary near Trebetherick Point (sx 927781 is described, and various suggestions about its origin reviewed. It is believed to have originated as a till left by the south Irish Sea Riss ice sheet, and suffered frost heaving and solifluction to its present site during three phases of the Würm.

On the 25 ft Raised Beach platform and generally below the Younger Head and above the Coarse Slaty Head and fine Laminate Slaty Head is a small patch of unfossiliferous, unstratified, ungraded gravel. It is 2 m thick, thinning rapidly both ways, and only 50 m in lateral extent. It consists of pebbles and boulders up to 300 mm across. Most are roughly rounded, a few angular, and a few well rounded and water worn. They rarely touch and are set in a matrix of bright orange clay. The gravel differs from the local head in the colour of the matrix, and the rarity of slate except at the margins, and from the present day beach gravel in the clay matrix, the rarity of flint and the abundance of granite. The most striking feature is the junction with the three heads. There is a zone of interpenetration in each case although the heads are believed to be of different

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ages. Many of the stones in the boulder gravel are from local quartz veins and elvans but there are also many granites, one of which may be from Lundy, quartzites, indurated shales, flints, one foliated granite which shows a much higher grade of metamorphism than belongs to this area, and a number of unidentified igneous rocks.

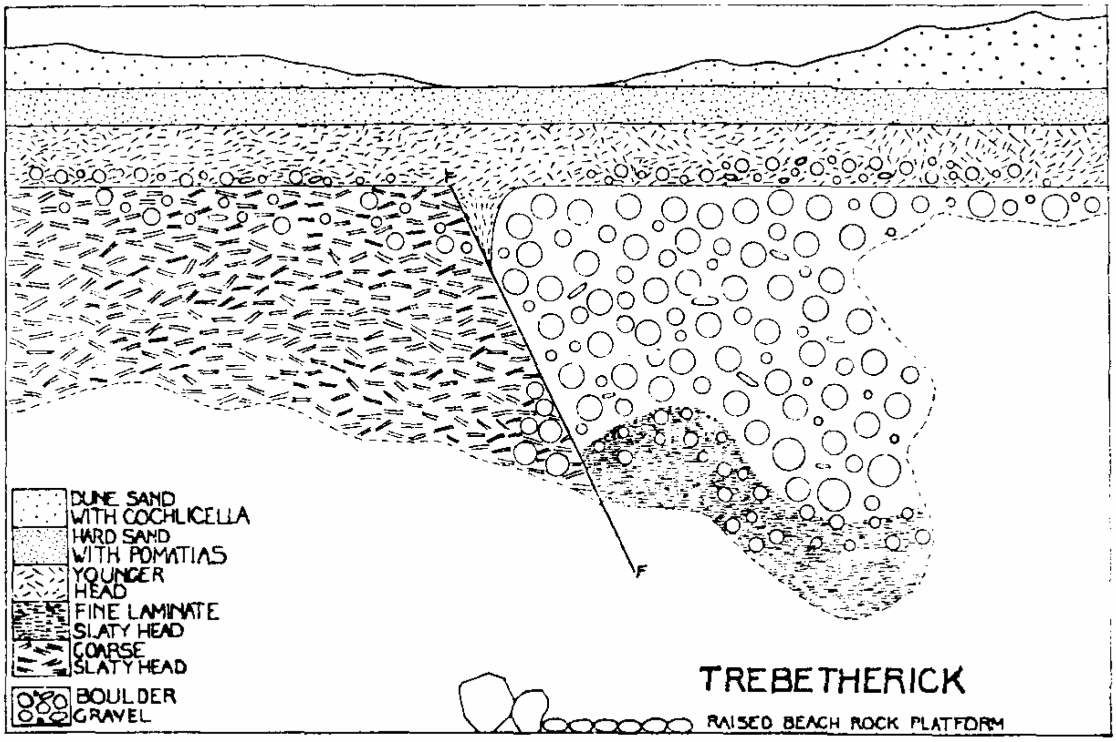

FIGURE 1. Section in the Quaternary deposits between Trebetherick Point and Shag rocks.

The gravel was compared by Reid and others (1910) with the coarse river gravel at Little Petherick creek and Penquean, thrown down by fast-flowing streams entering a tidal estuary made more slow-flowing by river ice. There is however no tributary stream at this point to bring down such coarse material. Arkell (1943) regarded this as a terrace gravel formed by a sea which rose to 45 ft O.D. and deposited a beach gravel of water worn pebbles mostly from the Camel valley, with flints derived, he believed, from the denudation of high level Tertiary platforms. The age he claimed to be Wolvercote or Micoquian Interglacial. Mitchell (1960) claimed the melting of the Riss ice sheet caused a rise in sea-level in the Hoxnian to 100 ft O.D. which left a series of beach gravels round the coasts of Devon and Cornwall of which patches remain, including Trebetherick. Stephens (1961) suggested the boulder gravel

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is head. This seems to be nearer the truth but the appearance of the gravel suggested to me (1965 a, b) a more definite glacial origin, a boulder clay. Mitchell (1967) agreed that the higher part is a till, possibly a weathered facies of the Fremington till, and the lower part either outwash gravel or raised beach.

The evidence against this being a terrace gravel *in situ* is the limited distribution in view of the hardness of the stones set in clay. One would expect more to have survived at a similar altitude. The boulder gravel lies upon and against loose soft slaty head. This is the most exposed part of the estuary facing south-west and if this were a terrace gravel waves charged with these stones must have removed the friable head down to the rock platform however short the duration of the high sea-level.

The evidence against this being simply part of the local head is the unusual colour of the clay matrix and the scarcity of slate and greenstone, the two common country rocks.

It is suggested that the agent that brought so many stones to this point in the estuary and set them in clay is glacier ice and this gravel originated as a patch of till. The slate and greenstone are decomposed in the clay matrix. While most of this is clay, there is a gravel fraction which is almost entirely frost shattered material. Some fragments have one rounded smooth surface, a relic of the beach pebble from which they were made. There is also a very small sand fraction which contains a proportion of highly polished millet seed grains produced, it is suggested, by winds blowing over sheet ice. The fact that the gravel interpenetrates the three heads suggests the patch of till is not now *in situ,* the glacier left it on higher ground, and it has been soliflucted to its present site in three stages.

Glacier ice would incorporate any beach gravels in its path. The quartzites are believed to come mostly from bands in the Staddon grit which form the southern watershed. Flints are more numerous in the present beach gravel than in the beach material in the boulder gravel. This suggests an exposure of Chalk or Tertiary gravel off shore which is now more exposed than when the ice sheet moved over it. This is a more likely source than a patch on Bodmin moor which has now been eroded away. The high proportion of granite may point to some of this being off shore in origin as only the De Lank tributary drains the Bodmin granite.

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For the origin of the ice I would look north to the Irish Sea rather than east to Bodmin Moor, but while two of the stones suggest Irish Sea ice a definite indicator erratic would be more conclusive. Evidence is gradually accumulating of an ice sheet of Riss-Saale age which surrounded Lundy Is. to 350 ft (Mitchell 1968), deposited the till at Fremington (Stephens 1966) extended south to Porthleven (Mitchell 1960) and the Scillies (Mitchell and Orme 1965, 1967). This sheet of ice blanketed the south Irish Sea and gave rise to till deposits in southern Ireland. I suggest it was a tongue of this ice that invaded the north projecting Camel estuary, gathering beach pebbles in its progress and leaving a patch of till. Quarrying at Stepper Point has removed any evidence of a marginal channel but the marine gorge at Tregudda (SX 894771) and the wider channel south of Porthcothan (SX 849720) could have begun as ice marginal channels.

If this ice sheet is correctly dated as Gipping (Mitchell 1968) the three cold periods of the Würm could have been responsible for the production of the head deposits in this estuary. Würm 1 gave rise to the Coarse Slaty head and detached from the till lying upslope a few large stones and some boulders, Würm 2 formed the Fine Laminate Slaty Head under rather wet conditions and brought down some of the gravel mixed with slate and then the main mass of the till largely intact. Towards the end of Würm 2 the soliflucted material was faulted in a frozen condition. The oncoming of the next cold period in Würm 3 formed a frostkeil along the fault plane and gave rise to the Younger Head. This brought with it the rest of the patch of till. The absence of the clay matrix and gravel from the till in the upper part of the Younger Head suggests there was no more left upslope.

I am indebted to Dr. J. R. Hawkes for examining the granites from the boulder gravel.

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THE STRUCTURE OF DAWLISH WARREN

by E. M. Durrance

Abstract. From historical evidence and a knowledge of the sub-surface structure presented by a seismic refraction survey, a sequence of events in the building of Dawlish Warren is postulated, which suggests that the position of the modern channel of the Exe at its mouth is the most stable than can be achieved, although the danger that the channel may break through the Warren and disrupt this stability is imminent.

1. Introduction

Problems of coast erosion in South Devon reach perhaps their greatest magnitude in the erosion that is now taking place of Dawlish Warren. This structure, extending from the western shore and running eastwards across the mouth of the river Exe as shown in Figure 1, consists of two ridges of low sand hills known as the Inner and Outer Warrens, separated by a low-lying area called the Greenland Lake which were it not for an artificial protective barrier, would flood at each high spring tide.

Martin (1872, 1876, 1893) and Kidson (1950, 1963, 1964) have shown that since 1787 a considerable portion of the Outer Warren has been removed by erosion, although much of the area once forming the Outer Warren is still represented by an expanse of intertidal sand which extends for some 300 m to the seaward of the present day high water level. This sand links to the east with an even more

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extensive inter-tidal bank known as the Pole Sand. Similarly, on the eastern shore of the Exe estuary the main river channel is considerably restricted by banks of mud, sand and gravel forming the Great Bull Hill bank and the spit upon which the lower parts of Exmouth are built.

On both the Warren and Exmouth spits and on the intertidal banks off-shore from the Warren and within the estuary a detailed seismic investigation into the thickness of sediment infilling the buried channels of the Exe has recently been performed (Durrance 1969). The results obtained are of some interest in determining the sedimentary history of the Warren, possible mechanisms of its origin and predictions for its future.

All levels are given with respect to high water of medium spring tides at Exmouth Dock, which is 2.4 m above Newlyn Ordnance Datum.

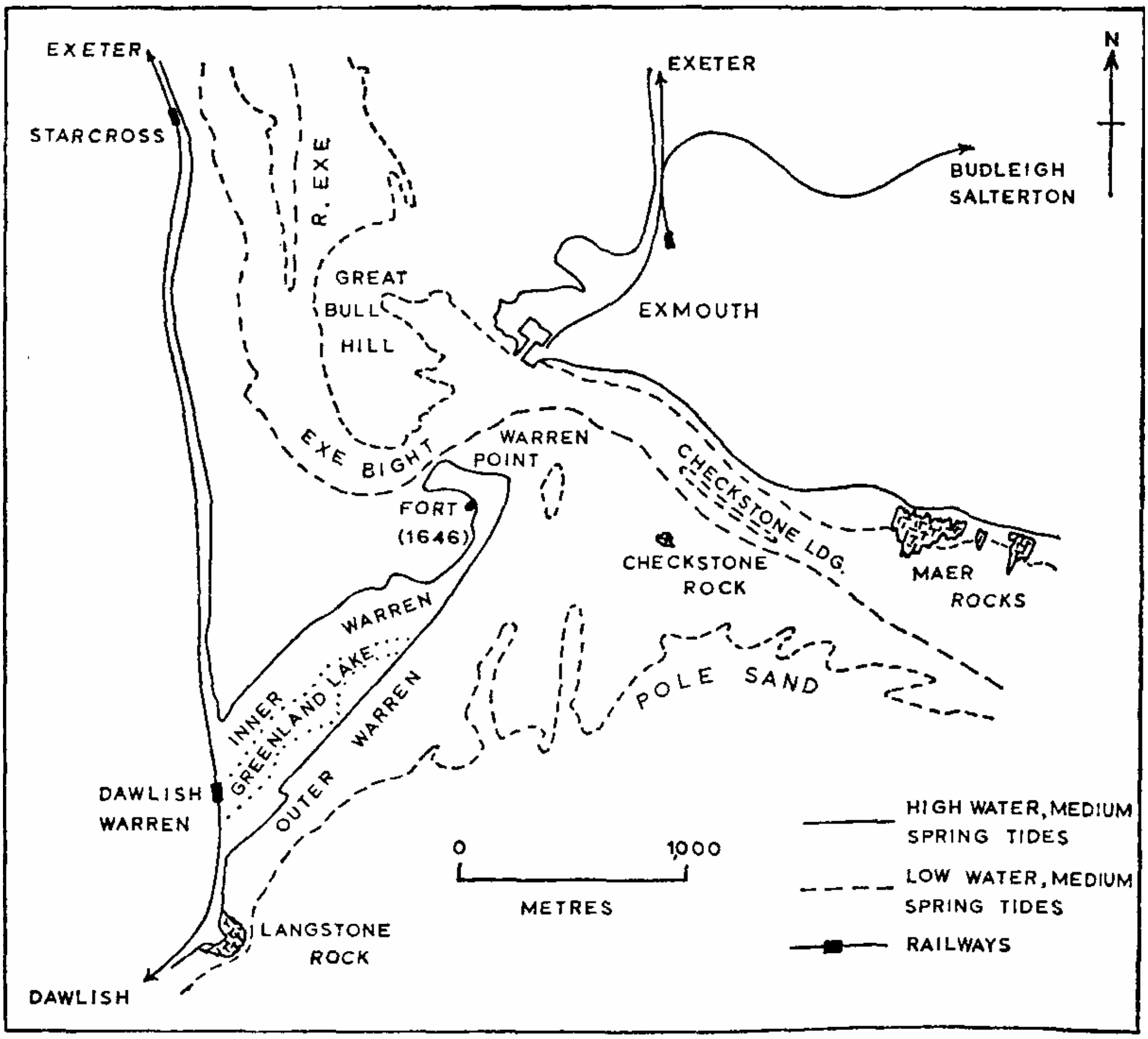

FIGURE 1. The Exe estuary and Dawlish Warren.

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2. **Recorded Development**

Steers (1946) and Kidson (1950, 1963, 1964) both considered Dawlish Warren to have been built by an easterly drift of sediment across the mouth of the Exe estuary from Langstone Rock, the period of construction continuing until the supply of material being deposited became balanced by the erosional effects of removal of material from the area of the estuary also taking place.

The subsequent destruction of the Warren was then explained by a decrease in the amount of sediment available for deposition and hence the increasing dominance of erosional forces. This decrease was first thought to be due to the building of the Great Western Railway betewen Exeter and Newton Abbot in 1849, which follows the coastline at the base of the cliffs west of Langstone Rock, effectively isolating them as a source of marine detritus. Martin in his series of papers has shown that this supposition is incorrect, because the Warren was being substantially eroded even before the railway was built. Kidson therefore considered that the decrease in the amount of sediment available for deposition was concomitant with a more general reduction in the amount of sediment being derived from the south coast shoreline. He argued that following the Flandrian transgression, and the drowning of the English Channel, new areas were exposed to marine erosion and provided abundant material. The supply of detritus gradually, however, began to decrease until the present stage is reached when all structures of recent deposition are at or near the end of their period of growth and stability. To substantiate this viewpoint he also noted that apart from the destruction of the Warren, between 1945 and 1954 there was a decrease in the area of the Pole Sand above low water of ordinary spring tides from 85 hectares to 72 hectares, accompanied by only a slight build-up of the Great Bull Hill bank from 34 to 42 hectares. The danger of generalising from such short term data is revealed by a study of the Admiralty Chart for 1960 which shows the area of the Pole Sand as 144 hectares, an increase of 59 hectares since 1945, and that of the Great Bull Hill as 52 hectares, an increase of 18 hectares over the same period. Further, this same chart also shows that although the area of sand above high water of ordinary spring tides, comprising the Warren, has considerably decreased when compared with the survey of 1809 as shown by Kidson (1950), that above low water still maintains the form of the original structure, and may even have increased in

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extent. The volume of sand being lost from the region is therefore comparitively small, being confined to those areas above high water level, and even part of this, it would appear, has been used to build up the Pole Sand and Great Bull Hill banks. It must be emphasised that maps and plans of coastal areas tend to give a subjective importance to land forms of recent deposition as delimited by the high water level, while the significance of the inter-tidal zone becomes subdued, and the effects of important changes may not be apparent. The processes of sediment transport and deposition which take place within this zone though reflected in the form of the structures built above high water level may therefore be masked by secondary factors affecting the areas above high water level along. Gordon (1968) noted that in the south-west areas of the British Isles during the present century, sea-level has been rising at an average rate of 0.2 to 0.3 m per century, upon which rise is superimposed a cycle, with a period of about 4.5 years, giving a variation of mean sea-level of 0.6 m. The general destruction of the Warren above high water level could thus be due to this rise in sea-level, periods of maximum destruction occurring at times of abnormally high water in the 4.5 year cycle emphasised by the action of south-easterly gales.

3. Sub-Surface Structure

The results of the seismic survey indicate that Dawlish Warren possesses a far more complex structure than had previously been thought. A platform of New Red Sandstone breccia slopes from its outcrop at low water level in the south-west at Langstone Rock to a depth of -23 m under Warren Point before outcropping again at low water level as the Checkstone Rock, Checkstone Ledge and Maer Rocks in the north-east. This platform is deeply incised to -52m by a number of channels running from north-west to southeast across it, which have been later infilled with Late Pleistocene (Middle Weichselian) gravels and then re-channelled to depths in the order of -30m. This composite New Red Sandstone breccia and Late Pleistocene gravel surface was then inundated by the Flandrian transgression and submergd to various depths. In the west, near Langstone Rock and in the east, in the area about Warren Point, this surface rises above low water of ordinary spring tides, and appears to have acted as a trap for a coarse pebble layer. On rising above high water level, possibly as a result of deposition

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during periods of high flood water and spring tides, this layer appears to have, in turn, acted as a trap for wind-blown sand.

Between the two high level areas of Langstone Rock and Warren Point, the intervening New Red Sandstone-Late Pleistocene surface is at a depth, exclusive of channels, of -14 m. During historical time this area appears to have been occupied by the main channel of the river Exe. Polwhele (1797) observed that “The mouth of the river Exe was formerly much to the south of Exmouth towards Starcross”, which lies on the western shore of the estuary, "At that time the bar of sand, [Dawlish Warren] was connected with the main land at Exmouth and on this bar stood Exmouth-Fort. But since the time when the river Exe altering its channel, and running towards Exmouth, broke through the bar of sand, it has been curious to trace Exmouth-Fort on the Starcross side where a cannon-ball has been found buried in the sands, with several vestiges of a fortification”. This same fort is dated as 1646 and marked by the Ordnance Survey on their 1933, (1 : 10560) map as having situated on the south-west shore of Warren Point, an ideal position for the command of a channel opening to the west of the present mouth of the Exe.

The present course of the Exe between Warren Point and the Exmouth shore occupies a channel cut through the New Red Sandstone - Late Pleistocene surface parallel to that of the Late Pleistocene channels beneath Dawlish Warren. Both the New Red Sandstone breccia and Late Pleistocene gravels outcrop above low water level of ordinary spring tides in the Pole Sand and Check-stone Ledge, and are covered by only a thin veneer of sand along most of the Exmouth shore. This suggests that the present channel which reaches a depth of -18 m off Exmouth Dock, where tidal scour is greatest, while elsewhere having an average depth of only -8 m, is re-excavating an older Pleistocene channel, and supports the statement of Polwhele that the modern channel has a comparitively recent origin.

4. Tidal Eddies and Spit Development

Neglecting longshore movement of littoral sediment, it would seem that spit development at the mouth of river estuaries can be broadly classified into two divisions, internal and external, depending upon the direction of spit growth. The Taw-Torridge in North

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Devon shows the former type, spits growing up-stream from either shore of the estuary, while the Tay east of Dundee possesses spits of marked external growth which prolong the estuary seaward. The internal direction of spit growth would appear to be correlated with modification of deposition in areas where average flood-tide velocities exceed those of corresponding ebb-tides, and those of external growth where the reverse holds true. This conclusion is fully confirmed by tidal data. In the Taw-Torridge estuary the flood-tide flows, on average, for some 64 minutes less than on a corresponding ebb-tide, while in the Tay at Dundee the ebb-tide flow occurs, on average, for some 50 minutes less than on a corresponding floodtide. This contrast also supports the supposition that the effect which river discharge has on spit development is negligible when dealing with large open estuaries in which a great tidal range is normally present.

The added effect of the presence of longshore movements of littoral sediment on this pattern is to increase the development of the up-drift spit at the expense of that down-drift. In Lyme Bay near shore ebb-current velocities are greater than those of the corresponding flood-currents, periods of flood tidal flow exceeding those of corresponding ebbs by, on average, 50 minutes. This conclusion has been confirmed by recent measurements (D. E. Newman, personal communication). These same measurements also show that the ebb tidal stream follows the shoreline of Lyme Bay from south-west to north-east, counter to the main tidal drift in Lyme Bay. The main easterly drift of littoral sediment in the western and central inshore areas of the bay must surely be emphasised by this dominant ebb-tide stream.

As shown in Figure 2.1, eddies associated with this tidal stream develop off the Teignmouth headland and could aid in producing a westward growing spit counter to the main though less stable spit which grows in a north-easterly direction from the Ness Point. Spratt (1856) described an observed sequence of events in the growth of this spit system across Teignmouth harbour, the main stages of which are shown in Figure 2.2. The first condition (Stage A) shows the growth of a long hook of coarse sand and shingle which extended north-eastward from the Ness Point for a distance of 1,000 m following the main tidal ebb stream. The second stage (B) was reached when the hook was broken by a channel close to the Ness Point. Following this breakthrough the

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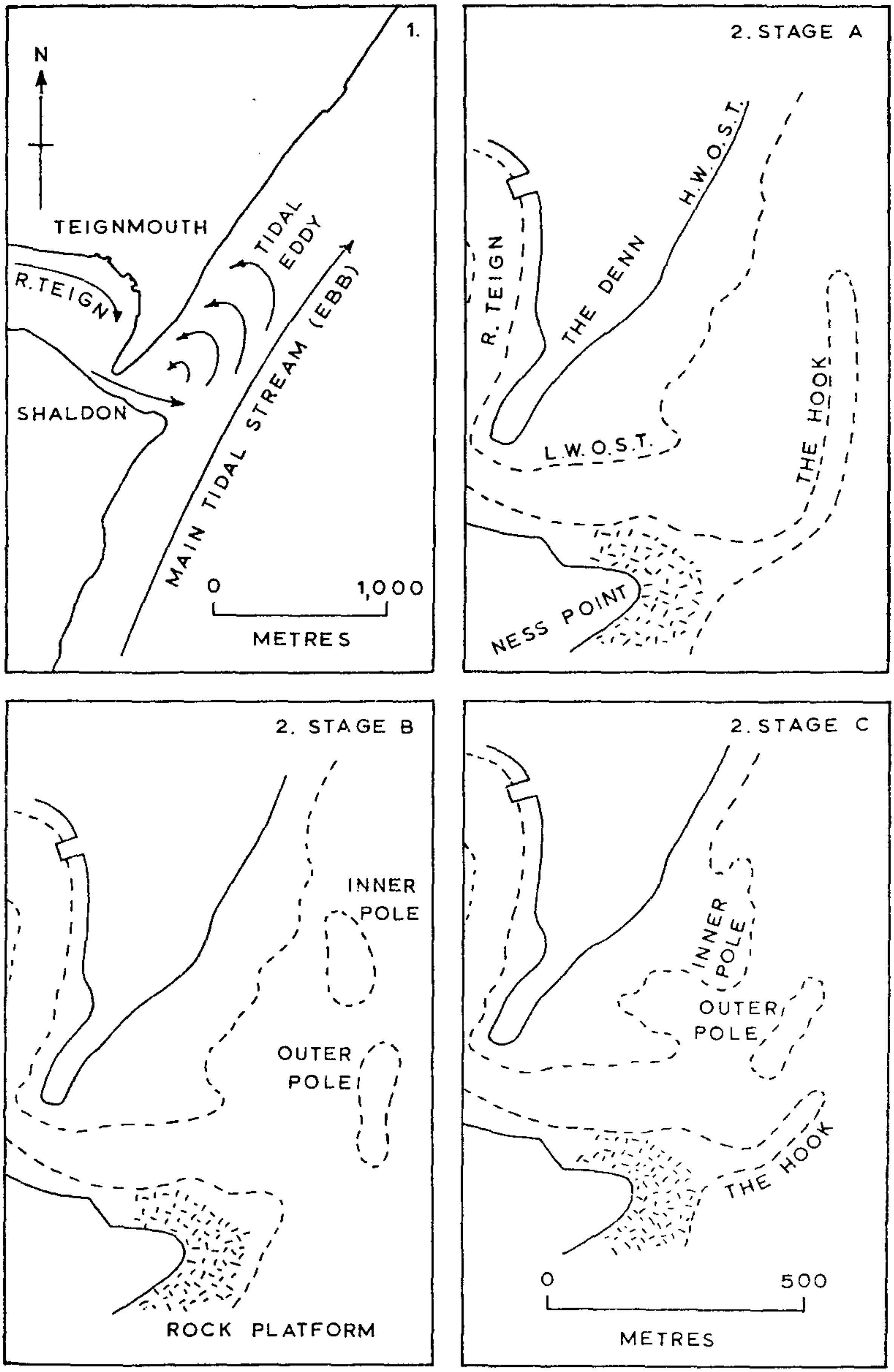

FIGURE 2. Spit development at the mouth of the river Teign.
(1) Tidal stream and eddies off Ness Point (from information supplied by the Hydraulics Research Station).
(2) Cycle of spit development (after Spratt, 1856).

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position of the old shingle hook was replaced by two banks called the Inner and Outer Poles, which had migrated slightly from their former position, due to the effects of the main tidal eddy, so that they lay partly across the position of the former channel. Stage C then showed the re-development of the Ness Point hook with a corresponding easterly displacement of the main channel and the driving on-shore of the Inner Pole bank to herald the commencement of a new cycle. This sequence of events has, since Spratt's observations, been seen to occur on several occasions, though no definite period of time can be recognised for its duration (D. E. Newman, personal communication). It is interesting to note that in the Teign estuary the only areas in which the spit system remains stable throughout the cycle are at Ness Point, where at a shallow depth an underlying surface of New Red Sandstone breccia is present, and at the Denn, which lies at the limit of movement of sediment carried by the main tidal eddy.

The Exe estuary presents a similar configuration of headland and bay to the ebb tidal stream as does the Teign estuary. An eddy configuration similar to that at Teignmouth is therefore likely to be present at the mouth of the Exe, a conclusion supported by the presence of the Exmouth spit whose westerly growth is counter to that of the main easterly drift of sediment indicated by the form of Dawlish Warren and the Pole Sand. A similar sequence of events as Spratt observed at Teignmouth may therefore be postulated to occur at the mouth of the Exe estuary, although the scale difference between these two areas would eliminate the possibility of any comparison of the time span in which such a sequence could be completed. Complicating this picture in the Exe estuary is, however, the presence of the fairly extensive unit of Late Pleistocene gravels within the mouth of the estuary at Warren Point. In addition to the stable positions offered by the New Red Sandstone breccia outcrop at Langstone Rock, which is akin to that at Ness Point, and Exmouth spit, which is akin to the Denn at Teignmouth, this stable area of Warren Point must also exert some control on the position of the main river channel. Taking into account the presence of this additional stable area a modified sequence of events similar to that taking place at Teignmouth may therefore be suggested. This sequence is shown in Figure 3. Stage A marks an initial position of the river channel, say to the west of Warren Point, with the development of the main spit off Langstone Rock

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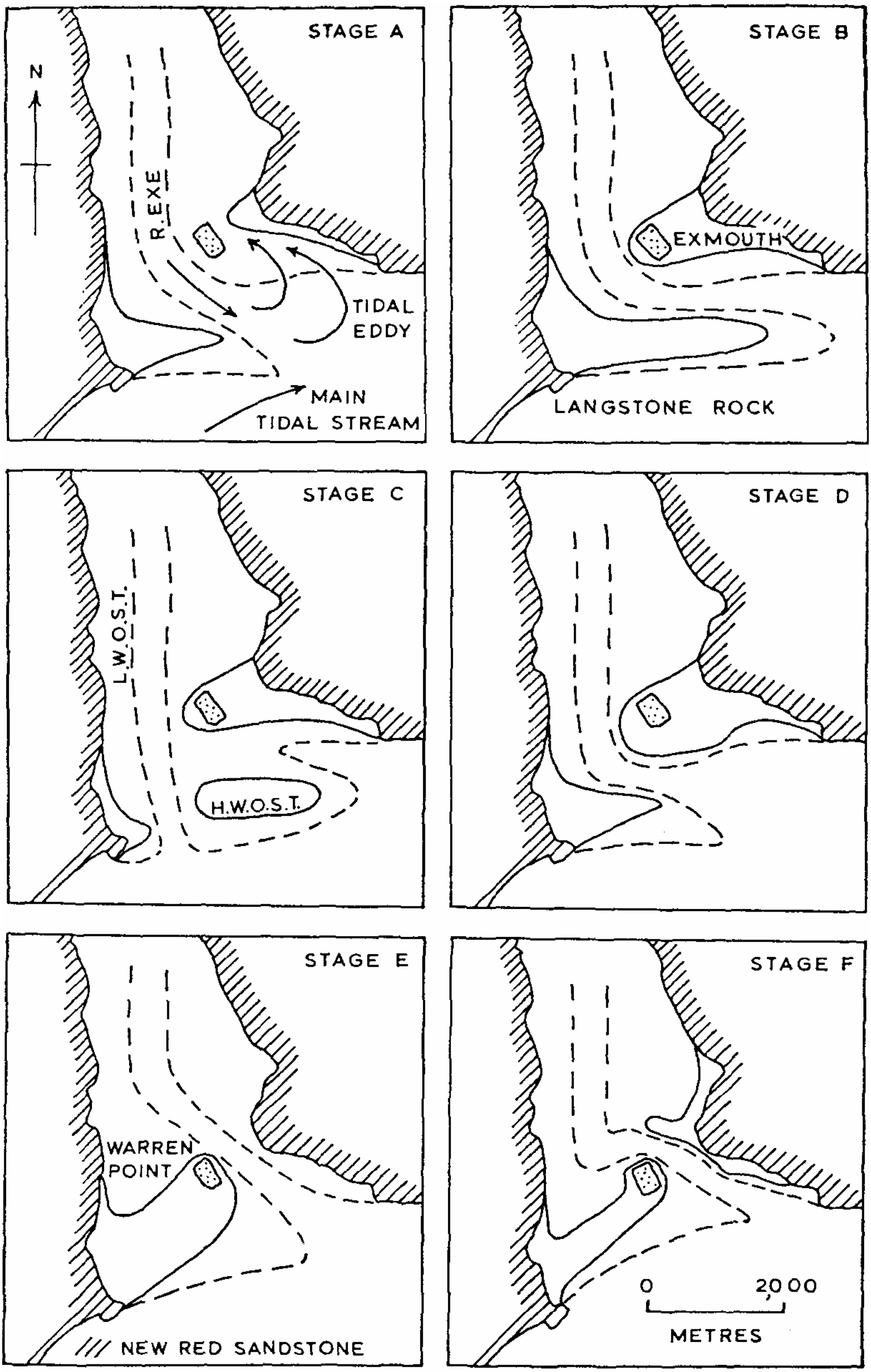

FIGURE 3. Spit development at the mouth of the river Exe. Stippled zone indicates area of gravel platform, above low water of ordinary spring tides, at Warren Point.

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and the counter spit at Exmouth although the cycle could with equal validity be considered as commencing at any stage. In Stage B these develop further, the Langstone Rock spit displacing the river channel to the east, and the Exmouth spit linking with the stable area at Warren Point. Stage C then marks the breakthrough of the channel close by Langstone Rock, isolating the outer part of the Langstone Rock spit to the east of the new channel. In Stage D this is then driven on-shore to link with the Exmouth spit, at Warren Point while the Langstone Rock spit commences its re-development. The growth of the new Langstone Rock spit then constricts the passage afforded to the now excessively tortuous river channel which finds by re-alignment, a new exit east of Warren Point in Stage E. Stage E is followed by a return to the development of the counter spit at Exmouth in Stage F with its eventual linking to Warren Point and a return to the conditions presented by Stage C.

5. Conclusions

As such a sequence of events is in accord with the recorded development of Dawlish Warren it would appear likely that the growth of the Warren could have occurred with very little net export of sediment from the area of the estuary taking place. Moreover, it is of interest to note that all the recent breaks by the sea through the frontage of the Warren have been in a position to re-open the old channels, (Durrance, 1969) where the sand is less resistant to erosion than the New Red Sandstone breccia or the Late Pleistocene gravels. This is a feature which too was noted by Polwhele, who observed that “On the Starcross side. . . . . . the sands are visibly yielding to the force of the current. . . . . . When a passage is made on this spot (which is almost effected) the river will again change its mouth and resume its old channel ", an event which were it not for protective works to maintain the *status quo* would surely have occurred.

Today, the area of greatest danger to the Warren still lies to the west of Warren Point, south of Exe Bight, where only an artificial barrier, acting as a trap for wind-blown sand, separates the high tide levels to north and south. The destruction of the Warren and the forcing of a new passage in this locality would result in the development of a second channel, initially turning the area south of Exe Bight, as was forecast by Peacock (1869), into “a dangerous bay of shoals”, and isolating the port of Exmouth from the sea.

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The present position of the channel between Warren Point and Exmouth probably, however, represents its most stable position. Efforts to maintain this rather than any other channel are therefore more likely to be successful. Further, the present channel, by occupying the position of a Late Pleistocene channel will become more stable the longer it so remains, allowing tidal scour to re-excavate the total length of the former channel from its infilling of Recent sediment. The danger of continued erosion of the Outer Warren, and further attack on the Inner, presented by a general rise in mean sea level is, however, more menacing. It may well prove that the destruction of the area of the Warren above present-day high water level cannot be prevented without the costly building of a sea wall along the entire face of the spit, as suggested by Kidson (1964), although in the long term even this could prove unsatisfactory.

ACKNOWLEDGMENTS. Grateful thanks are offered to Mr. D. E. Newman and Mr. J. B. Wade of the Hydraulics Research Station for their interest and co-operation, to Cdr. Glenn and Lt. Cdr. Powell of the Admiralty Hydrographic Office for tidal information and to Dr. J. M. Thomas and Dr. M. Stone for their many helpful discussions on the sedimentary history of Dawlish Warren.

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CORALS AND STROMATOPOROIDS FROM THE CHUDLEIGH LIMESTONE

by Colin T. Scrutton

ABSTRACT. Givetian and Frasnian corals and stromatoporoids are described from four localities in the Chudleigh Limestone.

Recent work by House & Butcher (1962: 28) and House (1963: 9) has established a complete but much reduced succession in the Upper Devonian and Lower Carboniferous of the Chudleigh escarpment above the massive limestones of this area. Dineley & Rhodes (1956: 244) had previously described Upper Devonian conodonts from just below the top of the massive limestone at Lower Dunscombe quarry, whilst Anniss (1933: 432) had considered all the limestones exposed in the Chudleigh valley to be of Frasnian age. House (1963: 9), however, recorded the presence of *Stringocephalus* sp. in the massive limestones of Holman's Wood quarry suggesting that they are, at least in part, of Givetian age. Corals and stromatoporoids from selected horizons in the Chudleigh Limestone, described here, provide further evidence on the age of the top of this unit and confirm the presence of the Givetian within it. Collections were made from Lower Dunscombe quarry (SX 88577906), the Riding Parks (SX 78758688), a small quarry about 350 yds. to the north-east of the Riding Parks (SX 78908716) and from Holman's Wood quarry (SX 88298119).

About 15 ft of massive limestone is exposed in Lower Dunscombe quarry. At the top of the quarry, the massive beds pass upwards with no apparent break into red, shaly limestones containing the Lower Dunscombe goniatite fauna of *cordatum Zone*

FIGURE 1. *Catactotoechus sp.* nov. R46690; x 2.5.

FIGURE 2. *Macgeea sp.* aff. *M. recta* (Walther). R46691; x 2.5.

FIGURE 3. *Disphyllum sp.* aff. *D. caespitosum* (Goldfuss). R46692 x 2.5.

FIGURE 4. *Macgeea sp.* nov. R46693; x 1.5.

FIGURE 5. *Marisastrum sp.* aff. *M. marmini* (Edwards & Haime). R46694; x 2.5.

FIGURE 6. *Caliapora battersbyi* Schliiter. R46695; x 3.

Numbers refer to specimens in the Collections of the Department of Palaeontology, British Museum (Natural History).

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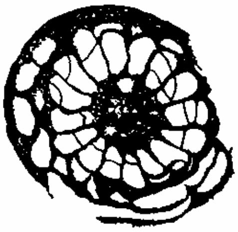
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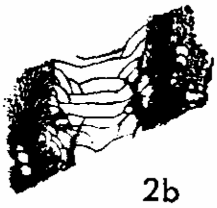
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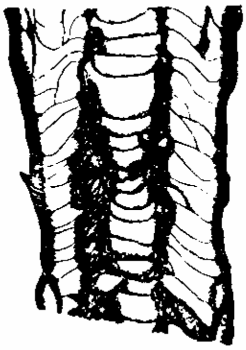
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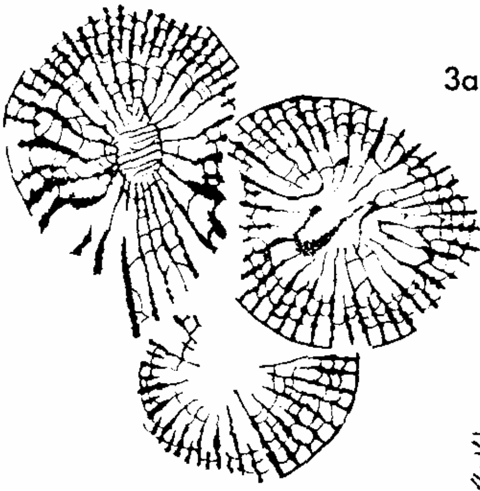


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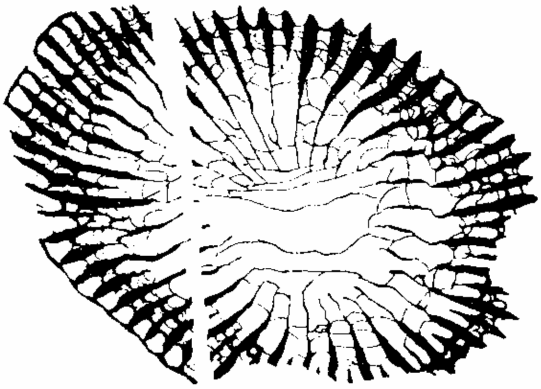
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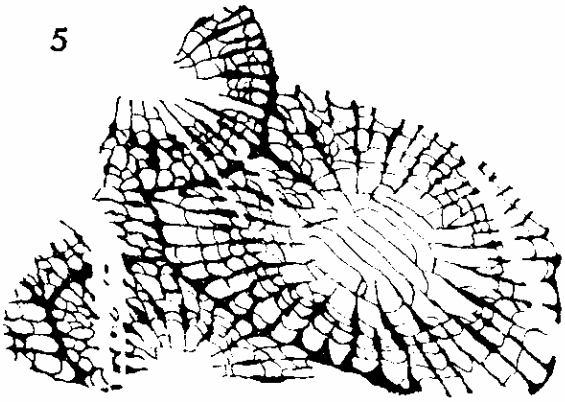

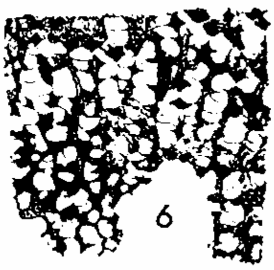
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age. The massive limestone contains a rich and varied fauna, although corals are not common. The Rugosa are represented by several specimens of a laccophyllid, *Catactotoechus* sp. nov. (Fig. 1), and *Macgeea* sp. aff. *M. recta* (Walther) (Fig. 2). *Catactotoechus* has been recorded previously only from the Upper Devonian of Western Australia, whilst *Macgeea recta* is known from the German Frasnian (Walther 1929: 150). Two other specimens are referred to ?*Ceratophyllum* sp., a relatively uncommon and often misinterpreted genus represented in the European Middle Devonian. *Alveolites* sp. is widespread and the corals are accompanied by brachiopods, crinoid ossicles and part broken fenestellid networks, all of which are common. *Styliolina* is abundant in some sections and fragments of trilobites and echinoderm spines were also noted.

The corals afford only weak evidence for the age of this fauna. The presence of *Macgeea* sp. aff. *M. recta* suggests correlation with the Frasnian of Germany, whilst the other elements are too poorly known to be given much weight. This age is supported by the work of Dineley & Rhodes (1956: 244).

In the Riding Parks, scattered Rugosa occur in beds approximately 15-25 ft below the local top of the massive limestone. Tabulate corals are common and there are some stromatoporoids. Fasciculate colonies of *Disphyllum* sp. aff. *D. caespitosum* (Goldfuss) (Fig. 3) are the chief rugose element but *Macgeea* sp. nov. (Fig. 4) is also well represented. *Thamnophyllum* sp. cf. *T. kozlowskii* (Rozkowska) and ?*Disphyllum* sp. also occur. *D. caespitosum* is widespread in the Givetian and Frasnian of Europe and *Macgeea* sp. nov. appears most closely related to *M. berdensis* Soshkina which, with *T. kozlowskii,* is found in the Frasnian of eastern Europe (Rozkowska 1953, fig. 40). Among the tabulates, *Alveolites suborbicularis* Lamarck and *Thamnopora boloniensis* (Gosselet), both from the upper Givetian and Frasnian of Europe, are common. *Amphipora* sp. and a few brachiopods also occur with crinoid ossicles.

The fauna is clearly upper Givetian or Frasnian in age and the species of *Macgeea* and *Thamnophyllum* favour a Frasnian horizon.

The small quarry to the north-east appears to expose beds equivalent to those immediately above the top of Palace Quarry, somewhat lower than the beds collected in the Riding Parks and

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about 50 ft below the top of the limestone there. Rugosa are rare but stromatoporoids and *Amphipora* are abundant. Although several indeterminate fragments have been found, the only determinable rugose coral is a single specimen of *Marisastrum* sp. aff. *M. marmini* (Edwards & Haime) (Fig. 5) which is found in the Frasnian and possibly the uppermost Givetian of Europe (Scrutton 1967: 269). The stromatoporoids are represented by *Hermatostroma episcopale* Nicholson, *Stachyodes* sp. aff. *S. caespitosa* Lecompte, *Stromatopora* sp. and *Trupetostroma* sp. These generally indicate a Givetian to Frasnian age although the extension of *S. caespitosa* into the Frasnian has not been established beyond doubt. *Arnphipora rudis* Lecompte is usually concentrated into dense bands apart from the rest of the fauna; this form also ranges from the Givetian through to the Frasnian. *Thamnopora sp.* and a few crinoid ossicles are also present.

The very limited evidence here suggests a horizon close to the Givetian - Frasnian boundary. The presence of *Marisastrum,* and the apparent absence of any of the typical upper Givetian corals from this locality may be taken as inconclusively favouring a Frasnian age.

In Holman's Wood quarry, the high limestone horizons in the north-west corner are rich in stromatoporoids with some tabulate and rugose corals. Only one rugose species, represented by several specimens, occurs closely associated with the stromatoporoids. This is tentatively referred to *Alaiophyllum*. This genus is rare and has been recorded previously only from the Givetian of Canada and Russia. *Grypophyllum denckmanni* Wedekind and a stringophyllid occur in black limestones poor in stromatoporoids; both indicate a Middle Devonian age (Tsien 1968: 280, 285). The tabulate corals, all occurring in the stromatoporoid rich facies, are represented by *Caliapora battersbyi* Schluter (Fig. 6), *Heliolites porosa* Goldfuss and *Scoliopora* sp. *C. battersbyi* is characteristic of the Givetian and *Heliolites porosa* is Middle Devonian in age. The stromatoporoids are *Stachyodes caespitosa* Lecompte, *S. radiata* Lecompte, which has a Givetian - Frasnian range in Europe, and *Trupetostroma* sp. *Amphipora rudis* Lecompte also occurs in thin bands.

This fauna confirms a Givetian age for at least part of these limestones as suggested by House (1963: 9). The evidence given here is insufficient to allow the precise horizon within the Givetian to be determined but Dineley & Rhodes (1956: 244) have recorded

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Frasnian conodonts from the upper level in the south-west corner of Holman's Wood quarry. Their sample presumably came from a higher horizon than that providing the coral fauna, although it would sugest that the latter is late Givetian in age.

In the higher horizons of the Chudleigh Limestones, the faunas are consistent with a gradual deepening of the environment during early Frasnian time. The beds rich in stromatoporoids and *Amphipora* seen at the top of Palace Quarry and exposed in the small quarry 450 yds to the north-east sugest shallow water with periods of restricted circulation represented by the horizons packed with *Amphipora*. Deeper, quieter conditions would favour the colonization of the sea floor by the fasciculate *Disphyllum* which is common in the Riding Parks fauna. Finally, the '*Fenestella*' - *Styliolina* - thin-shelled brachiopod association poor in rugose corals found in Lower Dunscombe quarry is directly succeeded by deposits of the schwellen type considered to represent sedimentation on submarine ridges.

The work on which this paper is based forms part of a project financed by the Daniel Pidgeon Fund of the Geological Society of London. I am grateful to Professor M. R. House for comments and suggestions on this work.

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Preliminary results from a borehole in Carboniferous and Devonian sediments near East Ogwell, Newton Abbot, (Abstract) :

by B. W. Riddolls.

The borehole was drilled by the Institute of Geological Sciences to establish the relationship of a small fault-bounded mass of supposed Carboniferous sediments south of Newton Abbot to the otherwise Devonian outcrops. Previous workers have recorded a quarry in which conglomerate overlies an erosion surface on tilted limestone, and interpreted this as marking a Carboniferous-Devonian unconformity. This locality is not now visible and as a similar feature was not encountered in the borehole, the question of an unconformity in this area remains in doubt.

The core succession indicates a sequence complicated by intense deformation. The argillaceous rocks are all strongly cleaved, and cleavage surfaces are commonly highly polished. Probable Carboniferous arenaceous sediments and black shales are faulted over Upper Devonian slates, which are underlain by massive limestone. Lithological and fossil evidence suggest repetition of beds, probably due to recumbent folds and thrust faults. This confirms the style of deformation indicated from surface mapping in the area of Upper Paleozoic outcrops around Newton Abbot.

This contribution has been approved for publication by the Director of the Institute of Geological Sciences.

Preliminary report on the Wilsey Down Borehole, North Cornwall (Abstract) : by E. C. Freshney.

A borehole was sunk for the Institute of Geological Sciences a± SX 17978890 near Hallworthy, north Cornwall, to ascertain the cause of a magnetic anomaly, and to prove the continuation with depth of a stratigraphical and structural succession mapped at outcrop to the south of the borehole site.

Beneath 250 ft of slates, siltstones and turbidite sandstones of the Crackington Formation the borehole encountered slates and limestones identical with those of the Meldon Chert Formation

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which does not crop out in the north Cornwall area. It is thought that the reason for the absence of these beds at the surface up-dip towards the south is the presence of large-scale isoclinal to tight folds closing towards the south, and intersected by faults dipping at low angles to the north. Below 1511 ft the borehole entered green Upper Devonian slates with infolded basal Carboniferous grey slates down to 2319 ft. From there down to the bottom of the borehole at 2501 ft there occur black slates, thin siltstones and very thin limestones probably of Lower Carboniferous age, together with a number of greenstone sills.

The magnetic anomaly was found to be due, at least in part, to pyrrhotite mineralization in the slates between 250 ft and 850 ft.

This contribution is published by permission of the Director, Institute of Geological Sciences.

The geology of the Staddon coast (Abstract) : by G. M. Gathercole.

The Staddon coast lies below Staddon Heights to the east of Plymouth Sound. In the south the Bovisand, or Meadfoot, Beds outcrop, followed northwards by the Staddon Beds, which are suceeded by the Jennycliff, or Middle Devonian, Slates. The Bovisand Beds consist of muddy limestones, with mudstones, and some thin sandstones and siltstones higher in the sequence. The Staddon Beds are predominantly alternating sandstones, mud stones and siltstones, with a few limestones and conglomerates, similar to the type lithologies of the Meadfoot Beds. Such strata, probably deposited in a tidal lagoon, make over 500 m within the Staddon Beds; the remaining 100 m occurring in the lower half of the Beds, are massive sandstones, The Jennycliff Slates are mudstones with some thin limestones, sandstones and spilites.

These strata have been folded into northward-facing asymmetrical zig-zag folds during the first deformation period. These folds have been subsequently tightened (in the alternating sandstones and mudstones) or warped (in the mudstones) by the second deformation. Changes of cleavage inclination of 50° occur after warping, the axial trend being similar to that of the first. Later deformation features include cross-folding, NW-SE wrench-faulting and N-S faulting with subsidiary kink-bands.

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Aspects of the sedimentology of the Dartmouth and Meadfoot Beds near Fowey, South Cornwall (Abstract) : by P. H. Bridges.

Uppermost Dartmouth Beds (lower Siegenian) outcrop at Lantivet Bay. Cyclic sequences in the west pass laterally into non-cyclic rocks in the east. Each cyclothem consists of grey slates and sandstones passing up into green and purple variegated slates. To the east, rapidly alternating grey slates and sandstones occur with moderate thicknesses of grey green slates.

Interpretation is mainly based on the general absence of sandstones from the variegated slates and the lateral relationship mentioned above. It is suggested that the environment was that of a coastal plain with distributaries, brackish lagoons and inter-lagoonal flats usually covered with shallow sheets of water. Subsidence was uniform, but sedimentation was naturally greatest in lagoons. The latter tended to migrate, and cyclothems developed as lagoonal conditions (grey slates and sandstones) alternated with inter-lagoonal conditions (variegated slates). To the east, distributaries brought mud and sand into a shallow brackish embayment. Ostracoderm remains were almost always found in "lagoonal" sediments.

Sandstones of the Meadfoot Beds display small scale current ripple lamination, pseudonodules and load casts. Moore and Scruton (1957) found similar "regular" layers on the margin of the Mississippi delta. At Gribbin Head graded, very fine sandstones interrupt a sequence of grey slates.

Observations on the deposition of the Bude Sandstones (Abstract) : by R. V. Burne.

The Upper Carboniferous Bude Sandstones were deposited by two distinct sedimentary processes, circulation of basin waters and bottom hugging currents or underftows. The former produced two types of deposit; black mud, deposited during almost stagnant basin conditions, and silt, during periods of more active basin circulation. Each has its own suite of trace fossils. The salinity of the basin

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is not known. The underflows varied in density, size, velocity, and rate of deceleration, and therefore their deposits show several associations of internal structures. These deposits vary from thick sandstones filling channels, to thinner but extensive sandstones and siltstones. Some underflow deposits show evidence of reworking by the underflow which continued to flow for some time after the sediment load was deposited. Others show evidence of the depositing current flowing in several pulses. The so called "slump beds" described from these deposits were laid down by very high density underflows which froze in the act of eroding sediment, leaving a quick bed which generated sand volcanoes at its surface. These foundered due to loading into the bed, resulting in a deposit of sandstone balls in a matrix of silty mud, also containing clasts of locally eroded material.

Preferred sequences of sediment types are likely to emerge from analysis in progress.

Limulid undertracks and their sedimentological implications in the Bude Sandstone (Abstract) : by Roland Goldring.

Limulid tracks were first described from the Upper Carboniferous, Bude Sandstones by King in 1966. A sedimentological study of the tracked siltstones, and associated sandstones and shales, shows that the feeding and mating tracks were made in relatively deep water, and away from the margin of a large water-body. Units of tracked siltstones have a lateral persistance greater than the (turbidite) sandstones though less than units of shale.

The tracked siltstones exhibit a variety of sedimentary structures, reflecting the balance between current strength and the amount of sediment in suspension. The limulids moved only over silt covered surfaces. Tracks rarely show deflection due to currents. Parallel lamination resulted from intermittant sedimentation as individual tracks may be followed for several metres at the same level. Longitudinal ridges and furrows (load structures) were formed prior to the formation of overlying tracks. Optimal conditions for track preservation occurred when silt was deposited from low velocity currents sufficient to maintain adequate oxygenation but insufficient to extensively scour the substrate.

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The sedimentological history of the Padstow area, North Cornwall (Abstract) : by M. E. Tucker.

The Middle and Upper Devonian bathyal sediments of the thrusted St. Minver synclinorium are exposed along the coast from Booby's Bay to Portquin, North Cornwall. The successions are significantly different on either side of the structure : sedimentation was influenced locally by positive rises.

The oldest sediments (Trevose Slates in the west) are finely laminated grey slates and distal turbidites, with a dominantly pelagic fauna. A series of allodapic limestones interstratified with black pyritiferous shales (Marble Cliff Beds) follows in the west. The limestones, interpreted as near-proximal turbidites derived from a rise to the south-west, are composed almost entirely of crinoidal and bryozoan debris, with no terrigenous material.

Volcanic activity followed giving rise to the Pentire Pillow Lavas and associated sediments in the north, which are partly equivalent to tuff and agglomerate bands in shales of the west (Longcarrow Cove Beds). A period of calm conditions then ensued giving variously coloured shales with goniatite bands (Merope Island Beds and Pentire Slates). A further rise effected local coarse sedimentation within the northern argillites (Gravel Caverns Conglomerates). Finally, stable conditions prevailed over the whole area, with the deposition of purple and green ostracod shales (Polzeath Slates).

Acknowledgements to G. Gauss (D. Phil. Thesis Oxford 1967).

Facies interpretations in the New Red Sandstone, S.W. England (Abstract) : D. J. C. Laming.

Lithological assemblages recognised in the New Red Sandstone are relatable to a sedimentary model of an infilling desert basin. Sediment assemblages B. C and D occur above A, weathered bedrock and fissure fillings. Basal sediments are usually B. breccias with locally derived fragments, passing laterally and upwards into C, finer grained breccias and fluvial sands with a wider range of fragment types. Mudstone sequences with sand lenses, D, follow. B and C may include eolian sands. Normal fining trends affect the

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deposits away from source both laterally and stratigraphically, the latter resulting from the sediment body gradually encroaching over the source area with consequent reduction of gradient.

The sedimentary model postulates that B facies is dominant when source area-to-infilled basin ratio is high; slopes are steep and sedimentation rapid. Enlarged basin and reduced source areas give facies C, with some D in the basin middle; slopes are flatter and vertical accretion slower. When the ratio is low, D facies is dominant, slopes are gentle and sediment from the source area mainly fine. Vertical accretion is slow unless subsidence is effective. In the resulting fining-upward sequence, the upper beds represent longer time intervals than the lower. The unconformity is eroded to a convex profile.

TERGIVERSATE FOLDS FROM SOUTH-WEST ENGLAND

by W. R. Dearman

Abstract: The name tergiversate folds is proposed for folds which, in turning their backs upon themselves, show wide variation in axial plunge within a common axial-plane. In Cornwall zones characterized by tergiiver-sate folds with axial trends varying by 180° occur in Middle Devonian rocks below the Lizard-Dodman thrust zone and also in the Upper Devonian and Carboniferous in the Tintagel area.

Folds produced by the first phase of deformation in the slates of South-West England may have a regional axial-trend that is either Caledonoid or normal to that direction. In particular areas one or other of these directions may predominate but never to the total exclusion of the other trend or of intermediate trends. Facing directions of the Caledonoid folds vary; north of Padstow it is to the south-south-east, while elsewhere it is uniformly north-north-westwards in folds that are recumbent or nearly so. On the other hand, folds trending NNW-SSE face either to the west or to the east, so that the two fold directions at right angles in fact involve changes in fold trend of up to one hundred and eighty degrees. The fold axes lie in the plane of slaty cleavage; that changes of fold trend of slightly more than ninety degrees can be achieved in a continuous fold axis within a common axial plane is known, for example, from the Southern Uplands (Shiells & Dearman 1963).

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There is no conceptual difficulty in accepting the even greater continuous swing implicit in the values of fold trend from the South-West, although such variations have not been observed on continuous fold hinges.

It is suggested that a useful descriptive term for such folds would be "tergiversate", from the Latin *tergum* the back + *vers-*, *vertere* to turn. Tergiversate folds turn their backs on themselves or on other folds of the same generation (Fig. 1) while retaining a common unfolded axial plane, the variation in fold pitch on the axial plane being ninety degrees or more. Such changes in fold plunge in excess of ninety degrees imply strong differential compression in the axial plane of the fold, if, as in the case under discussion, the pattern results from one deformation (Ramsay 1962a, Figs. 19 and 20; 1962b: 473). Tergiversate folds may of course be folded again during a later deformation.

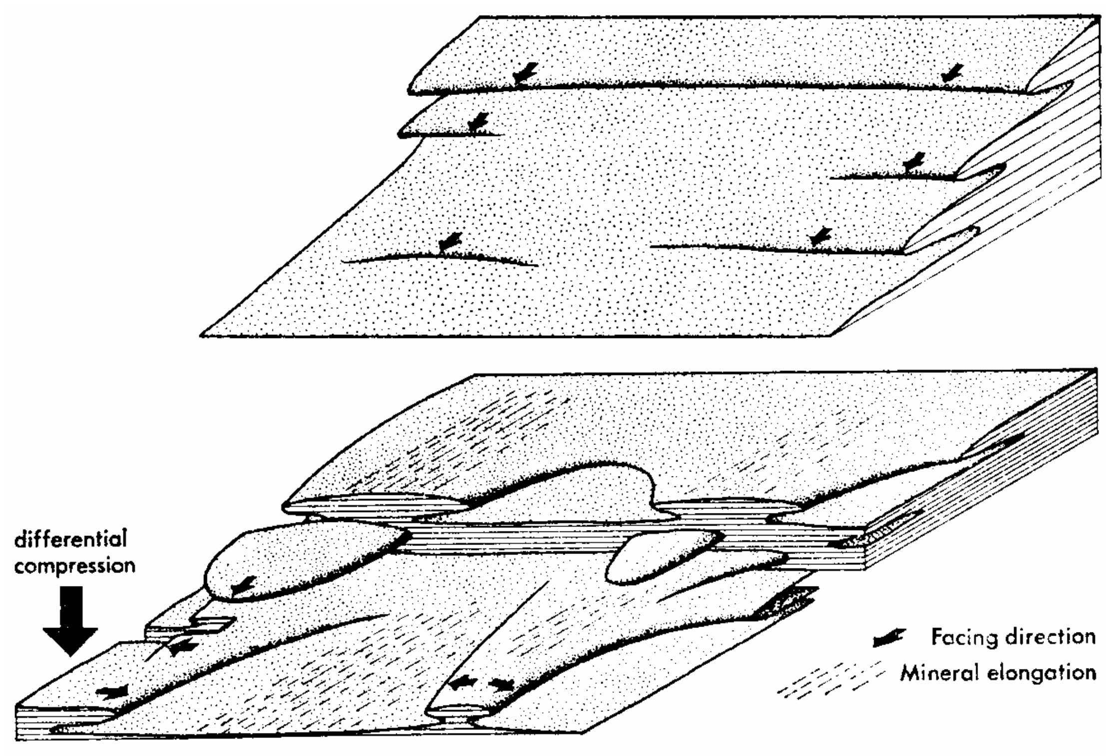

FIGURE 1. Formation of tergiversate folds by strong differential compression in the axial plane of the folds; *above :* folds at an early stage with subparallel fold axes that arise and die out along their length; *below :* tergiversation and a constant trend mineral lineation after differential compression. Note that the front of the block has been cut off.

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The 'Eyemouth-type' of refolded fold (Dearman and others 1962), if correctly interpreted as resulting from one phase of deformation, is tergiversate, as are the first phase folds at Boscastle (Dearman & Freshney 1966, fig. ld) and at Watergate Bay, Newquay (Ripley 1965).

Fold axial trends in a region of strongly developed tergiversate folds are likely to be parallel or subparallel to the usually accepted transport direction in the whole fold belt. **In** Cornwall, for example, where tergiversation is present at and beneath the southern margin of the main Carboniferous trough and also just to the north of the Lizard-Dodman thrust, the first folds trend predominantly north-north-west. These areas are thus regions of strong differential compression; in the north the folds mark the transition zone between an underlying infrastructure involving the Devonian and an overlying suprastructure in the Carboniferous strata; a mineral lineation, where developed, is much more constant in trend than the first fold axes (Fig. 1). The zone of tergiversation is continued east to the margin of Dartmoor (Fig. 2) where tergiversate folds are known to be developed in the Devonian (?) Slate-with-Lenticles Group inliers at Lydford and Meldon. In the south, where deformation started earlier, basement rocks overriding on the Lizard thrust might have been responsible for the strong deformation in the tergiversate zone in underlying Devonian sediments (Fig. 2).

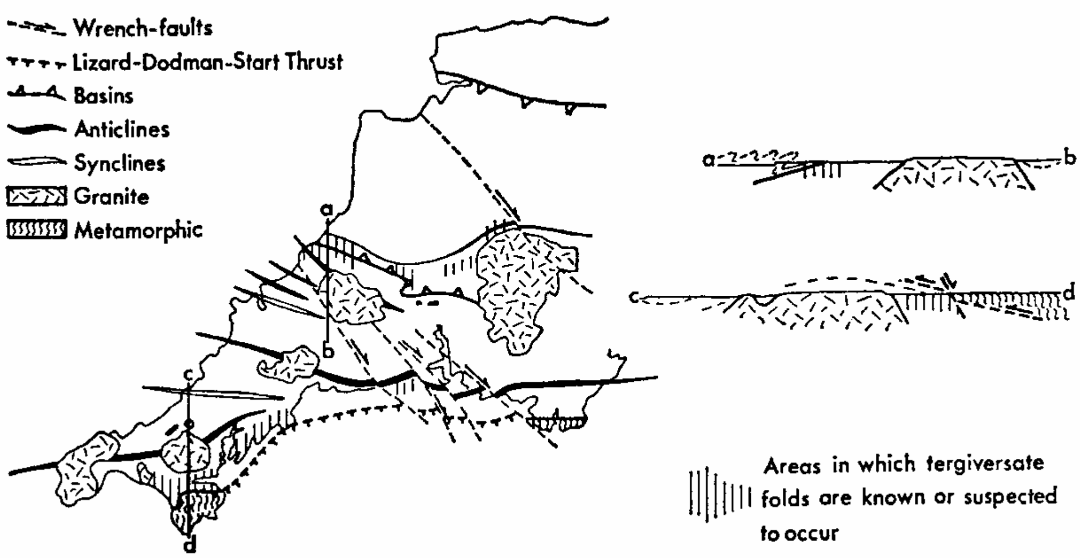

FIGURE 2. A map and sketched section showing the main structures of South-west England in relation to known or suspected zones of tergiversate folds. The map is based on the I.G.S. 'Tectonic Map of Great Britain'.

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ON THE ASSOCIATION OF UPRIGHT AND RECUMBENT FOLDS ON THE SOUTHERN MARGIN OF THE CARBONI FEROUS SYNCLINORIUM OF DEVONSHIRE AND NORTH CORNWALL

by W. R. Dearman

Abstract. Recognition of the secondary origin of both the recumbent folds associated with upright folds on the Bude coast and the recumbent folds along the north-west margin of Dartmoor casts doubt on the current interpretation of the coastal structures south of Wanson Mouth as the stretched out inverted limb of a major overfold. The latter and the Dartmoor structures could represent two or three repetitions of plicated major folds such as those present at Bude and along the northern side of Dartmoor.

Studies of large-scale structural patterns in the tract of Carboniferous and Devonian rocks lying between and to the north of Dartmoor and Bodmin Moor are few in number (Fig. 1). The slate tectonics of Tintagel, dealt with in modern terms by Wilson (1951) and subsequently modified in detailed interpretation (Dearman and others, 1964), are dominated by bedding and coincident slaty cleavage present as relatively undisturbed gently inclined planar structures. Recognition of a major overfold along the northern part of Dartmoor (Dearman, 1959) was developed into the broader picture of a pile of sliced up recumbent folds to explain structures along the north-west margin of Dartmoor (Dearman and

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Butcher 1959, fig. 13; Dearman 1962, fig. 2); Freshney (1965) working on the coastal exposures between Wanson Mouth and Boscastle provided a more realistic profile for the major anticlinal overfold, but retained the concept of northerly dipping low-angle normal faults to spread out the inverted south limb of the fold to occupy the whole length of the cliff section. To the north of Wanson Mouth, King (1966) had been able, by minute attention to stratigraphic detail, to integrate the small folds into a pattern of larger folds involving some 2,000 ft of beds. Apart from the maps of the Geological Survey, these studies in particular must provide the material for a structural synthesis of the southern margin of the Carboniferous synclinorium.

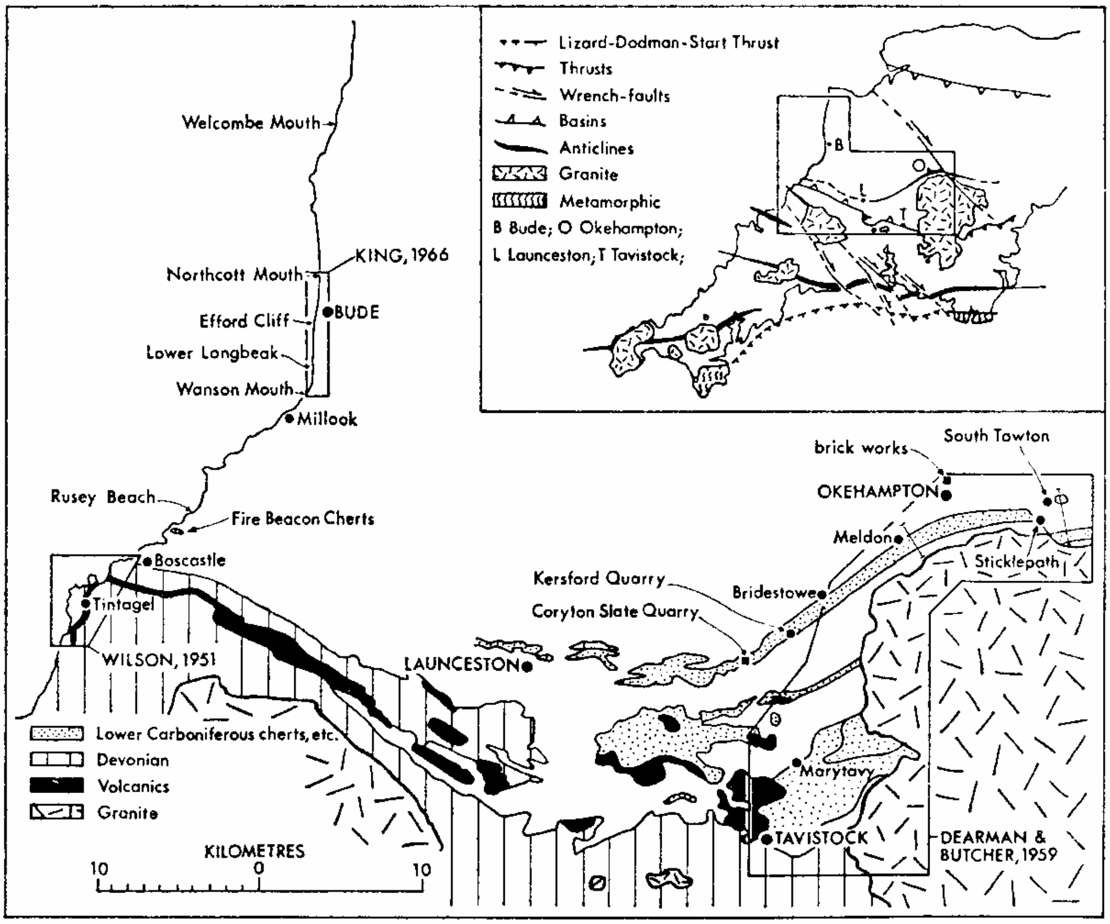

FIGURE 1. Outline geological map of the area from Dartmoor to the north Cornish coast showing the areas previously mapped and the main Lower Carboniferous chert ridges west of Dartmoor. The lines of section for Figs. 2b and c are marked. Inset: Tectonic map of South-West England showing the setting of the area; after Dunning, 1966.

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Structures one order of magnitude greater than the folds seen in the field have comparable dimensions regardless of locality. The Lower Carboniferous inlier skirting north Dartmoor at Meldon has a half wave length of about 1.5 km and an amplitude of 0.5 km. (Dearman and Butcher 1959, fig. 9); at Sticklepath (*ibid.*, fig. 12) the wavelength of the larger structure measured from the south side of the inlier to the South Tawton limestone quarries is about 2.5 km and the amplitude 0.5 km (Fig. 3). In what is regarded as the structurally unrelated Bude coastal section (King 1966), the wavelength of major folds extending for example from Northcott Mouth to Efford Cliff or from Efford Cliff to Lower Longbeak is about 2.5 km and the amplitude varies up to 0.5 km. With these dimensions in mind, it is not surprising to find that the easterly trending chert ridges between Launceston and Dartmoor have a similar periodicity, although no estimates of fold amplitude can be made on the presently accepted structural interpretation.

Recently it has been suggested that "The change in attitude from northern overfolds to recumbent folds in the south within the large-scale structure in the sediments bordering the (Dartmoor) granite now appears to be an original structural feature similar to that suggested by Freshney (1965) for the coastal exposures north of Boscastle. ......The Meldon overfolds would then lie on the crestal region of a major overturned fold, with the southern recumbent limb spread out by low-angle normal faults associated with the emplacement of the granite batholith to the south, while the overfolds in the crest pass northwards......into a broad zone of upright folds seen for the first time in Knowle quarry north of Okehampton". (Dearman 1968: 63). The Meldon structure, together with the folds in the upper Carboniferous to the north, is very similar in scale and detailed pattern to the Higher Longbeak overfold zone in the Bude cliff section (King 1966, fig. 1) and, if the effects of the Phillips's Point fault zone are removed, the folds to the north beyond Upton Cross are reminiscent of those north of Okehampton. The differences between the two structures may reside in their southerly continuations; it is pertinent to enquire here whether there are significant variations in the structural patterns of these two areas.

To deal with the overfolds and their northern hinterlands first, it is necessary to compare the minor fold structures and ideas concerning their tectonic development. The clue to the close associa-

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tion of folds of differing attitudes in Devon was first provided by Zwart (1964) and later amplified by Dearman (1967) for the Welcombe Mouth coastal section north of Bude. A basic pattern of upright folds has been deformed again to give co-axial inclined and recumbent folds *(ibid.,* fig. 4). At Bude early upright folds have been modified in the same way (Fig. 2); overfolds arise from upright folds in Efford Cliff, while at Phillips's Point beds have been pushed over fold crests into southerly facing recumbent folds. It seems a reasonable extension of this tectonic activity to produce from originally upright folds by limb rotation and attendant reduction in fold angle the largest type of overfold zone such as that at Higher Longbeak.

There is the same evidence for repeated deformation at Meldon and Okehampton; in Knowle quarry and the brickworks upright folds in Upper Carboniferous sandstones and shales have been refolded into box-folds, although it cannot be demonstrated unequivocally that overfolds with bent limbs have arisen in the same way (Dearman 1964; Freshney and others 1966: 47; Dearman 1967: 285). The three successive synclines forming the ‘Gullet

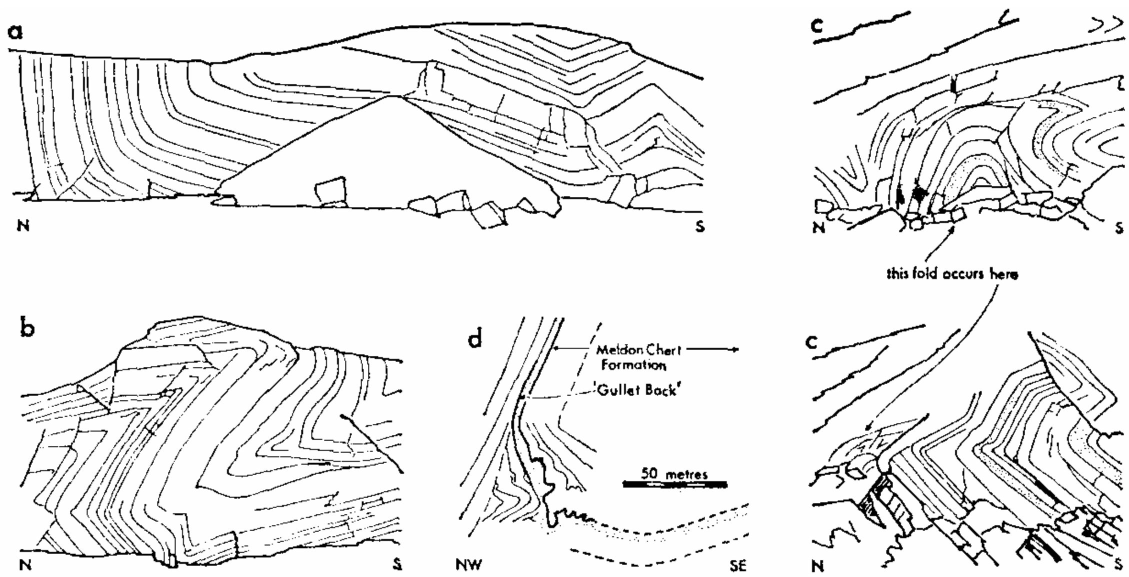

FIGURE 2. Deformed upright folds (a) Maer High Cliff, Bude, the face is 38 m. high; (b) Efford Cliff, Bude, the face is 60 m. high; (c) Phillips's Point, Widemouth, the folds in the lower illustration are about 15 m high; (d) 860 and 950 South Bays, Meldon Railway quarry. The 'Gullet Back' fold and associated minor folds.

Back' syncline (Fig. 2) in the railway quarry at Meldon (Dearman 1959, figs. 4 and l0a) are similar to the Efford Cliff fold south of Bude, and also are closely associated with recumbent folds (Dearman 1959, fig. 13f). The syncline in the north bay of the quarry changes attitude upwards from inclined to recumbent (Dearman 1964, fig. 4a) while there is the hardly acceptable evidence that isoclinally folded Slates-with-lenticles have themselves been overfolded in a central anticlinal core (Dearman 1959, fig. 9 and p.80; 1964, fig. 4b).

Now that it is admitted that the Meldon overfolds lie on the crestal region of a major overfold and were not lifted up by the granite from a recumbent position, the Meldon and Higher Longbeak structures are seen to be remarkably similar in size and style, and in the tectonic evolution of at least some of their associated minor structures. The one would serve as the pattern for the other, although the two major folds are in no way continuous structures (Fig. 1). Their differences lie in the present interpretation of contiguous structures immediately to the south. The structure

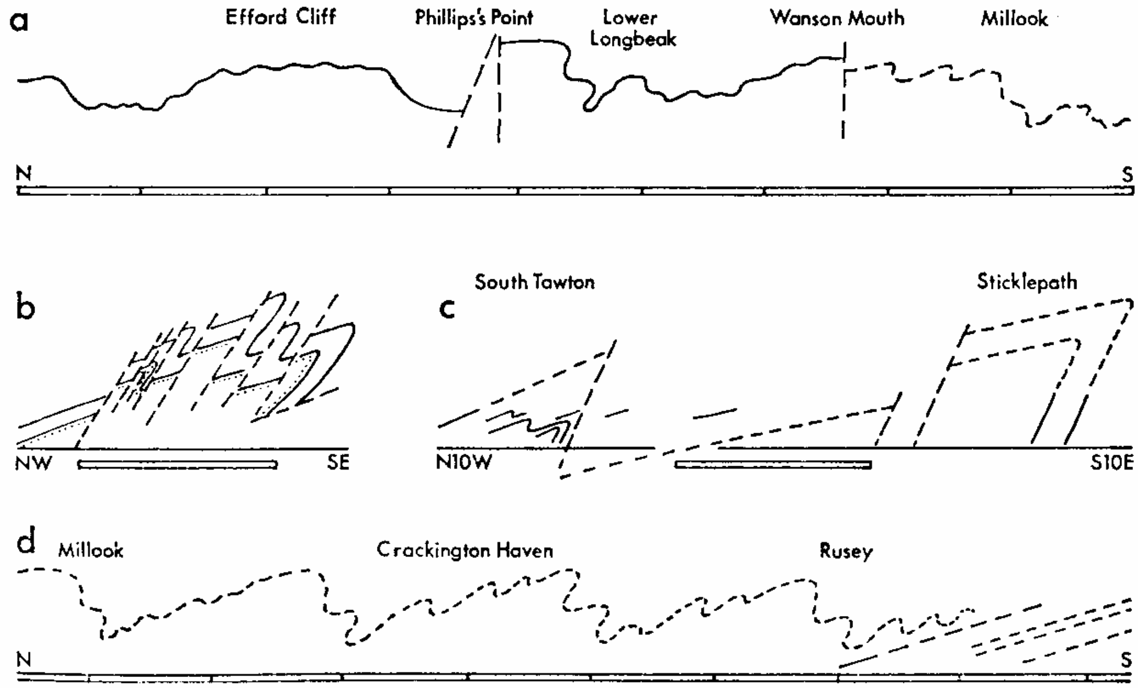

FIGURE 3. Sketch sections illustrating major structures (a) in Upper Carboniferous rocks from Bude to Wanson Mouth (after King, 1966, fig. 1) with sketched continuation to Millook; (b) in Lower Carboniferous rocks of the Meldon inlier; (c) in Lower Carboniferous rocks of the South Tawton and Sticklepath inliers; (d) possible interpretation of structures from Millook to Rusey.

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south of Higher Longbeak as far as Millook, a distance of 3.5 km, is a repetition of the major structure to the north, although there are changes in stratigraphic level.

On the 'Tectonic Map of Great Britain' (Dunning 1966), the Meldon anticlinal overfold is continued tentatively into the Boscastle area where an anticline is needed to insert the remnants of the Lower Carboniferous succession into the Boscastle Measures which are in normal succession to underlying Lower Carboniferous and Upper Devonian slates. Such an anticlinal axis can be accepted if its position near Launceston is moved somewhat to the north. The coastal section between Rusey and Wanson Mouth is thus correlatable on structural position with the Upper Carboniferous region north of Meldon. The latter has already been favourably compared to the Bude structures in style, whereas the former is considered to have the same structural pattern as the area south of Bridestowe along the margin of Dartmoor. Reconciliation of these conflicting ideas depends upon the correct interpretation of recumbent folds, that is whether they are primary or secondary structures.

For 7 km from Millook to Rusey, recumbent southwards facing minor folds are interpreted as remnants of the sliced up and flattened out southern inverted limb of a major overfold of which the original crestal region has been left at the Millook end of the section (Freshney 1965, fig. 2). An alternative interpretation would invoke generation of the apparently preponderant recumbent asymmetrical folds, with long inverted limbs, by a second phase co-axial deformation of upright folds similar to but perhaps more vigorous than that in the north. At the most, three additional major anticlinal units would continue the established structural pattern to just north of Boscastle where Lower Carboniferous slates, limestones and cherts emerge from beneath the Upper Carboniferous greywacke sequence.

In a similar manner, and for the same distance, recumbent folds have been observed or inferred from Bridestowe to Marytavy in the Dartmoor section. It is now becoming apparent, however, that recumbent folds such as those exposed in Coryton slate quarry and Kersford quarry are second phase folds. Detailed evidence, being prepared for publication, involves recognition of a slate fabric deformed by the present recumbent folds. It would seem appropriate to revert to the earlier interpretation (Reid and others 1911,

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1912) of the chert ridges as broad synclinal remnants separated by anticlinal ridges bringing to outcrop older Slates-with-Lenticles that are in part of proven Upper Devonian age. As has been mentioned above, the dimensions of these anticlines and synclines are comparable to those inferred for the major folds on the Bude coastal section. The recumbent folds would then represent second phase modifications of minor corrugations on the main synclines.

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Superposed cleavages in the Middle Devonian slates at Booby's Bay, Padstow, North Cornwall (Abstract) : by W. R. Dearman.

The Padstow area of north Cornwall is of particular interest in the interpretation of the regional tectonic structure of Cornwall since it is there that a northern belt of southerly facing folds confronts northerly facing folds that are generally held to characterize the remainder of Cornwall to the south. Folds in Booby's Bay are relatively open structures with an axial plane cleavage that has been accepted as slaty cleavage S_1 in first phase F_1 folds. Field and laboratory observations have shown that this cleavage, along which the rocks split with ease, cuts an earlier "slaty cleavage" at an acute angle. The relationships suggest co-axial deformation of early structures by the visible folds which must now be regarded as second phase F_2 structures with an axial plane ‘shear cleavage’ S_2. If this is accepted, then the facing evidence is invalidated and a search should be made for the refolded earlier F_1 folds.

UNROOFING OF THE DARTMOOR GRANITE AND POSSIBLE CONSEQUENCES WITH REGARD TO MINERALIZATION

by J. Dangerfield and J. R. Hawkes

Abstract. Evidence is presented to demonstrate that the Dartmoor Granite was unroofed before the end of the Permian. This fact allows certain deductions to be made concerning the possible level (with regard to rocks now exposed in S.W. England) of a late-Permian erosion surface. From available geological knowledge and recent isotope age data, it is argued that the proposed surface may have exercised a critical control over the lode-cassiterite mineralization. A further inference is that S.W. England subsequently became a region of thermal springs, with activity in various forms continuing intermittently into the Pleistocene.

The Dartmoor Granite was intruded in Upper Carboniferous times under an unknown thickness of folded Devonian and Carboniferous sediment. Isotope data indicate an age for the granite of approximately 295 m.y. (Fitch and Miller 1964, Miller and Mohr 1964), suggesting that in more precise terms emplacement may have occurred during the Stephanian. Several workers have examined nearby Permo-Triassic formations for evidence relating to the unroofing of the pluton. In reviewing the early work, Groves (1931) noted that although various granitic pebbles had been recovered from the Permo-Trias, none are of plutonic aspect. Thus while accepting that marginal apophyses and extrusive facies of the granite may have been exposed at this time, he concluded that erosion of the main plutonic mass had not yet begun. The results of his mineralogical study of southern England sediments indicated that Cretaceous (Wealden) beds are the oldest containing unequivocable evidence of detritus derived from the Dartmoor Granite. It is worth noting here that Ormerod (1875) considered the granite to be the source of the "murchisonite" (K-feldspar) fragments found in red beds around the Exe Estuary.

Scrivenor (1948) subsequently found a boulder of porphyritic granite on Labrador Beach (approx. SX 935708), but offered no comment as to its origin other than that it was indistinguishable from the porphyritic granites of S.W. England. He also recorded the presence of granite-porphyry pebbles in this area. Neither Hutchins (1963) working on the Permian of the Crediton trough, nor Laming (1966) in his re-examination of the S. Devon Permian sections, found definite evidence of material derived from the Dartmoor Granite. However, both remarked on the appearance of metamorphic aureole rock types in the higher beds of their respective successions.

This paper was prompted by the realisation that several of the granitic microgranitic pebbles found in exposures of the red sandy St. Cyres Beds in a road cutting on A 377, 400 m E.S.E, of Newton St. Cyres Church (SX 883979), match exactly granitized argillaceous xenoliths exposed within the Dartmoor Granite. The St. Cyres Beds are characterized by abundant, slightly worn, macroscopic crystals and cleavage fragments of K-feldspar ("murchisonite") which Hutchins (1963) considered to be sanidine of volcanic origin. Rock fragments recorded by Hutchins include lamprophyric, basaltic and rhyolitic volcanics, Culm sediments, quartz and quartz-tourmaline vein rocks, and granitic/microgranitic material.

The pebbles in question may be similar to Hutchins' microgranites or to Scrivenor's granite-porphyries. A brief description of one (E 37274) follows. It consists of partially or wholly K-feldspathized plagioclase megacrysts and rounded megacrysts of quartz, set in a fine-grained groundmass of quartz, K-feldspar, biotite and

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partly kaolinized plagioclase, with accessory tourmaline and zircon. In hand specimen appearance, texture (especially the grain-size of the groundmass) and modal composition (particularly the high biotite content), the rock affords close comparison with specimens of granitized, argillaceous xenoliths from numerous localities in the Dartmoor Granite, for example, E 30889 from Linscott Farm (SX 741879) and E 33069 from Metherall Quarry (SX 670837). A similar xenolithic fragment (E 1440) from near Kennford (approx. SX 916866), matches both the Newton St. Cyres pebble and the material from Linscott and Metherall.

Additional evidence of unroofing is provided by an aplogranitic fragment (E 1438) from the Crediton area. In general appearance, texture (especially the grain-size) and modal composition (notably the paucity of biotite) this specimen resembles aplogranitic rock commonly found in outcrops of the Dartmoor Granite, for example E 33078 from Haytor (SX 758771), E 33164 from Gidleigh Tor (SX 672877) and E 32368 from Cranbrook Castle (SX 737893).

For comparative purposes, the modal compositions and groundmass grain-sizes of each of the specimens referred to above are shown in Table 1.

TABLE 1. Modal compositions and groundmass grain sizes of specimens referred to in the text

	Granitized argillaceous xenolith material			
	Pebbles		**Outcrop**	
Specimen no.	E 37274	E 1440	E 33069	E 30889
Modal analysis				
No. of points counted	2042	1045	1061	1014
Feldspar	60.1	54.6	64.2	60.5
Quartz	27.2	28.5	25.1	27.6
Biotite	12.4	16.7	9.7	11.7
Other minerals	0.3	0.2	1.0	0.2
Average groundmass grain size	0.06mm	0.07mm	0.15mm	0.10mm
	Aplogranitic rocks			
	Pebble	**Outcrop**		
Specimen no.	E 1438	E 32368	E 33164	E 33078
Modal analysis				
No. of points counted	1000	1033	2126	2125
Feldspar	58.3	64.8	59.9	56.6
Quartz	35.2	34.2	37.3	39.2
Biotite	1.2	1.0	2.8	0.9
Muscovite	0.3	0.0	0.0	2.9
Other minerals	4.9	0.2	0.0	0.4
Average groundmass grain size	0.26mm	0.30mm	0.35mm	0.26mm

Numbers prefixed by E refer to specimens in the collections of the Petrological Department, Institute of Geological Sciences

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Where present-day granite tors contain aplogranitic rock (e.g. Great Mis Tor, (SX 563769) or granitized argillaceous material (e.g. Leeden Tor, SX 564719), boulders of these finer grained rock types form a disproportionately high percentage of the surrounding scree. Weathering obviously reduces fallen granite blocks to small fragments and mineral particles much more quickly. Little of the coarse granite debris that enters modern rivers survives intact beyond the margins of the granite mass (Dr. E. Freshney, personal communication). Consequently, as weathering conditions were probably harsher during the Permian, it may be supposed that few granite boulders reached the eventual sites of deposition before disintegrating completely. Assuming this to be the case, then the supposedly volcanic origin of the "murchisonite" fragments in the St. Cyres Beds can be questioned. It seems more likely that they are fragments of K-feldspar megacrysts derived from granite and granitized argillaceous xenoliths originally situated in the roof region of the Dartmoor pluton. Many have groundmass material adhering to their surfaces which matches Dartmoor granitic and xenolithic rock-types. Also, larger crystal fragments (e.g. E 37273) contains marginal streams of quartz, plagioclase and biotite inclusions, a feature commonly seen in the feldspar megacrysts of the Dartmoor Granite. The authors prefer Ormerod's opinion of the source of the "murchisonite" crystals.

The St. Cyres Beds are probably equivalent to the upper parts of the Crediton Conglomerates (Williams, in Edmonds and others 1968) and may therefore represent the youngest Permian strata in the Crediton trough. Hutchins (1963) certainly regarded them as such. Thus, although the exact stratigraphical position of the St. Cyres Beds is unknown, it seems certain from the foregoing evidence that the Dartmoor Granite was exposed, at least locally, before the end of the Permian. Several interesting implications follow from this.

From the distribution of the marginal, big-feldspar facies of the granite, it appears to the authors that erosion has penetrated perhaps no more than 50 to 200 m into the mass since it was unroofed. In other words, the present erosion surface may not be much lower with respect to the rocks than that existing at the close of the Permian. Provided this is also broadly true of the present and late-Permian erosion surfaces in the vicinity of the Cornish

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granites, a significant factor in the mineralization of the region may have been overlooked.

Assuming that erosion of the Armorican mountain chains during the Permian did produce a mature surface only a few hundred metres above that existing today, it follows that the rocks surrounding the upper parts of the S.W. England batholith must by then have experienced a considerable reduction in loading. As a consequence, the regional fracture system imposed by the batholith would have been free to open up.

Few would dispute that the pattern of the elvan (quartz-porphyry) dyke-swarms and metalliferous lodes in S.W. England is related tectonically to the batholith. It is also generally accepted from the nature of lode material that the metalliferous and gangue minerals were deposited by aqueous fluids moving in mainly open channels. Flow structures commonly seen in the elvans similarly point to a free flow of acid igneous fluid (Stone 1968), and carry the additional implication that intrusion was possibly accompanied by extrusive activity. There is therefore some justification for believing that a relatively open fracture system linked to the proposed erosion surface was a prerequisite for both the dyke intrusion and the development of the metalliferous lodes in their observed form.

This opinion clearly conflicts with established views as to the time and nature of these events. The intimately associated elvans and lodes are usually considered to result from late-stage activity connected with the Upper Carboniferous granitic batholith. Likewise, the zonal arrangement of metalliferous minerals in the lodes is regarded as evidence for a batholith-induced thermal gradient. However, as Darnley (1965) has pointed out, $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ isotope ratios obtained from 5.W. England uranium minerals indicate a repetition of uranium mineralization. Evidence for events at about 290 m.y., 225 m.y. and 50-60 m.y. seems fairly definite. Other periods of mineralization may have occurred at about 160 m.y. and 125 m.y. (Pockley 1964, Darnley and others 1960, 1965).

Two uraninite dates of around 290 m.y. suggest some form of mineralization roughly coincident with the instrusion of the granites. Zaghloul's (1958) record of uraninite in the Land's End Granite may be evidence for the occurrence of the mineral in a disseminated rather than a lode form, so the possibility of dispersed Armorican

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"pegmatitic" mineralization cannot be ruled out. Some of the disseminated sulphide mineralization in the northern aureole of the Dartmoor Granite almost certainly dates from this time (Edmonds and others 1968), and it is worth noting that although tin has been detected in the deposit, the element is confined to silicate phases like malayaite, andradite and grossular (El Sharkawi and Dearman 1966). There is no sign of penecontemporaneous lode-cassiterite.

A second set of uranium dates obtained both from uraninite and from pitchblende or pitchblende-coffinite lode samples group around 225 m.y. It may be that this uranium mineralization was emplaced, and situated where it is, under the control of the proposed late-Permian erosion surface. Equally significant are preliminary Rb/Sr isotope data on elvan material which indicate a maximum age of Middle Permian for the dykes, but suggest a more likely one close to the Permian-Triassic time-boundary (Dr. R. R. Harding, personal communication). There is a little geological evidence to support the latter age.

As demonstrated earlier, the Dartmoor Granite was unroofed by the late Permian. Consequently, if the elvan dykes of the area were intruded before this happened, pebbles and fragments might be expected along with the granite and country rock detritus found in the higher Permian breccias. Quartz-porphyry and rhyolitic pebbles are in fact common in breccias above the Cadbury Beds (Hutchins 1963) and Teignhead Group (Laming 1966). However, of 39 such specimens in the I.G.S. collections none could be matched with elvan-type quartz-porphyries. Most are biotite-rich rocks remarkably like the acid igneous rocks outcropping, for example, at Cawsand Bay and Withnoe, while a few spherulitic rhyolite specimens match extrusive material at present exposed in the Kingsbridge district. Tourmaline-bearing varieties of these two rock types were presumably derived from now-eroded sites within the granite aureole. Although this evidence may prove useful, it remains negative, the more so because elvan dykes are rare in the Dartmoor region.

The remaining S.W. England uranium dates range from 160 m.y. to 50 m.y. All were obtained from pitchblende or pitchblende-coffinite lode samples. Significantly, none of the events appears to be related directly to magmatic activity.

It is too early to fit the foregoing facts and observations conceming the mineralization into an entirely coherent picture. Tentatively, the authors submit the following framework hypothesis.

After denudation of the Armorican mountains during the Permian, there were, perhaps, outbursts of acid volcanism and fumarolic activity on a scale more extensive, but not unlike, that of Mount Katmai and the Valley of Ten Thousand Smokes, Alaska (Fenner 1923). The aqueous fumarolic vapours here contained HCI, HF, H_2S and minor boric acid, and they concentrated in various encrustations and sublimates appreciable amounts of Fe, Pb, Zn, Mo, Cu, As, Sb, Sn, Ag, Mn, Co, Ni, TI, Bi, Se, Te, Ba, several chlorides, fluorides and sulphates, and also silica in the form of opal (Zies 1929). Combinations of these substances are associated with acid volcanic fumarole activity elsewhere (White and Waring 1963). Of particular relevance to the origin of the Cornish tin are the fumarolic cassiterite veins which extend vertically for some 400 ft in rhyolitic volcanics, New Mexico (Fries 1940). Similar cassiterite deposits occur in Nevada (Fries 1942) and in Mexico (Foshag and Fries 1942).

Despite the two Armorican uraninite dates, it is suggested that deposition of cassiterite irn pre-existing channels (page 126) was initiated during this volcanic episode. At the same time, acid fluids connected with the magmatism may have drawn into the fracture system appreciable quantities of copper from country rock greenstones. Subsequently, S.W. England perhaps became a region of thermal springs, with activity in various forms (White 1955) continuing intermittently into the Pleistocene.

This proposition is not as unreasonable as at first seems. Thermal waters could have been responsible for the iron and manganese cementation observed by Hosking (1966) in the Pleistocene raised beach at Godrevy, and in pipe-like bodies in Pliocene beds at St. Agnes. Within the lodes, there is clear evidence of repeated mineralization, brecciation and cementation, involving both gangue and various iron, copper, arsenic and uranium minerals. Again, circulating waters connected with hot spring activity (and faulting) offer an explanation for these events, which, to judge from the scatter of pitchblende and pitchblende-coffinite dates, range from the Middle or Upper Jurassic to the Eocene. Quartz (including chalcedonic forms) and adularia are common gangue minerals : both are particularly characteristic of hot spring deposits. Similarly,

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the isolated occurrences of gold, antimony and mercury (Brammall 1926, Dines 1956, Hosking, oral communication) point in this direction rather than to deep-seated metallogenesis around a buried batholith.

Perhaps the most convincing evidence is provided by the upward-facing, funnel-and trough-shaped patches of kaolin in the Armorican granites (Bristow, in press). At Steamboat Springs, Nevada, circulating hot waters are kaolinizing plagioclase in underlying granodiorite, while the geysers in Yellowstone Park, Wyoming, are reducing feldspars in the dacitic and rhyolitic volcanics through which they erupt to montmorillonitic and kaolinitic clay minerals. Because of the shape, depth and distribution of the kaolin patches in S. W. England, it is tempting to attribute the alteration to an extensive keyser system operating along a network of north-westerly fault lines. As some elvans are affected, the period of kaolinization was probably post-Permian. There seems no reason why it should not have occurred at any time in the Mesozoic, or possibly during the Lower Tertiary when some north-westerly faults are known to have been moving.

If this approach to the lode-metallogenesis in S.W. England is valid, it may be asumed that the heat and some of the water and metalliferous substances for the initial events came from the same source as the elvans. Such a source could have been provided by the re-melting of granite or mobilization of screens of country rock within the Armorican batholith. Connate and meteoric water possibly played a part in mineralization at this stage. However during subsequent periods of thermal activity, the likelihood is that water supply was essentially meteoric, while the circulating fluids possibly leached various metals, silica, alumina, lime and alkalies from neighbouring country rocks during periods of thermal activity. Although appreciable quantities of heat may have been generated by exothermic chemical reactions while activity of this sort was in progress, the origin of the thermal pulses responsible for its inception presents a problem. The apparent frequency of uranium mineralization suggests that heat must have been supplied to this area of the crust from time to time, perhaps as a result of mantle activity connected with the dying phases of the Armorican orogeny and, later, continental drift and Alpine movements. Major faulting, and block movements of country relative to each other in Tertiary times certainly indicate a deep-seated tectonic influence.

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In conclusion it is emphasized that the precise location of minerals is probably due to a variety of causes, not least the positions of a succession of water tables. Thus, in exploration work it is important to realize that mineralization may in effect be hung from an erosion surface (or succession of surfaces) rather than disseminated upwards from a deep-seated source.

The authors wish to record their thanks to colleagues at the institute of Geological Sciences for reading the typescript and making helpful suggestions.

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THE CORDIERITE-CUMMINGTONITE-ANTHOPHYLLITE ROCKS OF LAND'S END

by J. R. Hawkes

Abstract. Although it is generally accepted that the cordierite-cummingtonite-anthophyllite-biotite hornfelses of the Land's End district result from the metasomatic alteration of greenstones, their sporadic occurrence among the hornblende-plagioclase-metabasic rocks of the granite aureole has not been satisfactorily explained. Views on the reasons for their existance are discussed. A new suggestion is that the mechanical behaviour of the granite magma perhaps caused erratic variations in pressure within the aureole. This in turn could have produced sudden, localized movements of hydrous fluid, so disturbing the critical pyroxene→hornblende reactions taking place in the greenstones.

Although it is now generally accepted that the cordierite-cummingtonite-anthophyllite-biotite-hornfelses of the Land's End district result from the metasomatic alteration of greenstones (Tilley and Flett 1930, Lacy 1958, Hawkes 1958, 1961, Floyd 1965), their sporadic occurrence within the pillow lava and doleritic masses of the granite aureole has not been satisfactorily explained. According to Dewey and Flett (1911), the greenstones of S.W. England are essentially spilitic in character : those of the Land's End region are in no way exceptional. Contact metamorphism by the various granite bosses converted the original augite-plagioclase (albite-oligoclase)-ilmenite assemblage to one typically consisting of hornblende, plagioclase (andesine where completely recrystallized), ilmenite/ sphene ± biotite. As the bulk of the Land's End greenstones conformed to this pattern, why the localized metasomatic exceptions?

Tilley and Flett considered that prior shearing was an important factor contributing to the development of the metasomatic rocks at Kenidjack and Botallack. However, cummingtonite and anthophyllite have been found in bodies which in places retain their igneous texture, and there are several instances where sheared greenstones bear the typical hornblende-plagioclase assemblage. Another suggestion made by Lacy (1958) links the genesis of the Kenidjack-Botallack hornfelses with the fact that the district is heavily mineralized. He argued that if fluorine is accepted as an important agent in carrying tin, then its presence in the region could have

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facilitated the required metasomatic reactions. It is now known that cummingtonite, anthophyllite and cordierite were generated at localities not markedly influenced by metalliferous mineralization, so the connexion seems tenuous. In addition, there is the possibility that these hornfelses were formed at depth when the granite was intruded in Upper Carboniferous times; the cassiterite-mineralization following perhaps during the Upper Permian/Lower Triassic after erosion had brought the region to within a few hundred metres of the surface (Dangerfield and Hawkes 1969).

Since neither of these lines of reasoning seems to resolve the problem, it is instructive to examine the sequence of mineralogical changes deduced from thin sections of the rocks. Fibrous sheaves of cummingtonite apparently developed instead, and partly by replacement, of hornblende. Later, anthophyllite started forming as overgrowths on the tips and prismatic faces of cummingtonite crystals, in many instances completely replacing them. The growth of cordierite at the expense of plagioclase began only after the non-calcic amphibole reactions were well established. This point is supported by the fact that while cummingtonite and anthophyllite commonly occur without cordierite, the reverse situation is not observed. As in the hornblende-plagioclase greenstones, biotite developed by replacement of amphibole. Rarely anthophyllite crystals were pseudomorphed by biotite, but more generally granular aggregates of the mica appear in place of both cummingtonite and anthophyllite.

These observed mineralogical steps suggest that the initiation of the metasomatic trend hinged on the disturbance of reactions transforming original pyroxene and uralitic constituents into hornblende. As Tilley's (1935) views implied, this could have been accomplished by the local removal of calcium. Once cummingtonite was being formed the series of ionic movements envisaged by Tilley might have become imperative.

In this context, the ideas of Floyd (1967) concerning the relative movements of hydrated cations in a thermal gradient are relevant. He suggested that in the aqueous environment of the Land's End thermal aureole, relatively small hydrated Ca cations in the greenstones may have been induced to move more readily and for further distances than larger, hydrated Fe and Mg cations. Thus

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he considered that calcium-deficient, cordierite-cummingtonite-anthophyllite-rocks might be generated in areas such as Kenidjack-Botallack close to the contact, while further out an influx of calcium could have led to the development of grossular-, diopside-, and epidote-bearing varieties like those seen in the greenstones at Tater-du (Floyd 1965). In between a balance between the influx and loss of calcium would have permitted the formation of the hornblende-plagioclase assemblage.

Assuming that ionic movements of Ca relative to Fe and Mg were due primarily to a granite-induced thermal gradient, a more widespread, zonal arrangement of the respective homfelses should be evident. This is not so and although it could be argued that the sporadic occurrence of the cordierite-cummingtonite-anthophyllite-rocks represents an early stage in the development of a thermal zonation, there is evidence of a sideways movement of calcium. At Botallack, for example, Tilley (1935: 184) noted that the plagioclase in a hornblende-bearing hornfels adjacent to calcium-deficient material is labradorite-bytownite. In similar greenstones elsewhere in the aureole the plagioclase is andesine. A particularly striking case occurs at Great Cliff, Tater-du where Floyd (1965: 233) observed lateral transitions between calcium-deficient hornfelses and grossular-diopside-bearing varieties. Because of the actual distribution of the metasomatic rocks, it seems that the movement of calcium was effected by a more localized control.

There is general agreement that heat, hydrous fluids and substances like potassium and fluorine were being transferred to the surrounding rocks during the intrusive phase, and that this presumably occurred under the influence of regional temperature and pressure gradients. However, no attention has so far been paid to the mechanical behaviour of the granite magma. The magma itself must have exerted some pressure on the country rocks while intrusion was taking place. Conceivably, relief occurred locally when large blocks became detached from the wall and roof regions, or when the magma was able to create or exploit structural weaknesses in the host formations. Although pressure fluctuations due to such causes may have been small, they could have initiated sudden and erratic movements of hydrous fluid within the aureole. In these circumstances, reactions converting the greenstone pyroxene to hornblende might have been disturbed. With any sustained flow of

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hydrous fluid, a relative separation of hydrated Ca and Fe/Mg cations would have been a distinct possibility. Maybe the development of hornblende was locally stifled by a loss of calcium effected in this way.

The widespread occurrence of biotite in the greenstones was dependent on the acquisition of potassium from the granite (Tilley 1935). Its observed patchy distribution may to some extent reflect similar, localized and erratic, pressure-controlled movements of hydrous fluid in the aureole.

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THE GEOCHEMISTRY OF THE CLIGGA HEAD GRANITE

by A. Hall

Abstract. Chemical analyses are given of granites, greisenised granites and greisens from Cligga Head, Cornwall. The unaltered granite, which is tourmaline-bearing, is notably rich is boron and fluorine. Greisenisation is marked by a decrease in the sodium content, and by increases in calcium, iron, boron, fluorine, lithium, manganese, rubidium, tin and zinc.

The Cligga Head granite is one of the smaller granitic intrusions of south-west England. It is situated about 3 km south-west of Perranporth, Cornwall, and is exposed in steep cliff sections extending for about 600 m southwards from Cligga Head. The granite has attracted attention for a long time because of the excellent examples of greisenisation displayed in the central part of the outcrop (Scrivenor 1903). In this area, the granite is traversed by numerous east-west greisen-bordered veins, many of which are mineralised and have in the past been worked for tin and tungsten from a mine situated on the top of Cligga Head (Dines 1956). In the area penetrated by the veins, the granite shows many indications of incipient greisenisation, but to the north and south of this area passes into unaltered granite, free of veins and not greisenised.

Specimens of the granite were collected in order to study the geochemical and mineralogical changes brought about by the greisenisation. Some representative analyses of rocks in different stages of greisenisation are shown in Table 1. The two unaltered granites (nos. 1 and 2) are from cliff exposures at the extreme northern and southern ends of the outcrop respectively, and the greisenised granites and greisens (nos. 3-6) are from Cligga Head mine.

Several interesting problems of chemical analysis are presented by rocks of this composition. Most constituents were determined by X-ray fluorescence, but the high mica contents of the greisens caused difficulty in the very fine grinding necessary in X-ray sample preparation. Major elements in the greisens were therefore determined by a combination of gravimetric and atomic absorption spectrophotometric methods. Sodium and lithium were determined in all the rocks by flame photometry. A new rapid method developed for the determination of fluorine was found to give very satisfactory results. This consists of fusion with sodium carbonate, followed by a simple chemical separation and colorimetric determination of fluorine by the alizarin fluorine blue method (Hall and Walsh 1969). Boron, which is also abundant in these rocks, was determined by the curcurmin method (Grinstead and Snider 1967) after an ion-exchange separation; subsequent experiments have shown that this separation may be eliminated by determining boron on the solution used for the colorimetric fluorine measurements.

TABLE 1. Chemical ananlysis of the Cligga Head granite and its greisens

		1	2	3	4	5	6
SiO_2	...	72.80	72.66	73.15	71.61	71.70	70.19
TiO_2	...	0.11	0.15	0.09	0.10	0.09	0.09
B_2O_3	...	0.29	0.25	0.63	0.29	0.36	0.67
Al_2O_3	...	14.79	14.90	14.18	14.78	13.81	14.15
Fe_2O_3	...	0.45	0.23	0.29	0.44	0.89	1.17
FeO	...	0.93	0.95	1.36	1.28	2.80	3.36
MnO	...	0.03	0.03	0.07	0.08	0.18	0.23
MgO	...	0.27	0.38	0.23	0.36	0.30	0.32
CaO	...	0.57	0.26	1.00	0.72	1.17	1.40
Na_2O	...	3.31	3.11	2.61	2.06	0.42	0.38
K_2O	...	4.66	5.40	5.53	5.41	4.71	4.39
Li_2O	...	0.09	0.12	0.07	0.16	0.30	0.24
P_2O_5	...	0.18	0.13	0.13	0.16	0.18	0.22
H_2O+	...	1.14	1.11	0.80	0.99	1.63	1.51
F	...	0.27	0.48	0.38	1.07	1.47	1.51
	...	99.89	100.16	100.52	99.51	100.01	99.83
O≡F	...	0.11	0.20	0.16	0.45	0.62	0.64
Total	...	99.78	99.96	100.36	99.06	99.39	99.19
		Trace elements (parts per million)					
Ba	...	80	220	150	140	130	80
Ce	...	100	90	140	90	110	100
Ga	...	40	40	30	35	35	45
Li	...	410	560	340	720	1400	1110
Mn	...	220	240	550	580	1400	1800
Rb	...	615	775	800	885	1155	1010
Sn	...	30	50	180	60	700	270
Sr	...	40	310	65	60	50	50
Zn	...	115	90	125	125	155	445
Zr	...	55	75	70	80	35	60

1-2 Unaltered granites
3-4 Greisenised granites
5-6 Greisens

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The unaltered granite shows many similarities to the other granites of south-west England. The calcium, iron, magnesium and titanium contents are low, and the ratio of potassium to sodium is high. Like the other granites, it contains unusually large amounts of fluorine and boron, the latter in the form of tourmaline, which is the principal ferromagnesian mineral. The boron content of the Cligga Head granite is higher than that of most of the other granites of south-west England, and is nearly a hundred times the average boron content of granitic rocks (*C*. 10 parts per million).

The trace element contents are equally distinctive. The granite is very low in barium and zirconium compared with most granites, but has unusually high concentrations of a number of other elements. In the case of tin, the enrichment might be expected, since the mineralised veins associated with the granite contain cassiterite. Zinc, on the other hand, is also rather abundant, but zinc minerals are of only minor importance in the veins. The high lithium contents are of interest in that they give rise to relatively lithium-rich micas. Analyses by the author show that the relatively scarce brown mica in the granite is a lithian siderophyllite (Li_2O 1.2-1.4%), while the more abundant muscovite is also lithium-bearing. The micas also accommodate the rather high gallium and rubidium contents of the granite.

The chemical changes associated with the formation of the greisens can be seen by comparing analyses 5 and 6 with analyses 1 and 2 in Table 1. Similar changes are detectable, but to a lesser extent, in analyses of the surrounding granites (analyses 3 and 4). The chemical evidence is thus in agreement with petrographic evidence that the whole of the area cut by the veins has been affected by incipient greisenisation.

A comparison between the chemical and mineralogical changes which have taken place is facilitated by recalculating the analyses to atomic percentages, as shown in Table 2. The unaltered granite is a porphyritic muscovite-granite containing small amounts of tourmaline and siderophyllite. The greisen is a quartz-mica rock containing minor tourmaline and accessory fluorite, topaz and chlorite, but no siderophyllite.

The reduction of the feldspars and the increase in muscovite are expressed chemically by the change in the ratio Al: (Na + K) from its value of about 1.4 in the granites to about 2.5 in the greisens, compared with ideal values of 1.0 in alkali feldspars and 3.0 in muscovite. The tourmaline in both granites and greisens has been analysed and in each case is rich in the schorl component (Na : B: Fe = 1: 3: 3). From the relative atomic percentages of boron and iron it will be seen that tourmaline must contain most of the iron in the unaltered granite, although not in the greisen; an appreciable part of the sodium in the greisen must also be held by tourmaline. The relative percentages of calcium and phosphorus show that very little calcium is available to form plagioclase after taking into account the presence of accessory apatite, and this is in accord with petrographic evidence that the plagioclases in the rocks are nearly pure albite. In the greisens, fluorite is the only calcium-bearing mineral, but the F: Ca ratio is much greater than 2: 1, so that a large amount of fluorine must still be accommodated by mica (and topaz).

TABLE 2. Chemical analysis of granites and greisens recalculated to atomic percentages.

		1	2	3	4	5	6
Si	...	24.31	24.27	24.59	24.28	23.99	23.66
Al	...	5.82	5.87	5.62	5.91	5.45	5.62
Ti	...	0.03	0.04	0.02	0.03	0.02	0.02
Fe	...	0.11	0.06	0.07	0.11	0.22	0.30
Mg	...	0.13	0.19	0.12	0.18	0.15	0.16
Mn	...	0.01	0.01	0.02	0.02	0.05	0.07
Fe	...	0.26	0.27	0.38	0.36	0.78	0.95
B	...	0.17	0.14	0.37	0.17	0.21	0.39
Na	...	2.14	2.01	1.70	1.35	0.27	0.25
K	...	1.99	2.30	2.37	2.34	2.01.	1.89
Li	...	0.12	0.16	0.10	0.22	0.40	0.33
Ca	...	0.20	0.09	0.36	0.26	0.42	0.51
P	...	0.05	0.04	0.04	0.05	0.05	0.06
F	...	0.29	0.51	0.40	1.15	1.56	1.61
H	...	2.54	2.47	1.79	2.24	3.64	3.40
O	...	61.82	61.58	62.05	61.34	60.77	60.80

1-2 Unaltered granites
3-4 Greisened granits
5-6 Greisens

Specimen numbers correspond to those in Table 1.

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Several trace elements are strongly enriched in the greisens. The increases in tin and zinc are clearly related to the mineralisation. Crystals of cassiterite and other ore minerals are sporadically distributed in the greisens adjoining the mineralised veins, but are not particularly associated with one another. Thus analysis 5 shows high Sn and low Zn, whereas analysis 6 shows high Zn and low Sn. Enrichment of the other trace elements is largely related to the solubility or stability of the minerals in which they occur. The enrichment in lithium and rubidium is connected with the increase in mica content, while manganese occurs with iron in several minerals, i.e. tourmaline, muscovite and chlorite. The elimination of feldspars in the greisens is obviously responsible for the depletion of strontium, which mainly occurs in feldspars, but barium, which can occur in micas or feldspars, is not so seriously affected.

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THE USSHER SOCIETY

Objects

To promote research into the geology and geomorphology of South West England and the surrounding marine areas ; to hold Annual Conferences at various places in South West England where those engaged in this research can meet both formally to hear original contributions and progress reports and informally to effect personal contacts ; to publish proceedings of such Conferences or any other work which the officers of the Society may deem suitable.

Constitution

Membership. A person shall become a member on written application to the Secretary and payment of the annual subscription.

Subscription. The annual subscription for all members is due on January 1st each year.

Conference Fee. All those who attend a Conference shall pay a fee each Annual Conference and shall elect the Organizing Committee and two auditors for the next Conference.

Annual Business Meeting. A business meeting shall be held during each Annual Conference and shall elect the Organizing Committee and two auditors for the next Conference.

The Organizing Committee shall consist of a Chairman who shall hold office for not more than two consecutive years and shall not be eligible for re-election to the office for a further two years, a Vice-Chairman who shall be the retiring Chairman, a Secretary, a Treasurer, an Editor and five others, any of whom may be eligible for re-election. The Committee shall have powers to co-opt.

Conference Guests. The Organizing Committee shall be empowered to invite a distinguished scientist, not a member of the Society, to attend an Annual Conference and address it on the topic of interest to the Society.

Amendment of this Constitution maybe effected by simple majority vote at the Annual Business Meeting.