PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME TWO
PART ONE

Edited by
E. B. SELWOOD

REDRUTH, SEPTEMBER 1968

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CONFERENCE OF THE USSHER SOCIETY
HELD AT PLYMOUTH, 1968

The proceedings of the seventh Conference of the Society were held, by kind permission of the Director, at the Marine Biological Laboratory, Plymouth on the 3rd and 4th of January. Members of the Society were particularly appreciative of the hospitality shown to them, both by the staff of the Laboratory and by the Lord Mayor of Plymouth who held a reception in their honour. At the meeting, Prof. D. L. Dineley of the University of Bristol gave the Invitation Address.

On Tuesday, 2nd January, Dr. S. C. Matthews led an excursion to examine the Culm sequences around St. Mellion, and the meeting was followed on 5th January by a half-day excursion, led by Dr. C. J. R. Braithwaite, to see the Plymouth Limestones.

CONTRIBUTIONS

CORNUBIA AND THE PALAEOGEOGRAPHY OF A CONTINENTAL MARGIN :

by D. L. Dineley

ABSTRACT

The record of mid- and late-Palaeozoic events in South West England is now relatively well known and the local palaeogeography and history can be related to that of continental western Europe. A somewhat similar sequence of palaeogeographic and tectonic events appears to be indicated in the Appalachian region of the Gulf of St. Lawrence. Both areas show geological structures which are truncated by the present coastlines and which appear to strike directly across the adjacent continental shelf.

Stratigraphic, tectonic and other data support the hypothesis of an initial Palaeozoic unity of these Atlantic regions, and their eventual separation by "continental drift". Interest in suggested mechanisms whereby such movement was accomplished by convection currents has recently been rekindled by geophysical work in the area of the mid-Atlantic ridge. Moverover, movements below the sialic continental masses may explain other Palaeozoic events in the Appalachian and Variscan provinces. A simple pattern of sub-sialic movement related to the opening of the Atlantic ocean basin could be invoked to explain the cause of such crustal movement in the Cornubian section of Palaeozoic Europe.

I. Introduction.

Within the last two or three decades the geology of South West England, Southern Ireland and of much of the Upper Palaeozoic terrain of westernmost Europe has been studied in detail. The relationship of facies in the western British Isles to others in the Hercynian or Variscan geosyncline which forms so large a feature in continental Europe is now more clear. The Cornubian segment of this geosyncline is slowly yielding to investigation but its position at the westernmost end of the Palaeozoic outcrops raises problems. Geological and geophysical work on the continental shelf beyond the Cornubian Atlantic cliffs indicates that under a Mesozoic cover the Cornubian (Variscan) structures may continue to the edge of the shelf. Did the geosyncline and its orogen originally terminate here, or may a westward continuation be found in North America ? This paper offers some discussion of these questions.

Recent work in the Palaeozoic areas around the Gulf of St. Lawrence and the northern Appalachians re-emphasises the palaeontological, stratigraphical, tectonic and other similarities and affinities to western European geology (see, for example, Boucot 1962). Much of this appeals strongly to protagonists of continental drift and a single Laurasian land miss. Bullard and others (1965) and J. T. Wilson (1962) have suggested a lit of continents around the North Atlantic in a pre-drift pattern (see especially Harland, 1965a). It is a remarkably convincing fit, and discussion of the role of con-

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vecting currents in the mantle as a drift mechanism has followed. True, the ideas are not new but they have recently been much in favour with geophysicists. Friend (1967), for example, indicated how geomagnetic evidence may be used to support the idea of oceanic widening about the mid-Atlantic ridge. In this hypothesis the European continental mass is progressively removcd eastward from the ridge while North America may be carried west. Some 350 or more million years ago the two continents were effectively one and have become progressively more different and widely separated in subsequent times. It is the present thesis that the sub-sialic movements away from the "mid-Atlantic area" may also have been responsible for the development and compression of at least the Cornubian section of the Hercynian geosyncline, if not every part of this late Palaeozoic feature as far east as Silesia.

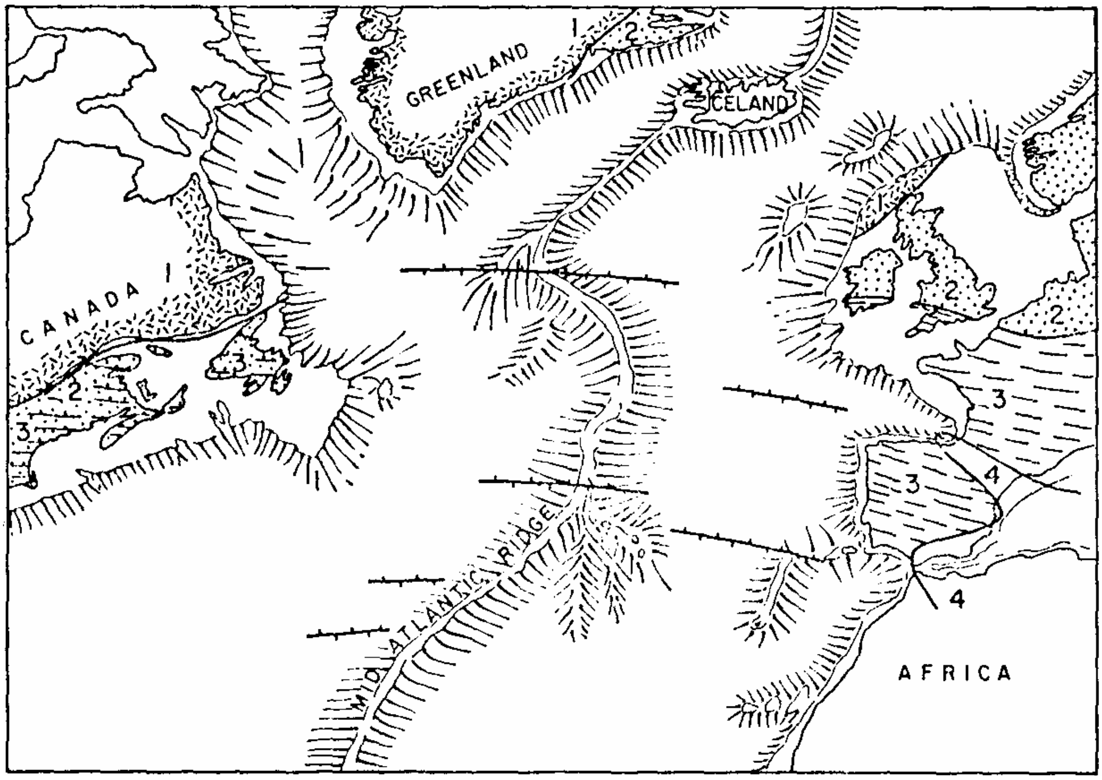

FIGURE 1. North Atlantic area showing roughly the configuration of the Mid-Atlantic Ridge, the continental shelves and some of the major transcurrent fault zones. I, areas of crystalline shield; 2, areas of early Palaeozoic compression ; 3, areas of late Palaeozoic compression ; 4, areas of Mesozoic and later compression.

II. The Record in Northwest Europe.

In its broadest terms the stratigraphic record of middle and late Palaeozoic events in Cornubia consists of largely geosynclinal Devonian and Carboniferous rocks with Permian post-orogenic rudites and red-beds. The record in continental Variscan Europe is much the same. Although Lower Palaeozoic rocks are known in Cornwall, events earlier than Lower Devonian

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are conjectural. The oldest Devonian in South Devon indicates a non-marine red-bed phase giving way to marine deposits. North Devon shows an alteration of marine and deltaic Devonian rocks. The Carboniferous is largely a thick sequence of flysch-like beds, comparable to formations in a similar tectonic setting in Europe.

There is in the British Isles no indication of where lay the southern margin of the geosyncline or its western termination. A strong component of pressure or movement from the south or southwest is indicated in the several distinct phases of diastrophism that crushed the trough. If the Laurentian continent were joined to Europe along its present continental margin at that

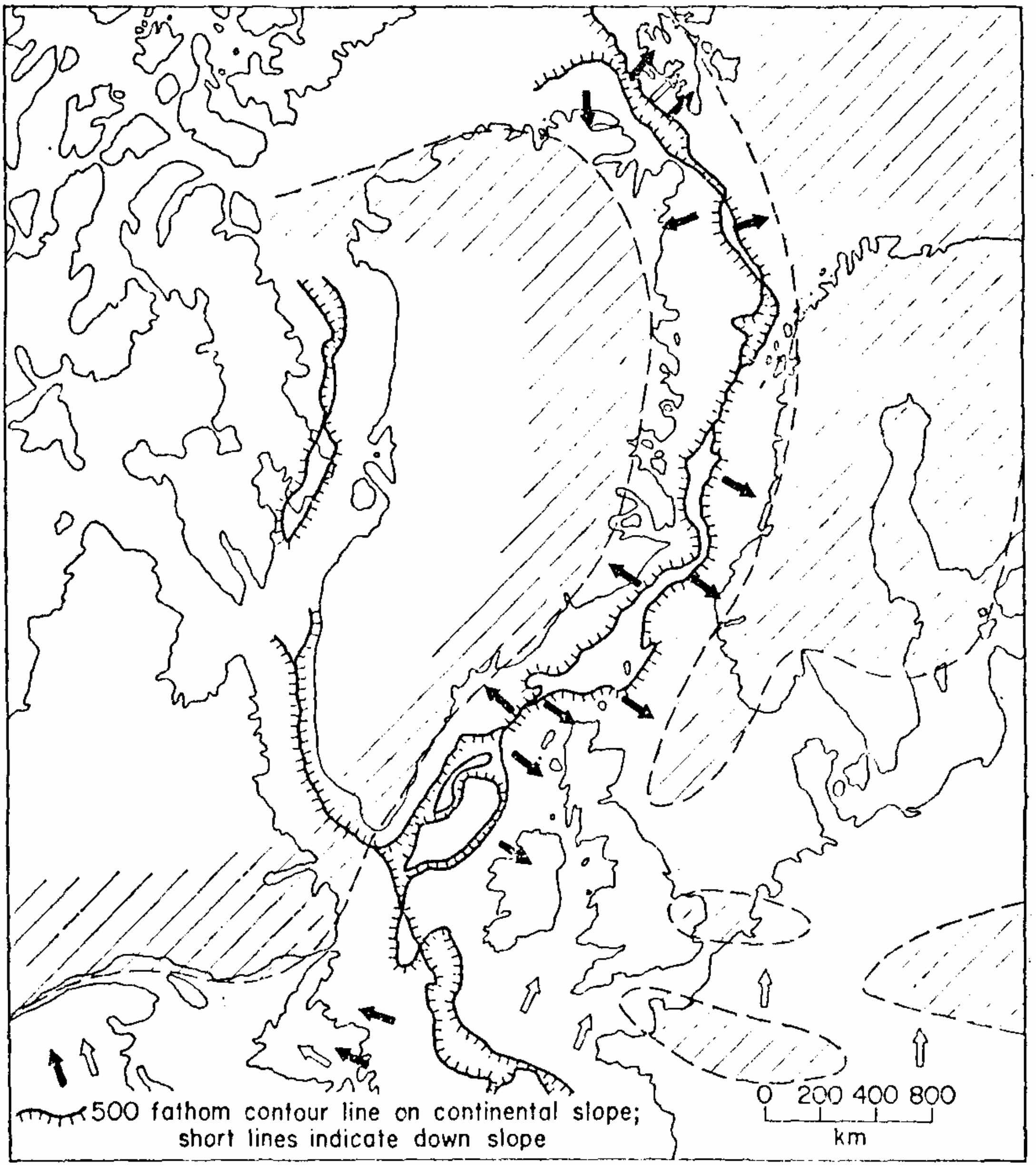

FIGURE 2. The "best fit" regrouping of continental masses (after Bullard et al. 1965). Black arrows, directions of early Paleozoic compression ; white arrows, directions of late Paleozoic compression. Shaded areas, persistent uplands throughout the late Palaeozoic.

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time, the picture becomes a little clearer, and a new possibility for the origin of the Cornubian features may be offered if the continents began then to separate as suggested by Friend (1967).

III. The Record in Eastern North America.

Much has within the last 25 years been added to our knowledge of the geology of the country around the Gulf of St. Lawrence and the northern Appalachians. The formations range from Precambrian to Permian ; many may be correlated with European equivalents and the recent Symposium on Continental Drift at Gander, Newfoundland (1967) showed how well the evidence speaks for continental drift. Marine and non-marine Devonian rocks, including volcanics, are well known. The marine formations show several facies, metamorphism and structures akin to those of the Variscan of Europe, and which were in part produced by the various earth-movements known as the Acadian.

The Carboniferous formations of this region reveal an apparent confusion of facies ; again marine and non-marine types are present. The floral affinities of some of these to European units has been indicated by Bell (1944).

The Appalachian earth-movements virtually terminated the structural evolution of the region in Permian times and Permian red clastics overlie the earlier rocks. The structures may have formed in response to movements

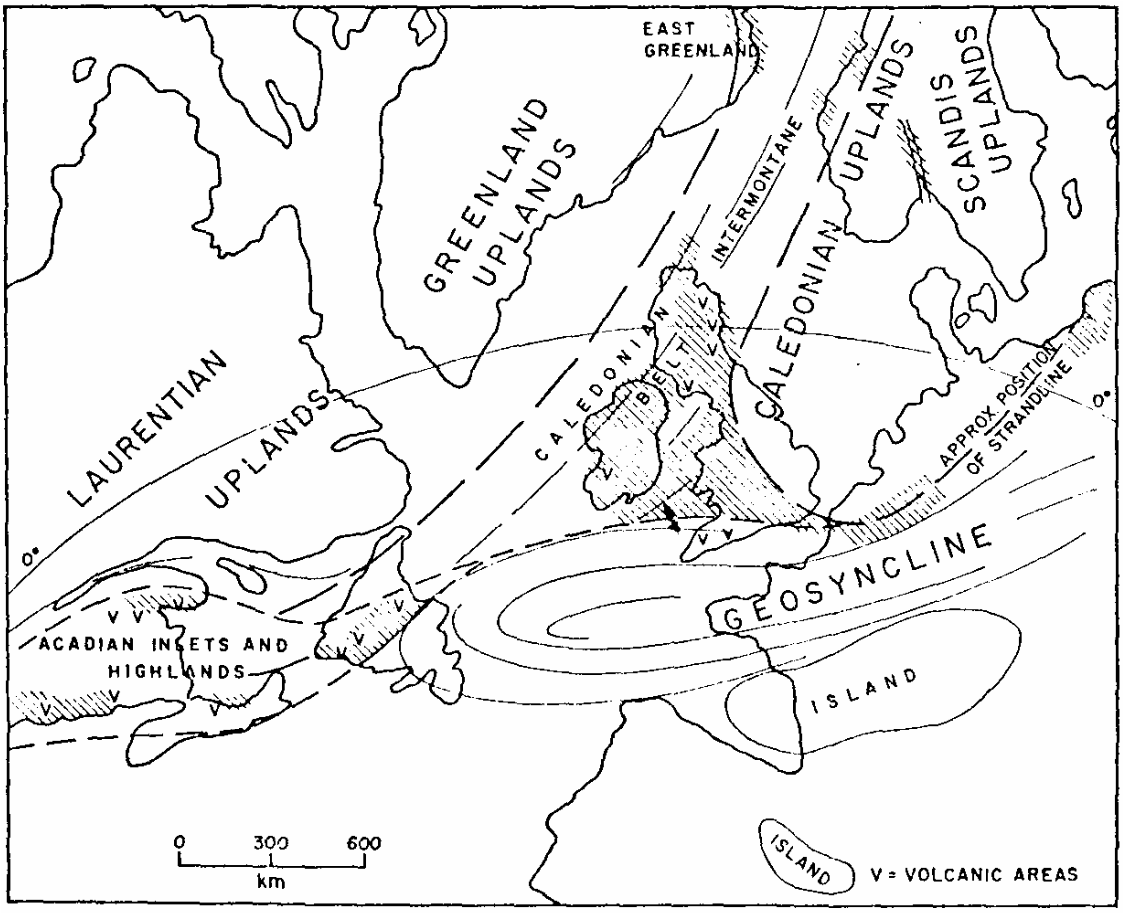

FIGURE 3. Tentative Devonian palaeogeography and position of equator. Areas of dominantly clastic non-marine sedimentation shown shaded.

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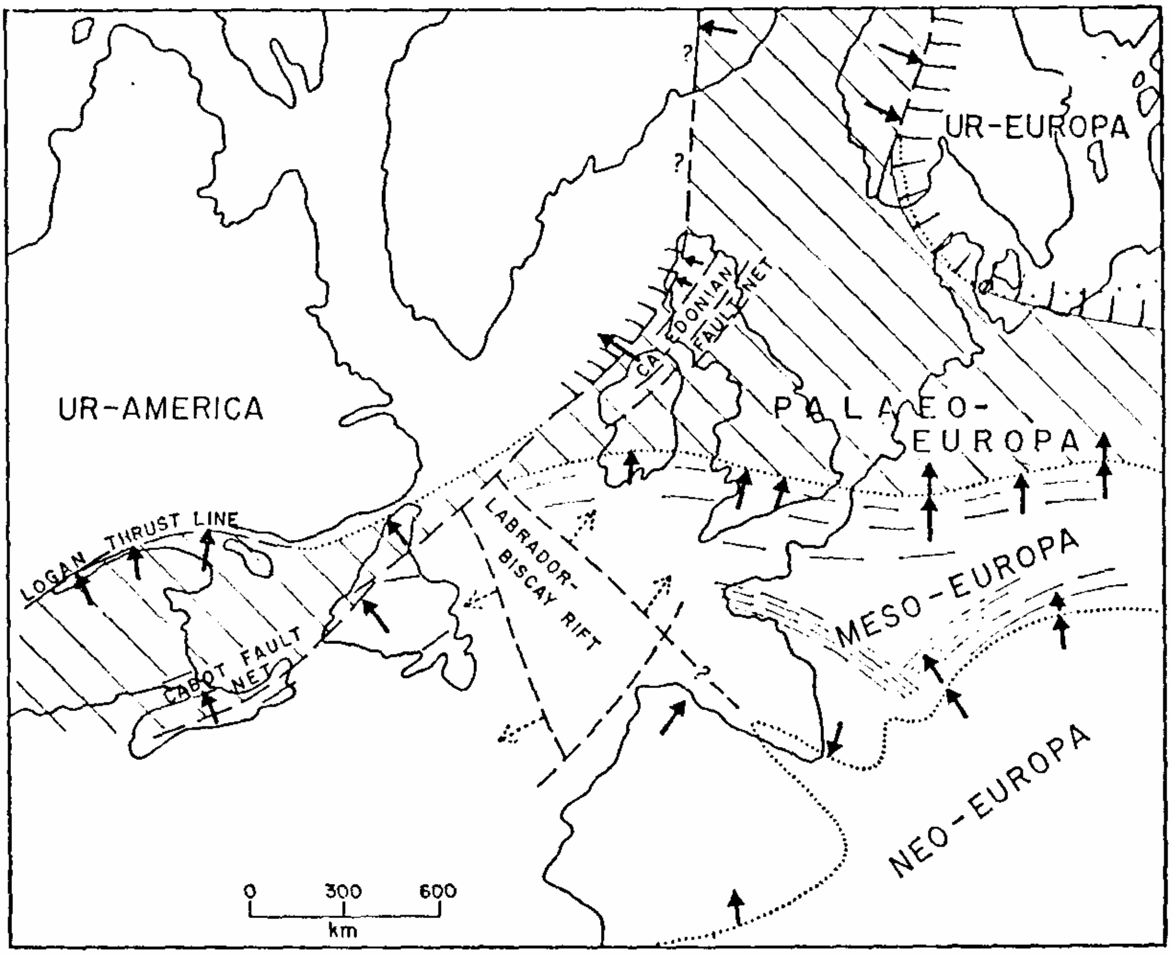

FIGURE 4. Major tectonic units around the North Atlantic with postulated Labrador-Biscay Rift (Webb 1968).

originating in the east or south-east. We have little evidence from the local continental shelf of what lay in those directions but the presence of a sub-static westerly flow might have been the cause for these disturbances.

IV. The Pre-Drift Picture.

A number of stratigraphical, palaeontological and tectonic features link not only the west of Europe with eastern North America but also northwest Europe and Greenland. In the "best fit" of continental shelves (Bullard et al. fig. 8, 1965) it is tempting to align, if not connect, many major tectonic units on opposing sides of the "split". Palaeogeographic features reconstructed on such a basis are in keeping with the kind of distribution of floras and migration of faunas throughout the region, amongst which are the nonmarine agnath fishes of Britain and Nova Scotia (Dineley 1967), and the Carboniferous terrestrial plants (Bell 1944, et seq.).

Higher in the stratigraphic column the geological similarities between trans-Atlantic areas diminish. Nevertheless, throughout the late Palaeozoic there persists a similarity not only in the type of tectonic activity but also in the sequence of these events (Harland 1965). The regions appear to have responded to a common source of tectonic activity ; the differences in direction of tectonic movement on opposite sides of the ocean point to a divergence from a mid-Atlantic locus.

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Palaeomagnetic and other evidence suggests that in the Devonian period Europe and Maritime Canada lay somewhere near the present equator, certainly within the tropics. On separating they have also moved away from the equatorial regions, possibly at rather different rates and with some rotational movement.

In the general palaeogeography for the Devonian of western Europe the major features are :

(i) the continental cuvettes, basins or embayments (Anglo-Welsh, Orcadian, etc.).
(ii) the tectonic uplands (C. Scotland, N. Ireland, etc.).
(iii) the Variscan Geosyncline.
(iv) the tectonic uplands of central France and southern Europe.
(v) the Tethyan basin.

Thus the geosyncline is bordered to the north by the Scandis craton and its attached tectonic belts, and to the south by the mobile uplands of Europe.

From the point of view of Cornubian geologists the important question is what became of the geosyncline to the west. There is no direct evidence to give in answer, but the trough probably merged with the shallow water mobile belt upon which was deposited the Upper Palaeozoic succession of Newfoundland and Nova Scotia. Palaeon tological and sedimentological similarlities between parts of the Cornubian and eastern Canadian successions are strong enough, in the author's view, to suggest such a relationship.

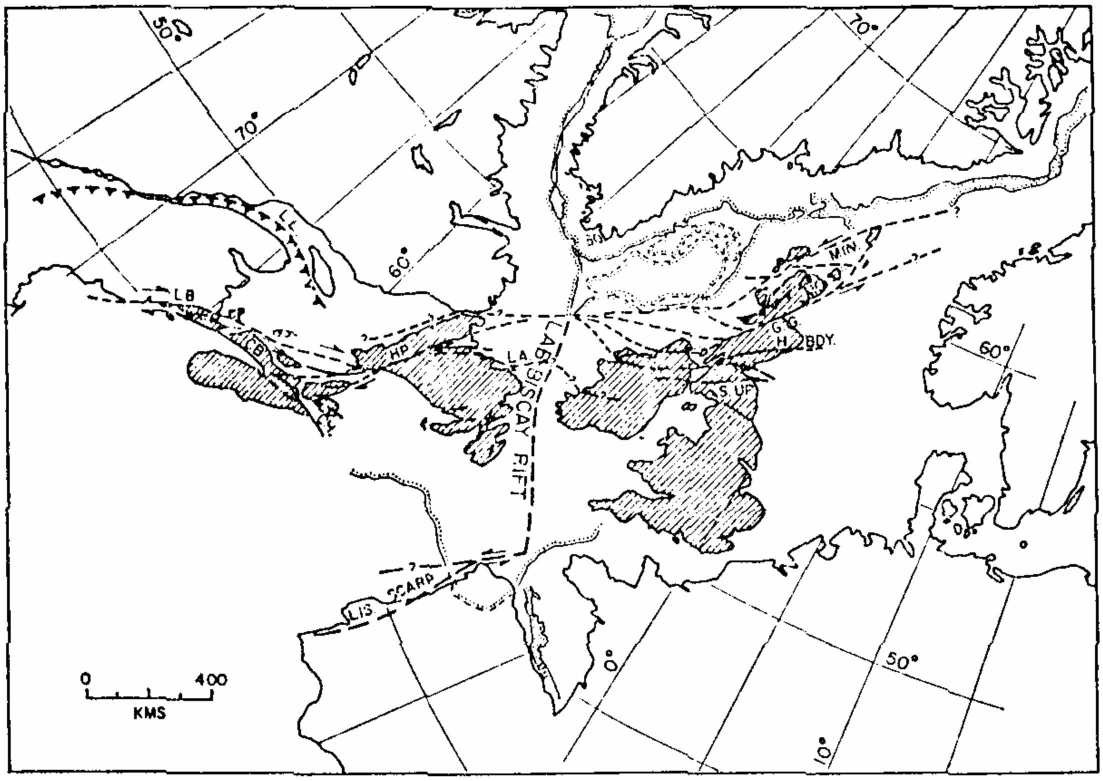

FIGURE 5. Pre-drift palinspastic map with compensations for wrench-faulting with Labrador-Biscay Rift closed as suggested by Webb (1968). Shaded area to emphasise shapes of fault blocks, etc. CB., Cobequid ; CH., Chedabucto ; LA., Luke's Arm ; LB., Lubec ; LAB., Labrador ; LIS., Lison ; MIN., Minch ; MO., Moine ; GG., Great Glen ; H.BDY., Highland Bounday ; HP., Hampden ; S.UP., Southern Uplands.

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V. The Means of Drifting and Source of Tectonic Activity.

Ever since continental drift was proposed, a mechanism causing movement of major portions of the earth's surface has been a matter for argument. [See, for example, Runcorn (1962), Wilson (1963, 1966) and Dietz (1966)]. Friend (1967) shows how the symmetry of geophysical anomalies about the mid-oceanic ridge near and on Iceland may indicate a spreading of the oceanic floor by upwelling simatic currents and dispersal to cast and west at the surface. The most acceptable model is a convecting simatic cell with a flow rising at the ridge and moving laterally from it on each side at the surface. The flow has parted the sialic continental slabs and the basaltic ocean basin has progressively widened. Although the idea is not new, Friend's use of magnetic data renews interest in it.

The points that press for consideration now are :

(a) What determined the site of the original upwelling and hence the rift between Europe and Laurentia ?
(b) What effects were impressed upon surface geology when the drifting began ?
(c) Can subsequent events at or near the continental margins be related to this movement ?

Other questions (about post-Palaeozoic events) must be omitted here.

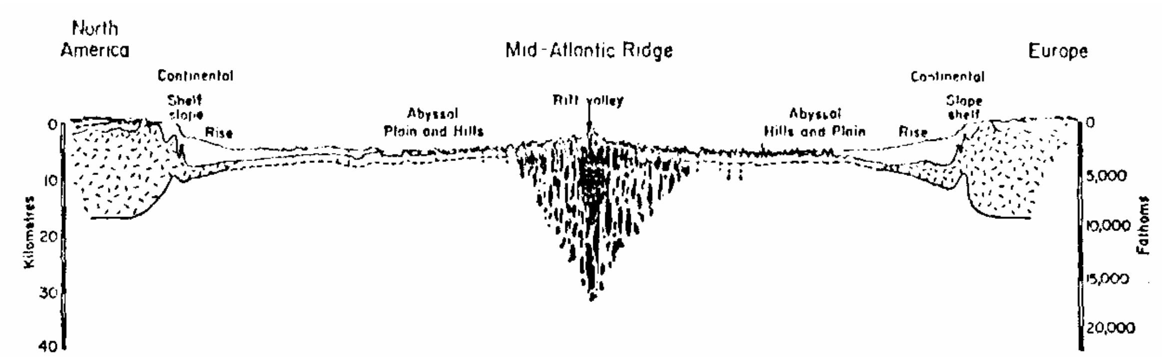

FIGURE 6. Crustal section across the North Atlantic (after Heezen in Runcorn 1962). The shaded area represents material below the Mid-Atlantic Ridge with may be altered upper mantle, Layers beneath the ocean represent sediments, ? volcanics and oceanic crust.

There is in the Royal Society's Symposium (Bullard et al. 1965) sonic discussion of the first question and Harland (ibid) drew attention there to the scale and distribution of pre-Devonian events to account for the present separation. The Atlantic part of the world oceanic ridge system seems to be a site of upwelling throughout its 7,000 mile length. Possibly the sialic shields around the northern section of the Atlantic ridge may have been placed there by earlier convectional movements in other parts of the system. It is difficult to postulate what determined the position, origin and vigour of the North Atlantic ridge but the activity which has produced it must have become significant by mid-Palaeozoic time.

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Movement, once begun, could have had a profound effect upon the overlying sialic slabs. Adjacent to their edges these slabs may have warped, crumpled and "shortened" in response to the movement beneath them. Heat, both frictional and radioactive, would increase the tendency of the sial to deform, and the translation of movement from sima to sial with its overlying sedimentary cover would tend to be unidirectional throughout a long period. It is, however, difficult to say exactly what the form of the sialic continental mass was. The effects of the Caledonian orogeny and the attendant variation in sialic thickness from place to place may have influenced response to the underlying sima currents. In the Variscan geosyncline, and especially in its Cornubian section, the movements were all from the south or south-west (see Bott and Scott 1964). The initiation of the geosyncline here, the initial northward transgression of its margin and the suspected northern migration of shoals or schwellen within it, and its ultimate boundaries may reflect a response to a simple underlying pattern of stress or drag below the sial. Thus the simultaneous separation of the "Old Red Sandstone continent" into several provinces (Allen, Dineley and Friend 1968) and the early evolution of the Variscan geosyncline may be different surface effects on the same underlying process. Harland (1965b), discussing crustal compression in relation to convection currents in the Symposium on Continental Drift held by the Royal Society, pointed out that Wegener's concept of continents as floating sialic rafts produced confusions now largely resolved. Tectogenesis

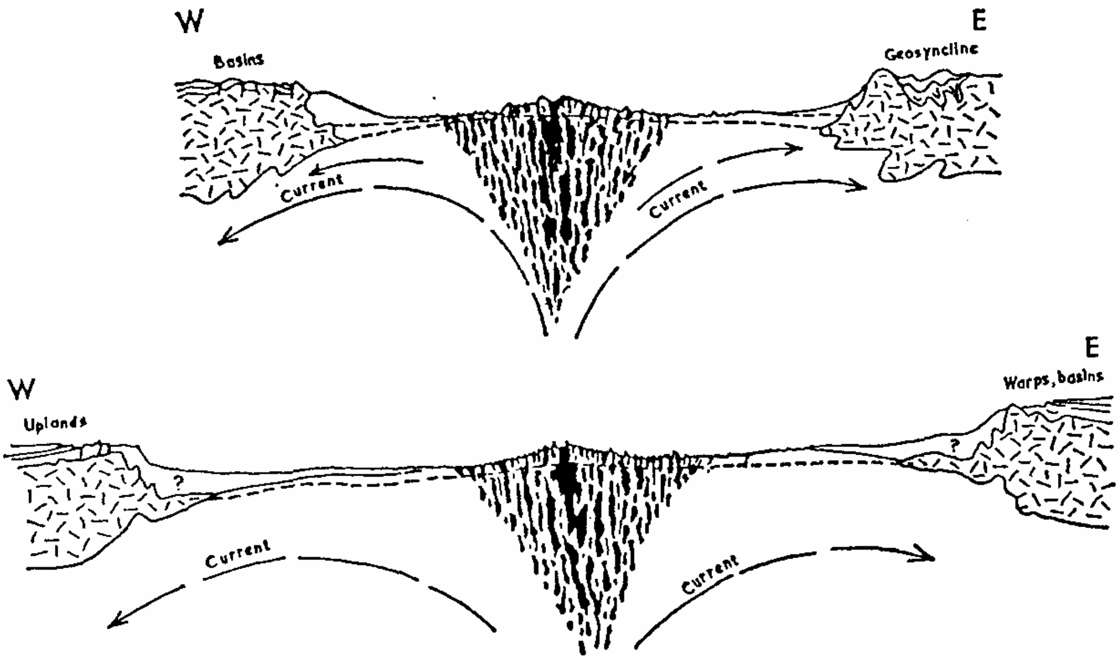

FIGURE 7A (above). Crustal section across the North Atlantic in late Palaeozoic times with sima currents carrying apart the continental masses, compressing by drag local continental edge and producing geosynclinal developments. Scale as in Figure 6.

7B (below). In Mezozoic and Cainozoic times the continents have moved further apart, the edges of the continental blocks are returning to equilibirium and compression is pro gressively reduced. Scale as in Figure 6.

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(orogenesis) has been regarded as the product either of crustal compression or of gravity sliding, and can, as Harland indicates, show the **minimum** amount, direction and time of displacement. The hypothesis of convecting cells presents a mechanism not only to carry out the ‘drift’ of sialic masses but **can** also provide the underlying cause of.tectogenesis - the evolution of a tectonic realm. Harland's figure 2 (1965b) illustrates diagrammatically a pattern of “related, developing, anastomosing and decaying tectonic realms”. The juxtaposition of American and Eurasion Precambrian and Palaeozoic realms is inescapable. This in effect appears as the result of the splitting of a single major tectonic “super-realm” and the events required to produce such a split must be continental in size and of great duration in time. In short, continental drift and tectogenesis around the present North Atlantic area are of a common origin.

VI. Late Palaeozoic Evolution of the Eastern Atlantic Margin.

The formation of the Cornubian section of the geosyncline may thus be seen as an ultimate effect of the simatic upwelling and lateral movement that began to separate the Laurentian and European continental areas in mid-Palaeozoic time. The Cornubian belt exhibits the usual geosynclinal features and similar phenomena are present in Appalachian America. Although not exactly comparable, the two regions do indicate that a sort of rough symmetry was effected at the end of the late Palaeozoic separation of the continents. Since then the continents have continued their progressively more. separate ways of evolution. Moreover, as they have moved further from the locus of upwelling their margins have suffered less violent deformation ; Mesozoic and Cainozoic warping is present but it is broad in form for the most part.

Simpson (1961) suggested a “tectonic timetable” for the Cornubian section of the Hercynian or Variscan geosyncline, and the pattern is essentially the same elsewhere within the belt east to Lower Silesia. To this may be added a suggested sequence of events in the lower crust.

(a) PRELIMINARY PHASE. Initiation of geosyncline ; sedimentation keeps pace with downwarps. Minor vulcanicity. Lower Devonian. *395-370 m.y. (i.e. 15 m.y.). Laurasian supercontinent begins to rift about the Atlantic upwelling. Stress under sialic margins causes local downwarps and basins adjacent to Caledonian mountain roots.

(b) SECOND PHASE. Reduction of rate of sedimentation compared with downwarp. Differentiation of the geosynclinal area into regions of more or less rapid downwarp. Creation of deeps separated by shoals in the areas of more rapid downwarp. Vulcanicity associated particularly with the deeps. Many minor phases. Middle Devonian to Lower Carboniferous.
370-325 m.y. (i.e. 45 m.y.). Continental separation now under way as sub-sialic currents grow more effective.

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*All dates based on figures from Friend and House (1964) ; Francis and Woodland (1964).

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(c) INITIAL OROGENIC PHASE. Strong warping, emphasis of existing troughs and differentiation of new ones (within and outside the geosyncline proper) and elevation of land-masses yielding arenaceous sediment for turbidite deposition in most troughs. Development of fore-trough north of the geosyncline proper with molasse-type sedimentation. Complete cessation of vulcanicity. Upper Carboniferous.
325-295 m.y. (i.e. 30 m.y.). High rate of sub-sialic movement persists and continental separation proceeds rapidly. Sub-continental stress reach a maximum.

(d) FINAL, OROGENIC PHASE. Continued orogenic deformation. Entire fold belt, including much of the fore-trough. elevated to become a belt of denudation. Some volcanic activity. Late Carboniferous-Lower Permian.
295-280 m.y. (i.e. 15 m.y.). Rate of sima movement diminishing but still appreciable throughout. The resultant stress is relieved in orogeny, warping and by block faulting in the foreland areas.

The Cornubian section of the Variscan geosyncline gives only a limited view of tectonic events in Europe, but it is clear that movement took place locally whenever stresses had built up to a sufficient level.

During the Mesozoic era the sub-sialic movement was slow, producing the broad swells and basins that are the basement over which the transgressions and regressions of the north European sea occurred. The Tethyan belt may reflect deep-seated movements from another quarter altogether, but in northern Europe sub-sialic movement on a small scale may account for the persistence of long-lived downwarps such as the Wessex and the North Sea basins.

The development of currents in the mantle causing the mid- or late-Palaeozoic opening of the Atlantic is much earlier than some writers have thought. Concerned principally with later events, they have nevertheless found the idea of underlying simatic currents attractive. Perhaps the cause of much of the earlier tectonic and morphological evolution of northwestern Europe may be attributable to mantle currents. Many authors, geologists as well as geophysicists, see good reason to postulate a periodicity to - or at least a fluctuation in - the current activity. This affects the present argument not at all. Orogcnesis in western Europe could have been from early Palaeozoic time onward a rhythmic process with both minor pulsations (Stille's phases) and major cycles as products of deep-seated continuous flow. It is interesting to speculate on the effects of this flow during Mesozoic and Cainozoic time, for some movement has persisted to the present. Herein may partly be the origin of many geological features in-the continental shelf and both geological and even of geomorphological features in the land mass itself.

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W. G. Maton and the geological map of S.W. England :
by N. E. Butcher.

In view of the present mapping programme of the Institute of Geological Sciences in S.W. England and the part played by the peninsula in the origin and early growth of official geological surveying in Britain, it seems appropriate to bring to light the geological work of William George Maton, M.D. (1774-1835). Maton appears to have been the first, so far as is known, to delineate the geological features of S.W. England in map form.

Although well known in botany and medicine, Maton is largely unknown in the history of geology. His work in S.W. England appears to have been his only contribution to the latter science. His biographer, J. A. Paris, tells of Maton's early interest in natural history. Maton entered The Queen's College, Oxford in 1790, developing his botanical interests whilst in Oxford, and in the summer of 1794 accompanied his friends Charles Hatchett and Thomas Rackett on a tour into Cornwall. Charles Hatchett was a leading chemist and mineralogist.

As a result of this tour and one made in 1796, through Dorset, Devon, Cornwall and Somerset, Maton published his *Observations* in two volumes in his native city of Salisbury in 1797. “The work is accompanied by a plan, so ingeniously engraved, as to represent the various rocks and sub-soils of which the country consists ; and, let me add, that this was the first attempt in England to construct A GEOLOGICAL MAP” (Paris 1838, p.16).

Maton's *Mineralogical Map, of the Western Counties of England,* at a scale of about 17 miles to one inch, makes use of line shading to portray nine divisions: 1. Chalk, 2. Limestone and Calcareous Grit, 3. Clay, 4. Argillaceous Slate and Schistose Clay, 5. Argillaceous Gritstone and Loam, 6. Killas, 7. Serpentine, 8. Quartz and 9 Granite and Granitello. In addition, stipple denotes Sand and Gravel. Maton's deliberate choice of lines to show the mineralogical variations inevitably leads to some obscurity in the finished map.

MATON, W. G., 1797. OBSERVATIONS RELATIVE CHIEFLY TO THE NATURAL HISTORY, PICTURESQUE SCENERY, AND ANTIQUITIES, OF THE WESTERN COUNTIES OF ENGLAND, MADE IN THE YEARS 1794 AND 1796. Salisbury.

PARIS. J. A., 1838. A BIOGRAPHICAL SKETCH OF THE LATE WILLIAM GEORGE MATON, M.D. London.

The succession and structure of the Middle Teign Valley:
by J. A. Chesher.

This progress report results from the first year of the resurvey of the one-inch geological map Sheet 339 (Teignmouth) currently being carried out by the Department of Geology at Exeter University on a research contract for the Institute of Geological Sciences. The area dealt with in this paper is the Middle Teign Valley portion of the sheet, which is delimited by the Dartmoor granite on the west, the Permian of the Haldon Hills on the cast, and from Bridford southward to Bovey Tracey. Apart from a recent Ph.D. thesis by Morton (1958), which dealt with the geology of the northern part of this area, and attributed the structure to a series of thrust slices : the last major publication concerning this area was the Newton Abbot Memoir (Ussher 1913).

The succession that has been established as a result of remapping in the Middle Teign Valley may be tabulated as shown on page 16.

This succession bears various points of similarity to other areas of Devon and Cornwall.

1. On the North Cornish coast in the region of Boscastle and Bude the Upper Carboniferous has been mapped as the Crackington (mainly Namurian) and Bude (Westphalian) Formations. These subdivisions have been mapped inland, using palaeontological evidence, as far as the Okehampton district (Geological Survey Boscastle (322) and Okehampton (324) Sheets, in press). **In** the Middle Teign Valley the Ashton and Kiddens Formations together are probably equivalent to the Crackington Formation, although at the present state of research this has not been proved palaeontologically.

2. The Ashton Formation is closely comparable to the Black Shale Beds (Dowhills Beds) in the Bampton area (Webby and Thomas 1965), which occur below the greywacke sequence of that area.

3. In the Okehampton district the Devonian-Carboniferous boundary is thought to occur within the Meldon Slate-with-Icnticles Formation (Dearman 1964). This formation may be equated to the Hyner and Trusham Formations together, although in lithology it is only comparable to the Hyner Formation.

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Upper Carboniferous	Kiddens Formation	Alternating shales and sand-stones.
	Ashton Formation	Predominantly shales with thin subordinate sandstones. Thickness 300-700 ft.
Lower Carboniferous	Spara Bridge Formation	Shales, pale grey siliceous limestones, cherts. *Posidonia becheri* and *Gonialites spirale* occur in these beds. Thickness 100-150 ft.
	Teign Chert Formation	Well-bedded cherts, calcareous in upper horizons, mudstones, siliceous shales, volcanics, manganiferous beds, and vesicular lavas. Thickness 400-600 ft.
	Combe Formation	Black shales, often with white laminations and fine closely spaced vertical joints infilled with white material. Thickness 300-500 ft.
Upper Devonian	Trusham Formation	Micaccous pale grey and green shales, sometimes mottled. *Sanguilina elliptica* present. Thickness 200 ft.
	Hyner Formation	Dark blue shales and mudstoncs which are often mottled and siliceous. They are characterised by siliceous nodules and calcare-ous bands and nodules. *Sanguilina elliptica* present in upper horizons.

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4. When the Hyner and Trusham Formations are compared to the succession established in the Launceston area (Selwood 1958), the lithology of the Hyner Formation compares to that of the Upper Devonian Stourscombe Formation, and the Trusham Formation compares closely to the Yeolmbridge Formation, which is transitional between the Devonian and Carboniferous.

The structural pattern shows a series of major symmetrical folds which trend E.-W. in the south of the area to N.E.-S.W. in the north, and plunge eastwards. The folds become overturned towards the north and increasingly so the further north one goes. The progressive overturning is associated with stretching of the steep limbs, and eventually with break thrusting resulting in the high angled Ashton and Scanniclift thrusts. The easterly plunge, which varies from 25-50°, is post folding and thrusting, presumably being associated with the intrusion of the Dartmoor granite. Associated with the folding is a poorly developed, high-angled, slaty-cleavage, being best developed in the argillaceous beds in the cores of the folds.

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

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The stratigraphy of the Carboniferous rocks of the Hartland area of North Devon : by L. J. Moore:

During the last decade tile Upper Carboniferous rocks of the Culm synclinorium, which outcrop on the coast of north Cornwall and northwest Devon, have been examined in detail in the north (Prentice 1960, De Raaf, Reading and Walker 1965, Reading and Prentice 1965) and in the south (Lovell 1965, King 1966). The central part of the synclinorium, from Peppercombe (SS385246) to Sandy Mouth (SS202100), has not been investigated for more than fifty years. The author has examined the northern part of this neglected coastline, from the small outlier of New Red Sandstone rocks at Peppercombe (SS385246), which forms the southern boundary of the area investigated by Prentice (1960), to the Devon-Cornwall border at Marsland Mouth, a distance of 16 miles.

Ussher's (1901) map of the Culm rocks shows Middle Culm outcropping in the Hartland Point area (SS230278) with a large area of Upper Culm to the south. Ussher produced this map by extending the structure he had found in the Bideford area to the west and never visited the area between Hartland Point and Bude (1901, p.8). Rogers (1910) and Arber (1907) examined the Hartland area for fossils and recorded goniatite bearing nodules and plants from various localities along the coast and inland. Ashwin (1957) drew a structural section across the entire Culm synclinorium. On the Hartland-Welcombe part of the coast he records about 4,000 ft of sediment, tightly folded and, on a regional scale, younging to the north.

In the present detailed study the lowermost 10m of cliff and, where the cliff was obscured, the foreshore were plotted on a scale of 1:200 from Hartland Point to Marsland Mouth. Stratigraphical measurements were taken across the limbs of each fold and bed thicknesses and sedimentary properties plotted on a scale of 1:20 in the form of graphic logs. Correlating these graphic logs a stratigraphical column 890m thick was established. Using the original structural section, as a control, the stratigraphy was then plotted visually, in the field, for the entire cliff face on a scale of 1: 2,500. The resulting structure confirms Ashwin's picture of a series of large open anticlines and synclines with wavelengths of about a kilometre masked by small scale “concertina” folds with wavelengths from 5 to 500m in a succession that youngs to the north.

The stratigraphic succession established on the west coast of Devon allows the limits of the Welcombe Beds to be defined and requires that two new stratigraphic units be recognised. The stratigranhical units proposed are

3. The Hartland Beds.
2. The Welcombe Beds.
1. The Black Mudstone Beds.

Figure 1 gives a summary of the lithological variations within this thick sandstone-shale sequence. The most salient features are the laterally persistent thick nodular shales, the occasional “slump” beds and the laterally

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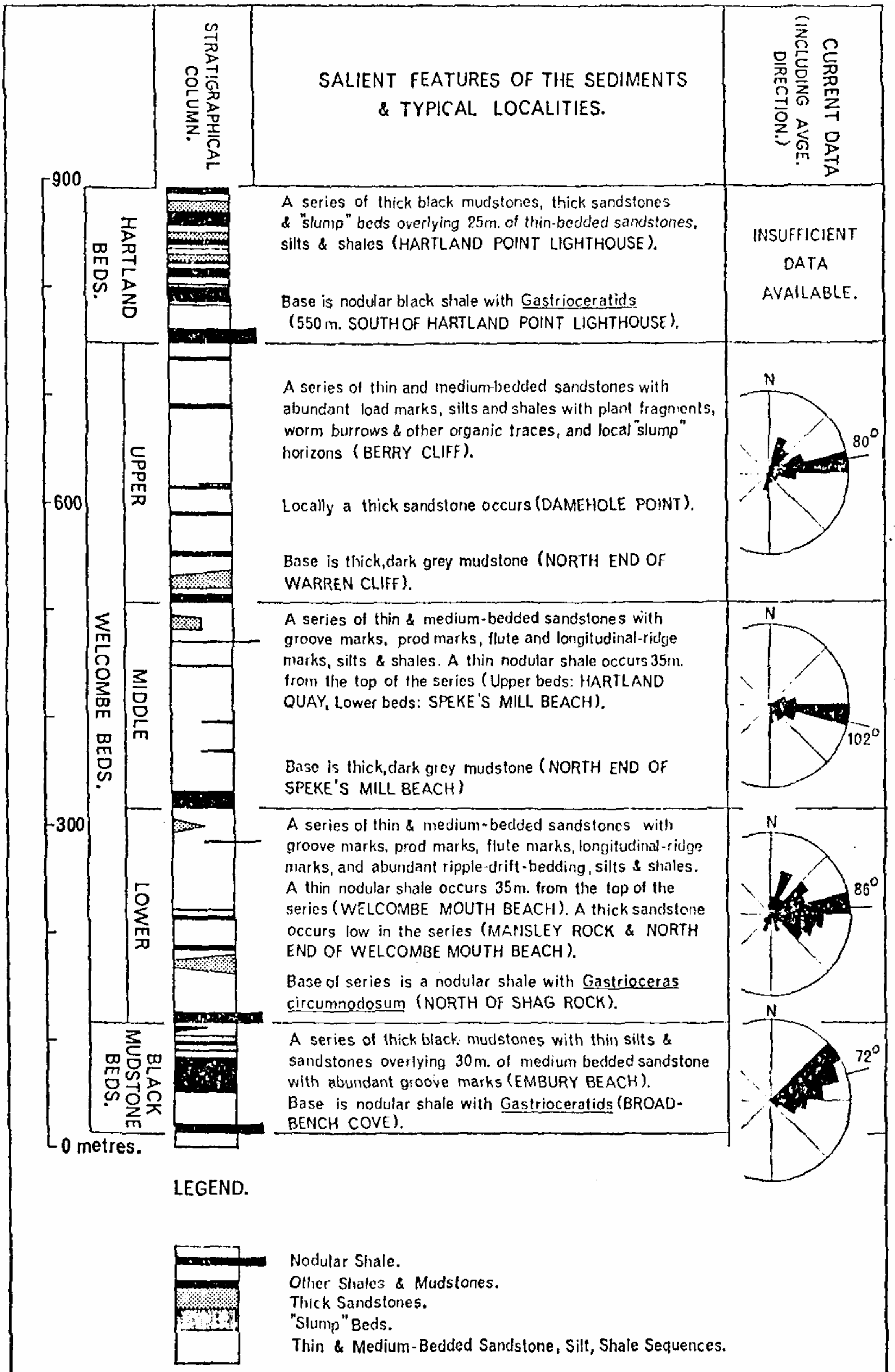

Fig.1 Stratigraphic column for the Hartland area of the west coast of Devon.

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restricted thick sandstones. The occurrence of **Castrioceras circumnodosum** Foord, north of Shag Rock (SS213190), (Butcher and Hodson 1960) in the nodular shale at the base of the Welcombe Beds is of particular importance because this goniatite is one of the **G. listeri** group of goniatites. Thus the age of the base of the Welcombe Beds is established.

The coastline from Windbury Head (SS287268) to south of Clovelly (SS325244) was examined using the same detailed methods as were employed on the Hartland Point-Marsland Mouth section. The resulting stratigraphic sequence belongs to the Black Mudstone Beds and the overlying lowest Welcombe Beds. The occurrence of **G. circumnodosurn** in a thick nodular shale near Mouth Mill (SS298267), at a mid-point in the sequence, confirms the lithological matching of the two sequences. A second nodular shale, with unidentifiable gastrioceratids, occurs low in the sequence. This nodular shale is about 30m above a major “slump” bed, which outcrops in the cores of two anticlines which occur 0.5km and 1km north-west of Clovelly. In Prentice's section (1960, Fig. 1) of the cliffs between Westward Ho!, and Portledge there are two infolded “slump” masses marked as Grecncliff Beds in Westacott Cliff. Lithologically these beds are identical with the Clovelly “slump” bed and not at all similar to the silts of the main Greencliff Beds outcrop to the north. The goniatites from Rowdon Cliff recorded by Prentice as **G. subcrenatum** (Reading and Prentice 1965) occur in the Cockington Flags (Prentice 1960, Fig. 2) at a level above the "slump" bed. Thus the nodular shale in the Clovelly section, which is the same nodular shale as that at the base of the Black Mudstone Beds, is at the same stratigraphic level as the **G. subcrenatum** marine horizon.

The recording of lithologically and temporally equivalent Welcombe Bcds, Cockington Beds and Instow Beds (Reading and Prentice 1965) over such a wide area of Devon and Cornwall suggests that Reading's idea that the Westward Ho !, Northam and Abbotsham Formations owe their present position to movement along a thrust plane may prove correct, the Cockington Beds, which had previously been considered to be stratigraphically above infolded Greencliff Beds, actually lying below the plane of thrust movement with the Greencliff Beds in Green Cliff being of tectonic rather than sedimentary origin.

Acknowledgements. The author would like to thank Dr. J. E. Prentice for advice given concerning this work, which was undertaken while the author was tutorial research student at King's College, London .

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Results of mapping the Haldon Hills: by R. J. O. Hamblin.

The Upper Greensand and Haldon Gravels of Great and Little Haldon have recently been remapped on the six inch scale as part of the Exeter University/Institute of Geological Sciences revision of the one inch Teignmouth Sheet of the Geological Survey. The Upper Greensand varies in thickness between 70 and 100 ft, probably due to a combination of variations in deposition and post-Upper Greensand erosion. Within the Upper Greensand of Little Haldon and the south end of Great Haldon a loose quartz conglomerate has proved a mappable horizon.

The Haldon Gravels overlie the Greensand and show two divisions. The first is a residual deposit formed by the solution of Chalk *in situ.* The greater part by bulk is flint in a matrix of white clay and sand. The flints are of all sizes, unrounded, with complete crust and no signs of abrasion. They show considerable shattering by temperature change throughout the thickness of the gravel ; this shattering is peripheral, chips of flint flaking off and increasing the sphericity of the flints. Fossils in the flints refer the Chalk to the zones from *Holnster planus* to *Marsupites testudinarius.*

The second division is a detrital gravel. There the bulk of the

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deposit is abraded flint, all sizes of flints to 20 in across, the smaller ones generally more abraded than the larger. These flints show both rounding and chatter-marking, and are less shattered than the unabraded flints, owing to their more rounded shape. There is more matrix and it is more varied. The proportions of sand and gravel vary widely, and beds of clean sand and clay occur. Quartz and schorl boulders occur abundantly, and are up to 12 in diameter. They are much more rounded than the flints and could have been derived from a littoral Chalk on the flanks of Dartmoor ; clearly they were introduced, already rounded, by the agent which rounded the flints - most likely river action. Wherever both divisions are seen in contact in a section, the detrital gravel is seen to overlie the residual, although over wide areas of the hills the residual gravel is cut out and the detrital gravels overlie the Greensand directly. Both divisions of gravel must have been formed after the Senonian Chalk and before the faulting of the Bovey Basin - an Eocene age is suggested.

The absence of any beds between the Upper Greensand, which is generally considered Albian in age, and the gravels, which contain only Senonian fossils, can be explained in three possible ways: - (1) The hiatus is not real, the Greensand being younger than is generally supposed ; (2) the hiatus is due to complete solution of Turonian or even Cenomanian Chalk ; (3) the hiatus is a normal diastem.

A “summit platform” is seen where the gravels are horizontal, but where they are inclined the land slopes with them, so there is no post-folding planation, i.e. no Pliocene surface. The “summit platform” seen is not an erosional surface, but came into existence with the formation of the rolled gravel. It is hence Eocene in age.

Faults with throws of 10 to 100 ft have been mapped, mostly detected where they cut the base or the Greensand or the Greensand conglomerate. Faults of post-Senonian and post-Eocene age can be proved, and slight tectonic folding of post-Eocene age, giving dips of up to 4°.

This paper is published with the approval of the Director of the Institute of Geological Sciences.

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New Red Sandstone stratigraphy in Devon and West Somerset:
by D. J. C. Laming.

Some 9,000 ft of New Red Sandstone strata are exposed in the coast section from Tor Bay to Seaton, Devon. These accumulated in the Wessex Basin, which extended from the present outcrop area (Fig. 2) eastward an unknown distance, out under the present English Channel, and into the Bristol Channel region. The coarsegrained rocks of the exposed succession represent deposits marginal to the basin, derived from the Variscan fold massif to the west upon which they rest unconformably. Deposition in a semi-arid terrestrial environment is indicated, mainly as alluvial fans and associated eolian and fluvial sands ; the fine-grained deposits represent basinal accumulations of river channel, flood-plain and possibly ephemeral lake environments.

Work on palaeocurrents and basin geology over several years has required the establishment of a stratigraphic framework for the New Red Sandstone. A number of *formations* (as defined by the American Commission on Stratigraphic Nomenclature, 1961, and the Stratigraphical Code Sub-Committee of the Geological Society, 1967) have been provisionally designated to include most of the exposed strata (Fig. 1). Each formation name includes the type locality and a descriptive lithological term, *Beds* indicating variable lithology. Related formations are linked in several *groups.* The New Red Sandstone as a whole, which spans Late Carboniferous(?) to the beginning of Rhaetic time (Laming 1965) is regarded as a litho-stratigraphic unit (a *sequence* or *supergroup)* with no chronomeric equivalence.

The coast succession is modified slightly from previously (Laming 1966), and many inland formations are newly designated. The terminology of the Crediton area is mostly that given in the Okehampton Memoir (1968), modified from Hutchins (1963). The Heavitree Breccias were described by Murchison (1867) and later by Ussher (1902).

In general, breccias composed of materials derived from the underlying Devonian and/or Carboniferous rocks dominate the lower parts of the sequence. Contemporaneous tectonism produced a small unconformity within the sequence north of Torquay, and

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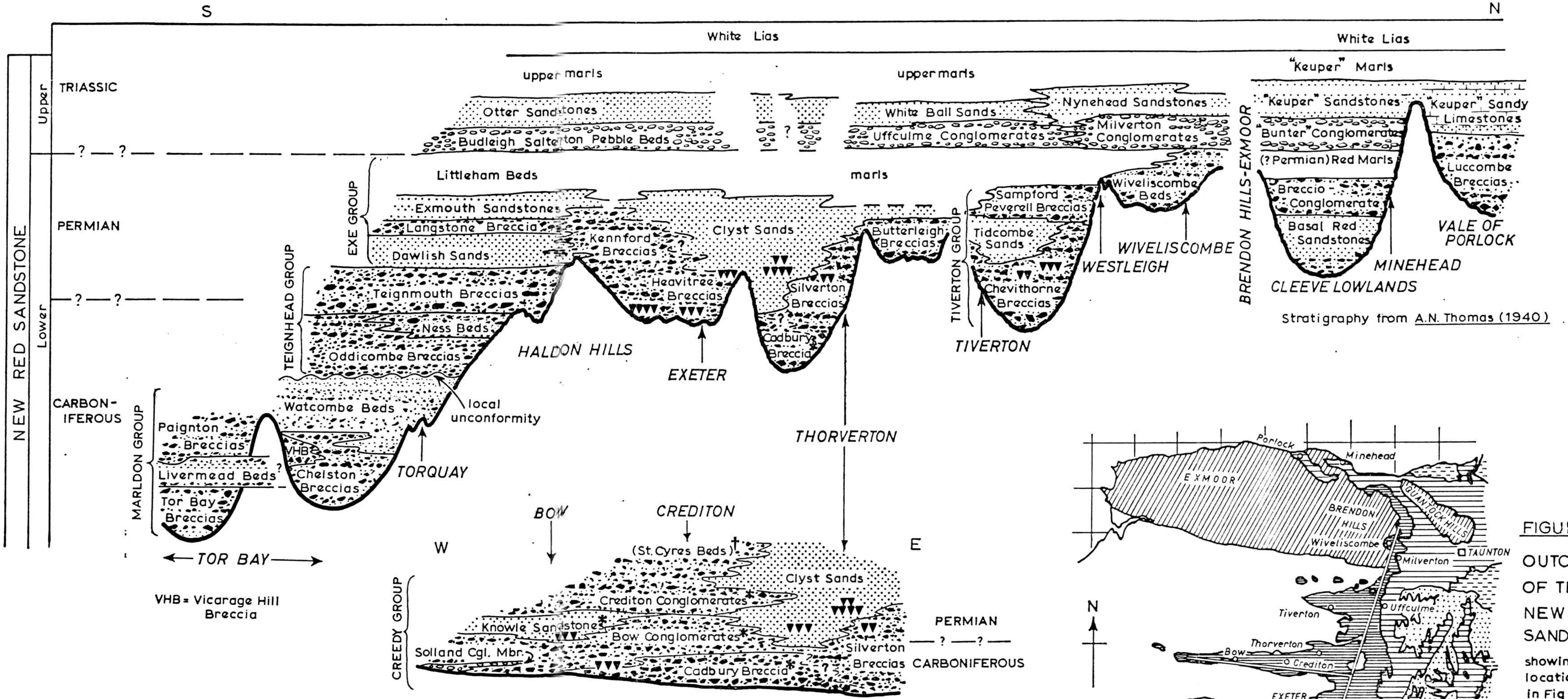


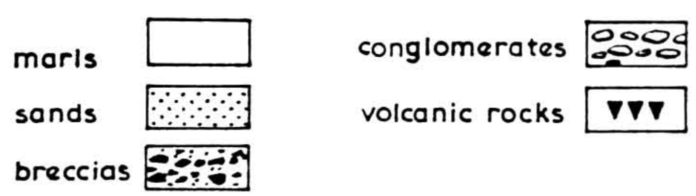
*names proposed by EDMONDS and others (1968)

†name used by Hutchins (1963)

FIGURE 1.

NEW RED SANDSTONE IN DEVON AND WEST SOMERSET

STRATIGRAPHIC RELATIONS



All boundaries are diagrammatic; dashed lines indicate uncertain relationships.

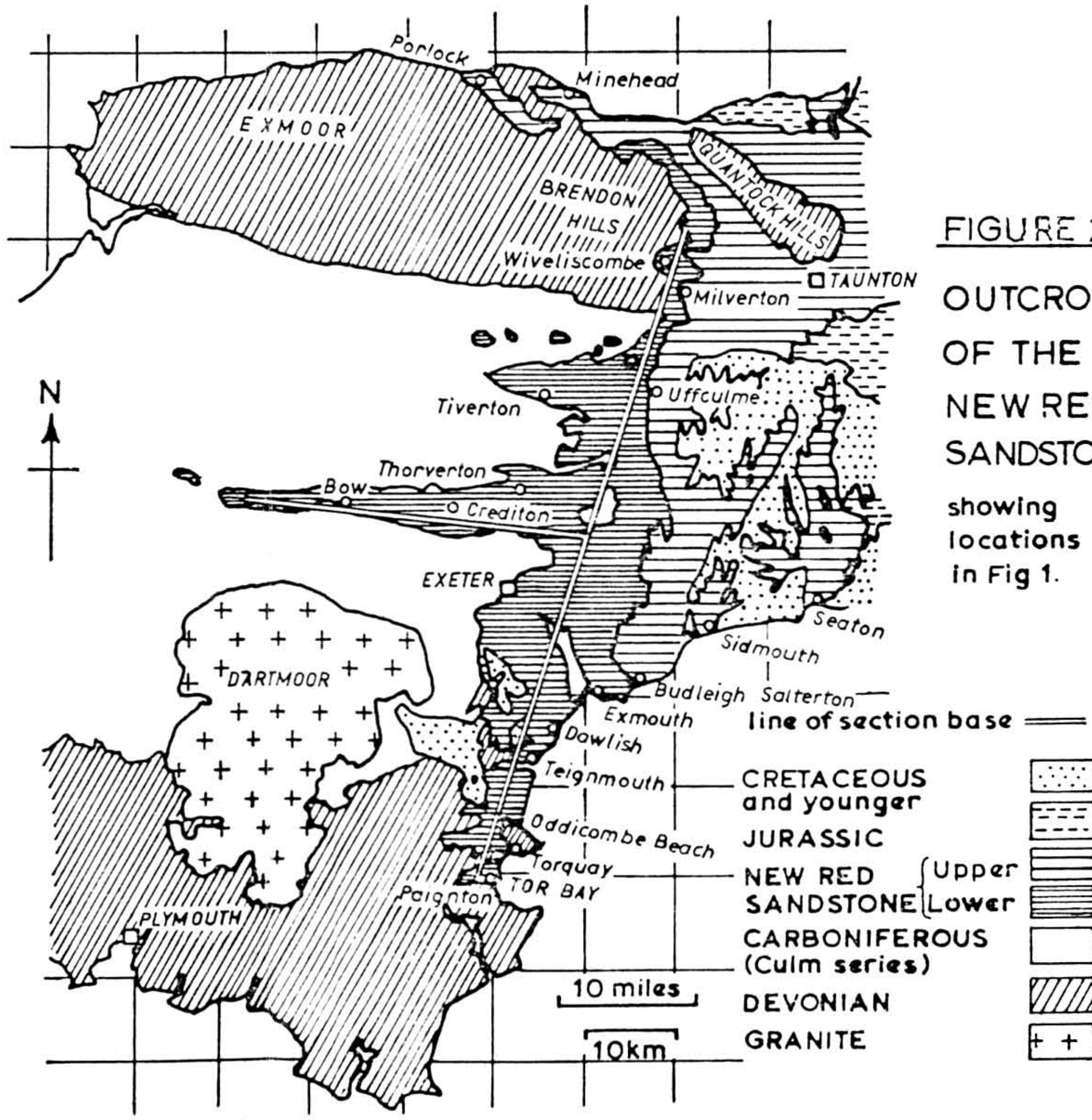


FIGURE 2

OUTCROP OF THE NEW RED SANDSTONE

showing locations in Fig 1.

initiated a flood of limestone detritus to form the Oddicombe Breccias ; these pass laterally into the Ness Beds, where a fragment suite derived from the region of Dartmoor appears. Higher breccia formations contain more mixed suites, including fragments derived from the granite aureole and the locally interbedded lavas. The approximate stratigraphic positions of these lavas is indicated in Figure 1, which also shows the probable correlation with the Minehead and Porlock successions (Thomas 1940).

The Sampford Peverell Breccias contain limestone pebbles clearly derived from the nearby Westleigh Carboniferous limestones. The southerly-derived Budleigh Salterton Pebble Beds, usually taken as marking the base of the Triassic, are probably correlative with the UfTcuhne Conglomerates, derived from the west: these in turn interdigitate with the Milverton Conglomerates, which contain abundant Carboniferous Limestone pebbles with South Wales affinities. A possible source, however, might have been a lost Carboniferous Limestone outlier in the Exmoor region. The Solland Conglomerate Member has Devonian limestone pebbles (Hutchins 1958) derived from the south.

The Dawlish and Clyst Sands show extensive eolian deposition ; relationships with the Kennford and Heavitree Breccias and the Bow Conglomerates require further clarification. The Exmouth, Otter and Nynehead Sandstones, and the Tidcombe and White Ball Sands are, however, almost entirely fluvial. The Littleham Beds and other "marls" consist of mudstones with occasional silty and sandy interbeds. The Livermead, Watcombe and Wiveliscombe Beds are mixtures of sands and fine-to-medium grained breccias.

Acknowledgements are due to Dr. M. Williams and others at the Institute of Geological Sciences for valued co-operation, to Professor F. H. T. Rhodes and Dr. D. V. Ager for advice, and to the National Research Council of Canada for support of the 1967 field programme.

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Granites and structure : some comments on S.W. England :

by W. R. Dearman.

Early work on the geological structure of the north-west margin of the Dartmoor granite (Dearman and Butcher 1959) appeared to show that the granite had made room for itself during emplacement by deforming the contact sediments. Large recumbent folds had been lifted up and tilted to the west and north, the stretching of the sedimentary envelope being helped by re-activation of pre-existing low-angle normal faults. At that time, this intrusive activity was regarded as the culmination of a single prolonged episode of deformation involving only one phase of folding. Freshney (1965) has since demonstrated in the coastal exposures around Boscastle that a second phase of folding is associated with movements on low-angle normal faults inclined to the north. He likens these faults to those re-activated by the granite in north-west Dartmoor ; a second phase of folding, similar in all respects to that at Boscastle, has affected the slates-with-lenticles around Lydford (Dearman 1964a).

The Lydford structures, unlike those at Boscastle, are within and affected by the contact metamorphic aureole of an exposed granite, so that it is possible to determine the geometrical relationships between the granite contact and the successive fold phases in the sediments. Folds of the first phase (F1) of deformation plunge on average to the north-west and there is no change in plunge away from the granite margin which can be related to uplift of the reclined folds by the granite. Bedding and slatv cleavage are parallel away from the hinges of the early folds ; the second phase of zigzags (F2) trend approximately N.E.-S.W, and hence have gentle plunges over the whole area determined by strike of slaty cleavage. The F2 folds head straight for the granite margin without deflection. Both F1 and F2 folds in the slates at Lydford are evidently unaffected by the adjacent granite. There is a third fold structure (F3), found wherever beds are steeply inclined, which implies a late phase of vertical flattening in the slates (Dearman, in

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press). The presence of these forms in contact altered slates fixes the time relations between all fold phases and emplacement of the adjacent granite.

The granite contact is not exposed at Lydford but it has been inferred that it dips at 10-20' (Dearman 1964b) ; it could be vertical as at Burrator further south. Whatever its attitude, the granite contact cuts across all folds without affecting the attitude of Fl and both F2 and F3 structures which were controlled by the dip of the slaty cleavage. Stretching of the sedimentary envelope by low-angle normal faulting and related F2 folding, followed by the vertical flattening phase of F3, are clearly dissociated from the Dartmoor granite. It may be that the structures are genetically related to the uprise of the main batholith instead of a local cupola upon it. The same argument could be applied to the F2 structures at Boscastle.

Interpretation of the behaviour of the Meldon inlier during granite emplacement was based first on a change in attitude from recumbent to inclined south, and second on a localized plunge change as the granite margin is approached (Dearman and Butcher 1959). It is now necessary to re-examine these ideas in the light of the Lydford structures. The whole fold belt does change attitude from upright to recumbent when traced from north to south, so that if the Meldon folds are more or less in their original attitude and have not been Uplifted by the granite then the change from inclined to recumbent within the fold belt must be accomplished somewhere between the Meldon and Lydford inliers. The change in attitude to recumbent along the strike might now be considered to reflect the proximity of the hinge line of the major overfold (cf. Freshney 1965, fig. 2A), although individual over-folds are known to change attitude to recumbent when the fold is traced up the axial plane (Dearman 1964b, fig. 4a). Change in fold plunge as the granite margin is skirted, interpreted formerly as folds rising to get up and over the granite, may simply be due to a fortuitous location of fold culmination within a variably plunging, but statistically horizontal, fold belt. Apart from some shouldering aside of the country rock (Freshney 1965) the major overturned structure in the sediments is pierced but otherwise little affected by the Dartmoor granite.

If it is accepted that the Dartmoor granite is a cupola, risen by piecemeal stoping of its folded sedimentary envelope from the main batholith beneath, then should the F2 and F3 minor structures be granite-linked then they must be genetically related to the rise of the main batholith beneath. The F3 Structures at Lydford, diminishing in intensity away from the granite margin, are found well beyond the mapped limit of the metamorphic aureole. 'They presumably occur as a Structural aureole moulded to the surface of the main batholith rising over the pre-natal swellings marking the sites for eventual piercement by the cupolas. The present day outcrop of the late structures, and to some extent the early structures, reflects the topography of the batholith, and the Dartmoor cupola could be removed from the geological map without seriously affecting the trend and distribution of lithological units and associated structural phases.

These remarks, here confined to the north-west margin of Dartmoor, are probably widely applicable in the south-west of England. Aureoles of batholith induced structures, involving vertical compression and lateral extension,

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should occur wherever original high spots on the batholith approach the present day surface. If Freshney (1965) is right, effects of the F2 deformation should be very much more widespread than those of the F3 deformation.

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Conodonts from the Dinantian of N.E. Devon :

by S. C. Matthews and J. M. Thomas.

Conodonts recently extracted from the Lower Carboniferous rocks of the areas around Bampton and Westleigh have added to the understanding of their stratigraphy and sedimentation. The lateral equivalence of these two successions was tested on conodont evidence and this confirmed the presence of two distinct facies in the Dinantian of N.E. Devon (Thomas 1962, 1963a).

The Westleigh Limestones have been interpreted as "shelf" carbonates immediately redeposited in deeper water, as occurs in the Tongue of the Ocean within the present-day Bahaman areas of carbonate deposition (Thomas 1963b, Rusnak and Nesteroff 1964). However, slender macrofaunal evidence had suggested that there may be some content of slightly older rocks within some limestone beds, and detailed work on the conodonts of selected parts of the succession was carried out to assess the amount of erosion in the original "Avonian" source area.

The conodont faunas so far recovered are dominated by gnathodids and suggested horizons high in cu II (above the *anchoralis*-Zone) and in cu III. Species of *Cavesgnathus, Mesto-gnathus* and *Spathognathodus* are available in an excellent state of preservation and confirm the general character of the earlier correla-tions (Prentice and Thomas 1960, 1965).

To assess the contribution of material from earlier strata,

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samples were taken from beds immediately below and above the *crenistria*-Bed (comparable in details of petrography and palaeontology with the *crenistria*-Bank of the Sauerland as described by Nicolaus, 1963) at a number of localities, and they yielded conodonts such as *Siphonodella* and *Scaliognathus* which clearly (by German experience) are not contemporaries of *Goniatites crenistria*. The implication is that these carbonate redeposits at Westleigh acquired either at source or in the course of their redeposition a considerable admixture of distinctly older material. A continuing programme of sampling is directed toward definition of the age of the lowest and highest exposed parts of the Westleigh carbonate succession and also toward the problem of dating the relatively intractable lower parts (Doddiscombe Beds, Hayne Beech Beds, Kersdown Chert) of the Bampton succession (Webby and Thomas 1965).

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The derivation of the Tertiary sediments in the Petrockstow Basin, North Devon: by C. M. Bristow.

It has long been held that the Tertiary kaolinitic sediments in the fault formed basins of North and South Devon originated from kaolinised granite in the Dartmoor area (Scott 1929, Clayden 1906, Dearman 1962). Rapid erosion of the large hydrothermally kaolinised areas on Dartmoor is supposed to have released large quantities of kaolinite into streams which conveyed it, together with the other erosion products of the granite, into fault formed basins in North and South Devon. Recent work by the writer at the Meeth end of the Petrockstow basin, carried out during exploration for commercial ball clay deposits, has indicated that these Tertiary sediments are more likely to have been derived from weathering mantle developed on Culm Measures shales and sandstones under the warm temperate or sub-tropical conditions of Lower Tertiary times. The main arguments for this revised interpretation are given, followed by a description of some X-ray and analytical work carried out to determine the nature of the mineralogical and chemical changes involved in deriving ball clay sediments from Culm Measures.

Distribution of Lower Tertiary kaolinitic sediments in Western Europe. Besides the kaolinitic sediments under discussion in Devon there are many other occurrences of similar sediments elsewhere in Europe. In the British Isles similar sediments of Lower Tertiary age occur in solution hollows in southern Pembrokeshire and southern Ireland. A large fault formed basin around Lough Neagh in Ulster also contains a Tertiary sequence of silty clays, silts, sands and lignites which are strikingly similar to the Devonshire sequences, except that the clays are too silty and iron-rich to be of commercial use. The Eocene of the Hampshire basin contains ball clays, lignitic clays and sands in the Wareham area. Lower Tertiary ball clays also occur in the Paris (‘Argille Plastique’) and Aquitaine basins and sporadically around the Massif Central. In Germany similar Lower to Mid-Tertiary kaolinitic clays and lignites occur over large areas.

It is inconceivable that all this material could have originated from hydrothermally kaolinised granites. In the case of the Lough Neagh basin the origin of the material is thought to have been from lateritic weathering mantle developed on the basalts, limestones, Millstone Grit and acid igneous rocks of the surrounding area (Wright 1924, Fowler and Robhic 1961). There is no large source of hydrothermally kaolinised granite to provide a source for the Lough Neagh sediments. The interbasaltic horizon in Antrim, of Lower Tertiary age, has a well developed tropical or sub-trooical weathering mantle, showing that lateritisation and bauxitisation were occurring in Northern Ireland prior to the deposition of the Lough Neagh clays (Eyles 1962). If the sequences at Lough Neagh and in Devon are so similar, it is likely that they had a similar mode of origin and that consequently the source of the Devon sediments would also be from weathering mantle. Similar modes of origin have been suggested for the Continental occurrences of ball clays and associated sediments.

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Nature of the clay minerals in ball clays. X-ray diffractometer traces described below, show that the argillaceous traction of the North Devon ball clays is composed of a mixture of micaceous mineral and kaolinite. The micaceous mineral is probably best described as illite, whilst the kaolinitic mineral is very fine grained (45-60% below 1 micron in commercial ball clays) and has a highly disordered lattice. This type of clay mineral assemblage is typical of ball clays and distinguishes them from sedimentary kaolins which are composed of coarser, less disordered kaolinite with smaller quantities of illite. Fine disordered kaolinite is formed under low temperature kaolinising conditions such as occur in weathering mantles or in the diagenetic alteration of micas (Keller 1964, Shover 1964, Jonas 1964).

Kaolinite produced by hydrothermal alteration of feldspars in granite has a well-ordered lattice and occurs as relatively large crystals compared with ball clay kaolinite (Exley 1959). As it is unlikely that the crystallinity index of kaolinite would be altered in a retrograde way during transport from Dartmoor, it would seen) more likely that the ball clay kaolinite has been derived from weathering Mantle or by a diagenetic alteration of other minerals.

Nature of the sands associated with the ball clays. The main by-product of china clay production is a coarse sand, in part gravel by particle size definition, which usually contains noticeable quantities of tourmaline. On average the ratio of sand to clay is about 4 : 1. If the sediments in the Petrockstow basin had originated from kaolinised granite on Dartmoor, we would expect to find considerable quantities of this coarse tourmalinitic sand interbedded with the ball clays. In fact the drilling of hundreds of boreholes over the southern part of the basin has failed to show an appreciable amount of coarse sand. However, there are considerable thicknesses of a fine silty sand which never contains any noticeable quantities of tourmaline. If the material in the basin had been derived from Culm Measures this fine silty sand could be attributed to the fine sandstones of the Culm Measures which contain only very small quantities of tourmaline. It is clear that derivation by weathering of Culm Measures is the most satisfactory alternative.

Nature of the processes involved in the derivation of the sediments from weathered Culm Measures. Several boreholes around Woolladon pit, near the southern end of the basin, passed through the Tertiary sediments and penetrated the weathering mantle developed on the underlying Culm Measures. In order to examine the possibility that this weathering mantle was the source of the Tertiary sediments a number of whole rock analyses and X-ray diffractometer traces were made on fresh Culm Measures and Tertiary sediments.

Six samples of Culm Measures were taken from localities around the Meeth basin (three from railway cuttings south of Meeth, two from a quarry near Merton and one from a stream section near Dolton). All the samples appeared to he unweathered, with the possible exception of the sample from the river bed at Dolton. There was an intentional bias in the sampling towards argillaceous material, so that comparisons with the weathered argillaceous members of the Culm Measures and ball clays could be made. Also, the changes which would be involved in the transition from Culm Measures

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sandstones to the silts and sands in the Tertiary sequence would be relatively minor and of much less interest. These six samples of dark silty shales were analysed and X-ray diffractometer traces taken to determine their mineral contents individually. All the samples appeared to be basically similar, the main variation was in the quartz content.

A second set of samples was taken from a borehole sunk on Woolladon Moor which traversed weathered Culm Measures between 105 ft and the bottom of the hole at 123 ft from surface. Overlying the weathering mantle a peculiar iron stained silty clay was found which appeared to be transitional between the weathering mantle and the Tertiary clays ; this is interpreted as slumped weathering mantle. Overlying this was found the normal sequence of silts, sands and clays found in this part of the basin. For the purposes of this work a bulk sample of the weathering mantle was analysed and X-ray diffractometer traces taken at 3 ft increments. X-ray diffractometer traces were also taken of a typical slightly silty ball clay from the upper part of the hole and the supposed slumped weathering mantle. Analytical data for commercial ball clays was obtained from published technical data sheets.

Figure I shows X-ray diffractometer traces of a typical Culm Measures silty shale, the bottom and top of the weathering zone encountered in the borehole, the supposed slumped material and the trace of a typical ball clay from the upper part of the borehole. The Culm shale traces were all very similar and the one selected shows a quartz content of about one-third. Peaks which can be attributed to mica (probably illite or clay mica) and chlorite are present. A rather greater quantity of illite (about one-third) than chlorite (about one-quarter) appears to be present. Small quantities of anatase, kaolinite and soda-feldspar are probably present. The trace of the deepest sample of weathered Culm shale from the borehole shows many differences from the parent rock. The chlorite peaks are barely recognisable and the illite peaks are less well defined, indicating a more disordered lattice than in the fresh Culm shale. The kaolinite peaks are more prominent than in the Culm shale and increase in sharpness and intensity towards the top of the weathering mantle. The trace from the top of the weathered Culm shale also shows that the last traces of the chlorite peak have been removed. No traces of the soda-feldspar noticed in the Culm shale remain in either of the samples from the weathering mantle. The anatase appears to remain relatively constant. The supposed slump material shows an even more marked kaolinite peak and the mica peaks are smaller and broader, indicating a smaller quantity of mica and a greater degree of disorder in the mica lattice. The ball clay trace shows a further increase in kaolinite content. The sharpness of the peaks indicates a greater degree of order in the crystal lattice, although it is still a disordered type by comparison with hydrothermal kaolinites.

A comparison of these X-ray traces shows that the ball clay, slumped weathering mantle and the tipper part of the weathered Culm shale show strong similarities in their mineralogy. The deepest sample from the borehole shows certain similarities to the fresh Culm shale, but still has many features in common with the ball clay. This sequence clearly indicates that the Tertiary sediments have been derived from the weathering mantle

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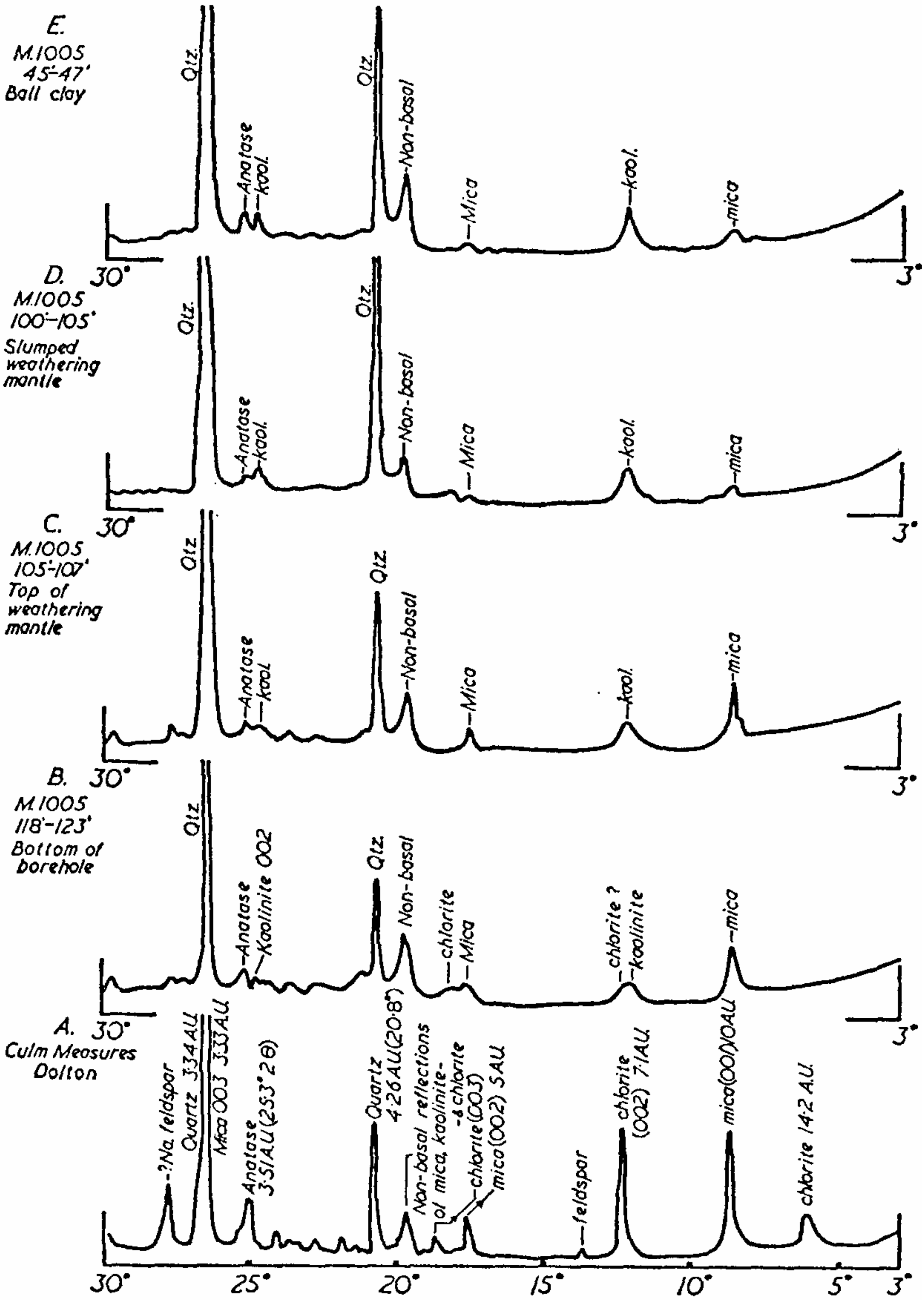

FIGURE 1. X-ray diffraction traces (see text for details).

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developed on the Culm shales. It would seem to indicate that the mineralogical changes involved in a transition from Culm Measures shale to ball clay are almost wholly accomplished in the weathering process.

Chemical analyses were taken of the six Culm Measures shale samples and of a composite sample of the weathering mantle. Ball clay analyses were obtained from technical sales literature. Three ball clay analyses were chosen so that the average had a comparable silica content to the parent Culm shale

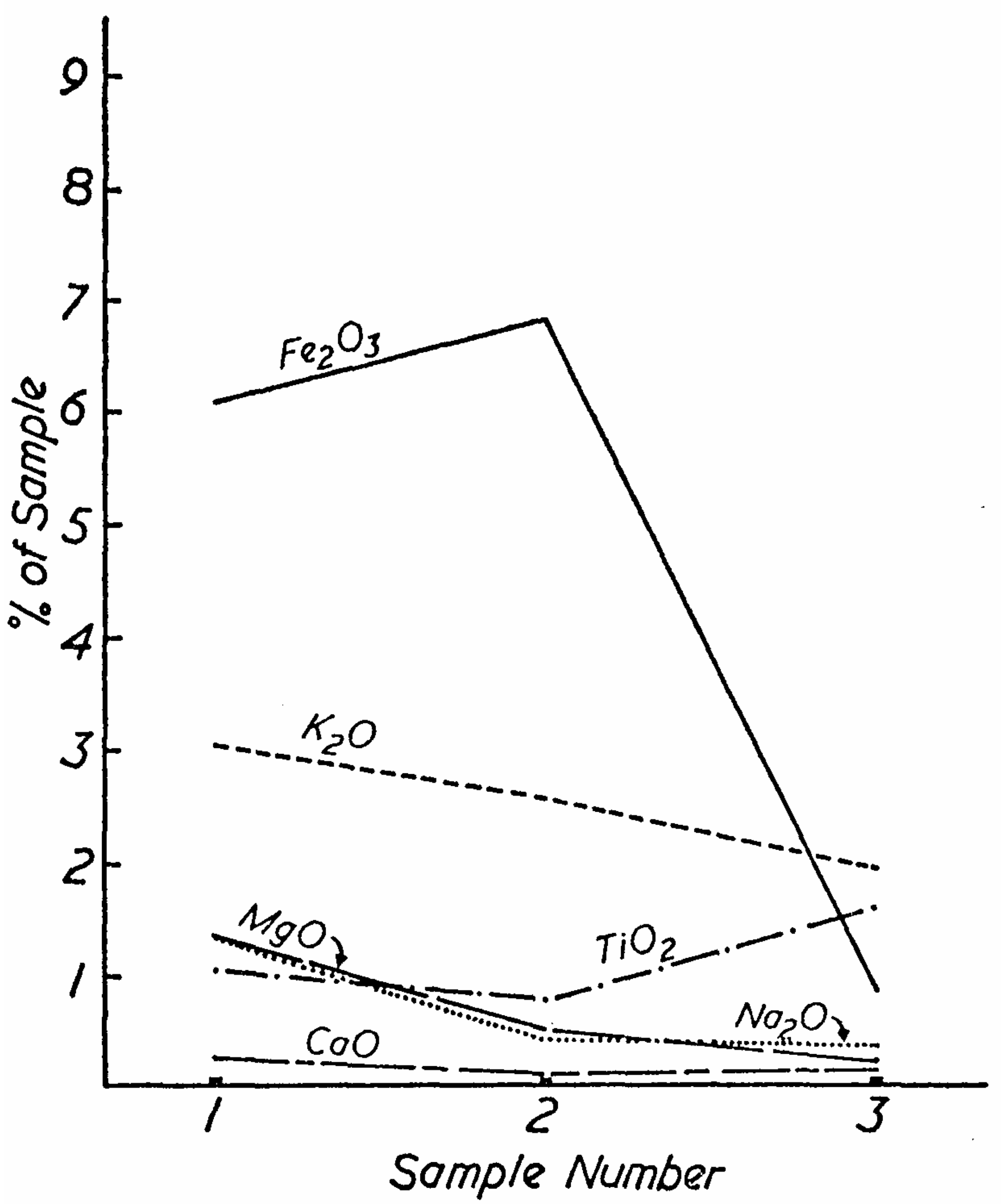

FIGURE 2. Graphical plot of the analyses given in Table 1; Sample 1 is the average of six Culm Measures shales samples, Sample 2 is a composite sample of the weathering mantle found between 105 ft and 123 ft in borehole M 1005, adjusted to 65.1% SiO_2, and Sample 3 is the average of three analyses of commercial ball clay samples.

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	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	loss on ignition
Culm Measures average of 6 samples	65·1	17·55	6·09	1·045	0·26	1·35	3·06	1·34	4·1
Weathered Culm shales, from below Tertiary sediments	57·1	21·7	8·8	1·0	0·13	0·66	3·3	0·58	6·6
Ditto adjusted to 65·1% SiO_2	65·1	16·9	6·85	0·78	0·10	0·51	2·57	0·45	6·6
Average of 3 commercial ball clay samples	66·29	22·24	0·87	1·62	0·14	0·22	1·98	0·37	6·13

TABLE I. Table of Analyses.

in order to enable valid comparisons to be made. For the same reason the analysis of the weathering mantle material has been adjusted so that the silica content is similar to the Culm shale and ball clay. These analyses are set out in the accompanying table and in a graphical manner in Figure 2.

Some increase in silica content would be bound to occur because of the removal of other more mobile elements, but if bauxitising conditions occurred some desilication would also occur. The alumina content seems to reflect the removal of the more mobile elements. The Fe_2O_3 content increases in the weathering mantle, due to lateritisation and drops sharply in the transition to ball clay. Commercial ball clays are valued for their low iron content and consequently this result may not be typical. The TiO_2 content shows an overall increase from Culm shale to ball clay ; this may be due to its fine particle size causing a concentration in the well classified Tertiary sediments as opposed to the poorly classified Culm Measures shales and sandstones. It should be noted that the TiO_2 content in all the analyses (1.0-1.5%) is very much higher than in any kaolinised granite (about 0.1% or less). The MgO content decreases sharply in the weathering process ; this can be directly attributed to the breakdown of the chlorite noticed in the X-ray traces. The K_2O also shows a decrease in the weathering process and also in the changes during transport and deposition as a ball clay. This loss of K_2O is due to removal of potassium during the breakdown of illite to form kaolinite. The decrease in Na_2O during the weathering process is probably due to the breakdown of soda-feldspar to kaolinite.

CONCLUSION

The data obtained from the X-ray and analytical work are in good agreement and a clear picture of the mineralogical changes which have taken place during the weathering, erosion, transport and deposition as ball clay emerges. There seems little doubt that the Tertiary sediments in the Petrockstow basin have originated in weathering mantle developed under humid sub-tropical or warm temperate conditions from Culm Measures shales and sandstones. It would appear that the most important changes occurred during the weathering in place of the Culm Measures shales. The chlorite was wholly converted to disordered kaolinite, together with some

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of the illite. The soda-feldspar was also wholly converted to kaolinite, but the quartz and anatase remained relatively constant. In the process of erosion, transport and deposition as a ball clay there was a continuation of the conversion of illite to kaolinite and a considerable loss of iron. The degree of crystallinity of the kaolinite also appears to increase slightly.

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The S.W. England granites and the concept of the "ternary" minimum: by J. R. Hawkes.

The concept of the "ternary" (isobaric) minimum embodies the view that granitic and allicd rocks result primarily from the fractional crystallization of hydrous, "residual" magmas under isobaric conditions. It was formulated by Tuttle and Bowen (1958) to account for the apparent coincidence between the actual C.I.P.W. normative compositions of most granitic rocks and those predicted by the position of minimum melting in the experimental system $NaAlSi_3O_8$ - $KA1Si_3O_8$ SiO_2 – H_2O at 500 kg./cm.^{2}- (PH_2O).

Since the C.LP.W. normative compositions of the S.W. England granites fall close to the " ternary " minimum position, it could be

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inferred that these plutons are simply the end products of the isobaric fractionation of an acid magma. However, the situation is more complex. Stone and Austin (1961) have shown that the K-feldspar megacrysts in the Tremearne Pegmatite and the Carnmenellis Granite grew in the solid state. Textural evidence in the other granites not only confirms this proposition, but suggests that probably all the K-feldspar developed by replacement of plagioclase. The replacive relationship between the two minerals is reflected in the modal compositions of individual specimens which, allowing for the plagioclase in perthite, may approximate to granodiorite, adamellite or even to true granite. As there is no regional, zonal pattern to this variation in the plagioclase/K-feldspar ratio, the feature cannot be ascribed directly to crystallization conditions required by the "ternary" minimum. Some might argue that it is due to post magmatic exsolution, but it is considered that the textural relationships favour autometasomatic K-metasomatism (Hawkes 1967, Edmonds and others in press). How then was this achieved ?

Tuttle and Bowen emphasised that crystallization in a hydrous melt need not be isobaric. A steady fall in pressure would allow the escape of dissolved water and so stimulate crystallization. Crystallization would proceed even though the temperature might rise if the heat of melting was not dissipated sufficiently quickly. Tectonic structures in the country rocks surrounding some of the Cornubian granites (Dearman and Butcher 1959, Freshney 1965, Edmonds and others in press), coupled with the low metamorphic grade of the region indicate that the intrusions reached a very high level. Because of this and a termination in the upward migration of the magma, it may be that falling pressure conditions in the upper parts of the batholith caused crystallization to switch from being isobarically controlled to become isothermal or perhaps partly adiabatic. It seems that due to the behaviour of dissociated water molecules, alkali cations arc more loosely held in a hydrous silicate melt than are the associated anion groups (Lacy 1960). Consequently, if the proposed switch in crystallization conditions occurred after the widespread nucleation of plagioclase but before any K-feldspar began to nucleate the dissolved hydrous phase could have extracted K-cations from the melt as it came out of solution.

A sudden loss of this K-rich fluid from the system may have been prevented if heat conducted from the margins of the intrusions

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rapidly built up relatively impermeable metamorphic aureoles. It is suggested that a steady migration of K-rich fluid from the interior of the batholith into the boss regions was instrumental in the K-feldspathization of plagioclase and thus a more immediate factor in determining the observed compositions of the granites than the theoretical "tertiary" minimum.

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A study of the Praa Sands elvan and its bearing on the origin of elvans : by M. Stone.

The elvans of S.W. England are generally grey or grey-green dyke-like bodies having "chilled" margins and a very fine-grained groundmass. They are commonly either quartz-feldspar porphyries with abundant megacrysts, e.g. Praa Sands, or felsites, which are poor or deficient in megacrysts and well-banded, e.g. Trevean Cove, Perranuthnoe. A general account of the field relations and petrology of elvans has been given by Exley and Stone (1964) who refer to evidence for emplacement at different periods and also to the multiple elvans of Tremore (St. Austell) and Praa Sands. The latter elvan is described in some detail below.

Field relations. The elvan is a 17 m wide vertical dyke emplaced in steeply-dipping Mylor Beds, containing F2 folds (Stone 1966), at the western end of Praa Sands. The north-west to south-east strike is parallel to the local

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hypothermal lodes and to the nearby similar elvan of Tregonning Hill. The dyke is a multiple body composed of two intrusion phases :

Intrusion I. A fine-grained felsitic banded rock, 30 to 45 cm wide, in contact with the Mylor pelites on each side of the central intrusion. Banding is parallel to the contacts.

Intrusion II. A coarse central intrusion, markedly porphyritic, but having a fine-grained groundmass that is distinctly coarser than Intrusion I. Towards the sharp contact with Intrusion I, the matrix becomes finer-grained and the megacrysts decrease in size. Rounded and ovoid lumps of fine-grained elvan (5 to 50 cm across) occur within Intrusion II. These lumps tend to contain fewer megacrysts of potash feldspar than the host rock.

Petrography. INTRUSION I is a "fluxion" banded felsite with millimetre-grained megacrysts of anhedral potash feldspar and 0.5 mm grained rounded quartz. Banding is due to an alternation of light and dark coloured layers, 0.5 to 1 mm thick, that are often discontinuous, and resemble the layering found in many rhyolitic rocks.

INTRUSION II. The coarse centre is a microcrystalline rock containing abundant megacrysts of subhedral potash feldspar (up to 30 mm long), rounded quartz (up to 8 mm in diameter), rectangular pinite (1 to 3 mm across) and subhedral tourmaline prisms (<2 mm long). The groundmass is granular, 0.1 to 0.3 mm grained, and composed of anhedral granular quartz, interstitial potash feldspar, chloritised biotite, muscovite and accessory apatite and zircon.

Rounded quartz megacrysts commonly have optically continuous prolongations that extend from a "straight edge", interpreted as a former crystal boundary. Former crystal boundaries are also marked out by planes of matrix inclusions. Several rounded or ovoid grains are compound grains. Potash feldspar occurs as subhedral megacrysts with anhedral graphic margins. It is cloudy and slightly microperthitic. Quartz grains, like those that occur in the groundmass, are included together with small sets of optically continuous graphic quartz. The innermost limit of the graphic zone is a straight edge that marks out a euhedral, graphic-free centre. The width of the graphic zone is 0.2 to 0.3 mm. Some grains have no graphic zone, but small apophyses of potash feldspar, optically continuous with the megacryst, penetrate between the quartz grains of the groundmass from a straight edge. $2V\alpha$ is 70" for potash feldspar megacrysts and 62° for smaller 0.3 to 1 mm diameter grains.

At the margin of Intrusion II, the matrix becomes almost cryptocrystalline (<0.05 mm) and contains many 0.2 to 0.5 mm sized grains of quartz and potash feldspar. Many of the quartz megacrysts have markedly rounded and embayed outlines. Graphic intergrowths are rare. $2V\alpha$ of potash feldspar is 62°, like that of the smaller megacrysts in the coarser parts of Intrusion II.

In these rocks, some of the potash feldspar shows sericitic alteration, like that commonly found in the plagioclase of nearby lithionite granites. There are also indications of former multiple twinning. Such grains take the

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cobaltinitrite stain and resemble similar "transformed" albites that occur in some greisens (Exley 1959, p.212 ; Stone 1965a, p.150).

Chemistry. Four new chemical analyses of the Praa Sands elvan are given in Table 1, columns 1 to 4. Most of the constituents have been analysed by the methods of Riley (1958), but MgO CaO, Na_2O and Li_2O have been determined by atomic absorption methods, and water was analysed by a Penfield method (Peck 1964). For comparison, analyses of the Tregonning Hill elvan are shown in columns 5 and 6, and an earlier analysis of the Praa Sands elvan given by Phillips (1875) is shown in column 7.

TABLE 1. Chemical analyses of elvans

		1	2	3	4	5	6	7
SiO_2	...	70.4-	72.3-	71.3--	73.8-	72.12	71.8-	73.8-
TiO_2	...	.38	.12	.26	.04	n.d.	.19	.22
Al_2O_3	...	13.93	14.46	14.05	14.37	13.31	13.77	13.28
Fe_2O_3	...	1.88	1.19	1.45	1.09	tr	1.61	2.17
FeO	...	1.71	.42	1.60	.61	3.87	1.33	.87
MnO	...	.06	.05	.05	.05	.62	.06	.04
MgO	...	.53	.23	.48	.23	1.52	.45	.45
CaO	...	.19	.39	.28	.49	.60	.44	.31
Na_2O	...	.18	.26	.20	.20	.43	.09	.14
K_2O	...	9.00	8.33	8.78	6.70	6.65	8.50	6.89
Li_2O	...	.03	.04	.03	.03	n.d.	.04	.05
P_2O_5	...	.22	.32	.26	.37	n.d.	.25	.25
H_2O+	...	1.62	1.36	1.41	1.53	.49	1.25	.91
H_2O	...	—	—	—	—	.11	—	—
		100.14	99.47	100.15	99.51	100.11	99.78	99.38

Columns 1-5: Praa Sands.

1. Loose block of fine-grained inclusion in coarse elvan (MS 0013).
2. Margin of Intrusion II (MS 0023).
3. Coarse centre of Intrusion II (MS 0025).
4. Fine banded contact, Intrusion I (MS 0026).
5. Coarse porphyritic elvan, Praa Sands (Phillips 1875. Anal. I, p.335).

Columns 6 and 7: Tregonning Hill (Exley and Stone 1964, Table 9).

6. Porphyritic centre of elvan dyke (MS 0060).
7. Fine-grained banded margin of dyke (MS 0054).

Columns 1-4, new analyses : Analyst M. Stone assisted by R. Ellis.

Examination of the analyses shows clearly that there are similarities between Intrusion I and the margin of Intrusion II, when these are compared both with the centre of II and the "inclusions" in II, although there are clear differences in the K_2O and TiO_2, contents. The "inclusions" (column 1) are very similar to the centre of II, and cannot be considered as relics of the earlier Intrusion I. The very high contents of K_2O and the extremely small

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amounts of Na_2O in all four samples are striking, as also arc the differences between these data and those of Phillips (column 5). There is a much closer affinity between the elvans and the biotite granites (cf. Exley and Stone 1964, Table 6, column 1) than between the former and the lithionite granites. The differences in SiO_2 and K_2O between Intrusions I and II are also reflected in the edge and centre respectively, of the Tregonning Hill elvan, although in this elvan there is no evidence for more than a single intrusion phase.

Interpretation of the textures. The occurrence of rounded, and particularly of rounded compound grains of quartz, "clumps" of quartz and potash feldspar and the presence of granite xenoliths in some elvans, e.g. Trevean Cove, point to the origin of coarser components as xenocrysts. This is further supported by the association of "chilled" groundmass with smaller megacrysts. It would seem that megacrysts have been transported with or close to the groundmass that now surrounds them. However, it is clear that the larger megacrysts have also acted as nuclei for further growth in place. Optical continuity of prolongations from megacryst into groundmass and graphic intergrowths from straight edges indicate continued growth after the groundmass had " crystallised " and ceased to move.

Rounded quartz has been interpreted as corroded quartz (Barrow 1906, Hill and MacAlister 1906, Reid and Scrivenor 1906). Corrosion could result from the diminution of the quartz stability field in the quartz-feldspar-water system as the partial pressure of water vapour falls upon intrusion to higher crustal levels (cf. Tuttle and Bowen 1958). Here again it is implied that the megacrysts have been brought up from deeper levels. Thus, the Praa Sands and similar elvans would appear to be composed of three distinguishable textural components: (i) A fine-grained groundmass, interpreted as a "condensed" mobile phase. (ii) Early megacrysts, interpreted as xenocrysts. (iii) Later growth and recrystallisation on (ii).

Origin. The decrease in grain size from the centre of the Praa Sands elvan towards its margin indicates chilling. However, as suggested by Reid and Scrivenor (1906 p.51), the change in grain size could be due to the influx of progressively coarser material into the centre of a widening fracture. This would account for the change in grain size of both megacrysts and groundmass. A break in the flow of material would result in the appearance of a multiple intrusion. It is implied here that there may be some sorting of grain size with time.

The occurrence of pinite suggests either contamination by pelite, or, perhaps the partial fusion and mobilisation of pelitic material. However, contamination by or selective fusion of pelite would not, by itself, produce rocks so rich in potash and so deficient in soda. The Q-Ab-Or plot (Fig. 1) shows that the compositions of Intrusion II and the centre of the Tregonning Hill elvans, plot close to the Quartz-Orthoclase eutectic at 3,000 bars partial pressure of water vapour. The marginal phases are distinctly richer in quartz. It is unlikely that these compositions have been derived from the direct crystallisalion of magma : such magmas are unknown and, in any case, they would have very high viscosities (Reynolds 1958, Tuttle and Bowen 1958). Most alkali-rich siliceous igneous rocks that are thought to have had a

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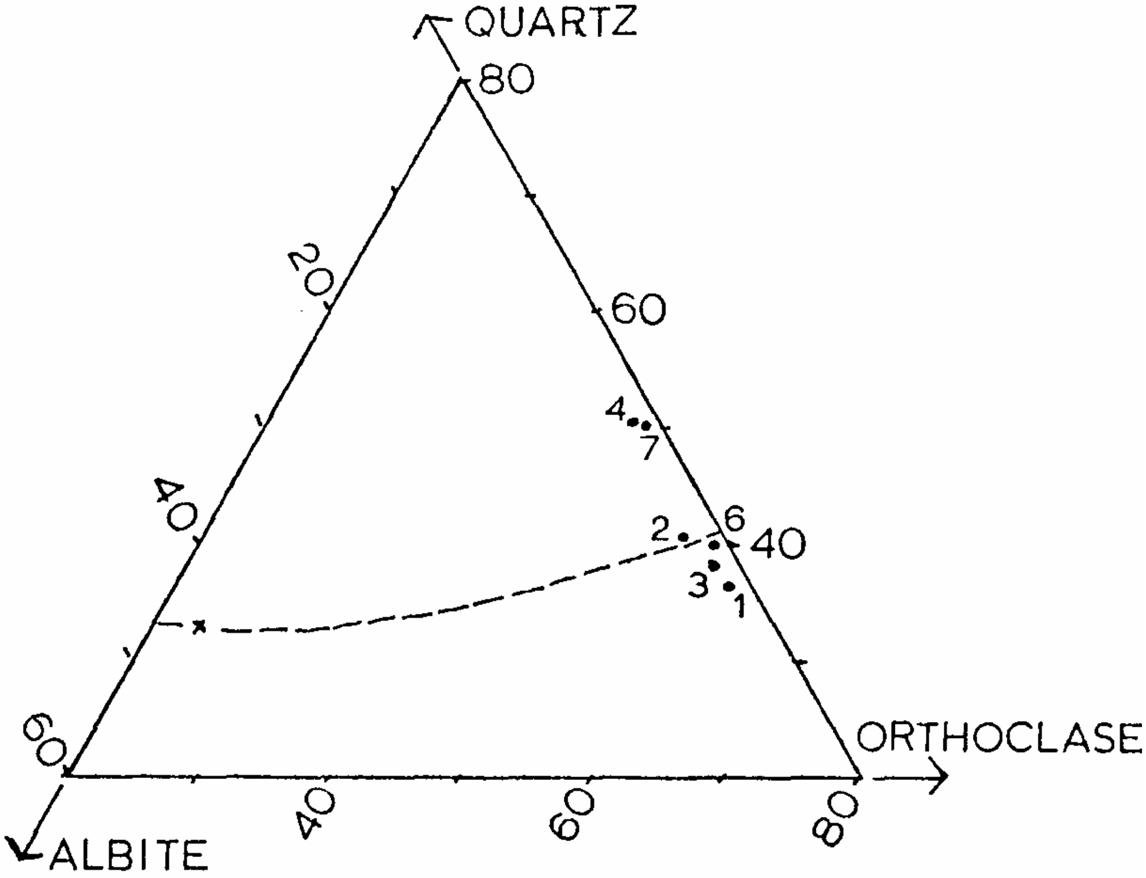

FIGURE I. Plot of molecular norms of elvans in the ternary diagram Quartz-Albite-Orthoclase. Numbers correspond with analyses listed in Table l. The experimental minimum and cotectic at 3,000 bars water vapour pressure (from Tuttle and Bowen 1958, Fig. 25) are shown.

magmatic origin plot in the region of ternary minima in the alkali granite system (Tuttle and Bowen 1958, Exley and Stone 1964).

The position of the plots in Figure 1 and the textural evidence for the late replacement of both groundmass and former plagioclase crystals suggest that the present compositions could have been attained by alkali ion-exchange. Indeed, the analysed elvans lie at the potassium end of the regression line in the K_2O-Na_2O diagram given by Stone (1965b Fig. 2d) and as this trend is considered to result from alkali ion exchange, the elvans show the extreme enrichment in potassium at the expense of sodium. Such marked enrichment can only be attained by an efficient exchange mechanism like that in an ion exchange column. This implies a mobile phase that passes through a particulate medium.

Features consistent with those given above might be found in a magmatic (i.e. crystal-silicate liquid) system that has undergone ion-exchange after its emplacement and consolidation or in a particle-fluid system that can undergo reaction during transport. The latter system, which is essentially a fluidized one (see Reynolds 1958). would account for grain size variation in terms of elutriation, for potassium enrichment in terms of highly efficient ion exchange and for the alignment of megacrysts in the coarse central phase of Intrusion II. Recent work by the writer on Caledonian felsites near Callander and

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Comrie, in Perthshire, shows that some of these are associated with explosion brecciation and have probably been emplaced as "fluidized" systems.

Clearly, more data are required before firmer conclusions can be drawn concerning the nature of the clvans at the time of emplacement. However, it is reasonable to conclude that the present composition of the elvans have been derived from normal granitic material (biotite granite) by alkali ion-exchange.

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Fluorine and chlorine in some granitic rocks :

by R. Fuge and G. M. Power.

Although previous workers have provided a reasonable number of fluorine analyses from tile granitic rocks of South West England, only a few chlorine analyses have been made and most of these only record "trace" amounts of chlorine. Using a modification of the colorimetric procedure outlined by Huang and Johns (1967) a variety of granitic rocks from South West England have been analysed for chlorine and fluorine.

From our analyses it may be seen that the unaltered granites tend to have between two and three times as much fluorine and chlorine as the average for world granites. When the granites are altered, however, they tend to have much lower halogen contents.

The high fluorine and chlorine contents of the unaltered granites may be explained by simply assuming that the granite melt was far higher in these elements than would normally be expected. This may be a phenomenon associated with Hercynian granites in general, as certainly some of those of Germany are much higher in fluorine than the world average. Alternatively, we would like to postulate that one of the reasons for the high halogen content of the South West granites could be an association with the potassium metasomatism which has been shown to be quite extensive in these granites. (See Exley and Stone 1964.) Here it might be interesting to note that Sahama (1945) records an analysis of a composite sample of rapakivi granites in which chlorine and fluorine are extremely high. These granites are also extremely high in potassium.

In order to consider the possible role of potassium metasomatism in more detail, it is necessary to outline the possible behaviour of fluorine and chlorine during crystallisation. From a study of the fluorine and chlorine contents of glassy and crystalline rocks from a suite of extrusive igneous rocks, Noble, Smith and Peck (1967) conclude that on slow crystallisation of a lava as much as half the original fluorine and four-fifths of the chlorine are lost. By analogy, a similar loss may take place from the magma during the cooling of plutonic rocks. During differentiation of a granitic magma, fluoride and chloride ions are competing for the same lattice sites, that is mainly the hydroxyl positions in the hydroxysilicates.

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Fluorine is more likely to occupy these sites because its ionic radius is very similar to that of the hydroxyl ion so that as crystallisation proceeds more fluorine would be taken into the crystallised fraction and only comparatively little chlorine. As few sites are available for chlorine most of the original chlorine together with a large amount of the original fluorine may be lost from the magma. However, if the magma were to become enriched in potassium during differentiation then the strongly electropositive potassium ions might exert a "binding" influence on the strongly electronegative halogen ions so tending to hold them in the magma. Fluoride ions would still be preferentially accepted into lattice positions and some of the chlorine held within the magma might be retained in the crystallised fraction as fluid inclusions or by adsorption on to surfaces. Thus, chlorine may well be present in two ways in the crystallised rock, that "firmly" held in lattice positions and a larger amount "loosely" held as inclusions and by adsorption.

From our analyses a summary may be made of the effects of alteration on granitic rocks and their chlorine and fluorine content. During the initial stages of alteration there is a large decrease in chlorine, perhaps corresponding to our supposed "loosely" held chlorine, and only a small decrease in fluorine. As alteration proceeds a point is reached where the chlorine content shows only small changes with further alteration but the fluorine content now decreases more rapidly. This is a simplified model and does not account for the possibility of several superimposed phases of alteration, or the introduction of either of these elements during alteration, as for example during greisening when fluorine appears to be introduced.

Further work is in progress in which we hope to define the geochemistry of these elements more fully. We would like to thank Drs. B. Booth, C. S. Exley and M. Stone for providing granitic samples for analysis without which this work could not have been attempted.

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Tin and lead in the Land's End aureole, Cornwall : by P. A. Floyd.

In view of the extensive Cu-Sn mineralization of the Land's End granite and its aureole rocks, a series of "greenstone-hornfelses" were analysed for some of the metalliferous elements that compose the mineral lodes. This is part of a larger geochemical programme to determine the mobility and degree of metasomatic activity of various ions in hornfelses of basic rock parentage. This note is essentially a progress report outlining the distribution of Sn and Pb. These elements are largely concentrated in acidic rocks and characteristically depicted in both magmatic and metamorphic basic rocks. On the other hand, Cu is concentrated in basic rocks relative to acidic and will be dealt with separately (p.49).

The samples were collected to represent areas showing different degrees of mineralization (two with numerous ore veins and two with little or no evident mineralization) in an attempt to determine if a zone showing abundant mineralization was reflected by an anomalously high Sn and Pb content of the host hornfelses. That is, although some of the zones had suffered extensive mineralization, largely confined to structural planes in the rocks (the regional pattern of veins), had the adjacent hornfelses also been invaded by "dilute" ore fluids during contact metamorphism? As none of the rocks examined in thin section showed any ore minerals (cassiterite and galena) present, it was assumed that the Sn and Pb were largely confined to the silicate phases.

Table I shows the Sn and Pb averages and concentration ranges for the different sample areas (Cu added for comparison). Although few samples are available, these preliminary results indicate that the metalliferous content of the hornfelsic host bears little relationship to the density of workable lodes in the area. That is, Sn, Pb (and Cu) analysis of the metamorphic hornfelses of the Land's End aureole would not be a guide to the regional location of any ore veins. Metal anomalies encountered during geochemical prospecting (using stream sediments or soils) would be considerable more productive in delimiting metalliferous regions.

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TABLE 1. Average Sn, Pb and Cu content for the four sample zones around the Land's End aureole. All values in p.p.m.

Traverse zone			"mineralized" (workable lodes)		"non-mineralized" (few or no economic lodes)	
			Zawn-a-Bal	Kenidjack	Tater-du	Newlyn
Sn	average	...	22[1]	<5[2]	14	16
	range	...	6 — 50	(<5)	<5 — 59	5 — 31
Pb	average	...	<10[1]	<10	<10[5]	<10
	range	...	(<10)	(<10)	(<10)	(<10)
Cu	average,	...	70	43	64	136
	range	...	6 — 183	6 — 180	13 — 180	86 — 175
Number of samples.			5	10	16	3

Notes :

1. Excluding 1 sample of 480 p.p.m. Sn.
2. All samples below detection limit (5 p.p.m.).
3. All samples below detection limit (10 p.p.m.).
4. Excluding l sample of 96 p.p.m. Pb.
5. Excluding 1 sample of 51 p.p.m. Pb.

For the purposes of comparison only, all values below the detection limit for Sn have been included in the averages as zero p.p.m. Thus the Sn averages are relative only and do not reflect "real" average values.

Of the "greenstone-hornfelses" analysed some were metamorphic hornblende hornfelses and others metasomalic hornfelses (Fe-Mg-rich hornfelses and Ca-rich hornfelses). Table 2 lists the analytical results for the different hornfelsic groups. In every case (excluding the anthophyllite-bearing hornfelses) the actual concentration of Sn (or the average Sn values) in the hornfelses exceeds the average value of about 1 p,p.m, for basic rocks (Hamaguchi and others 1964, Onishi and Sandell 1957). Although Pb is below the detection limit (10 p.p.m.), it probably has a range comparable to the average value of 6 p.p.m, found for balsaltic rocks (Turekian and Wedepohl 1961). The two very high values probably represent "contamination" by galena.

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TABLE 2. Distribution of Sn and Pb in metamorphic and metasomatic hornfelses from the Land's End aureole

No.	Sample No.	Sn (p.p.m.)	Pb (p.p.m.)	Mineral assemblage	Traverse location
Actinolite hornfelses					
1	LE 12	5	<10	Biotite-actinolite-plagioclase	Newlyn, Penlee Pt
Hornblende hornfelses					
2	LE 38	<5	<10	Plagioclase- diopside-hornblende	Tater-du
3	LE 40	<5	<10	Biotite---hornblende	Tater-du
4	LE 48	<5	<10	Hornblende	Kenidjack
5	LE 47	<5	<10	Biotite-hornblende (rare anthophyllite)	Kenidjack
6	LE 58	6	<10	Hornblende-biotite	Zawn-a-Bal
7	LE 41	12	<10	Plagioclase-diopside-hornblende	Tater-du
8	LE 57	13	<10	Biotite-diopside-hornblende	Zawn-a-Bal
9	LE 11	13	<10	Hornblende-plagioclase	Newlyn, Gwavas
10	T 4	14	<10	Plagioclase-biotite-hornblende	Tater-du
11	LE 42	15	<10	Diopside-hornblende	Tater-du
12	T 22/1	25	<10	Sphene-diopside-hornblende	Tater-du
13	T 5/2	29	51 (a)	Plagioclase-hornblende	Tater-du
14	LE 10	31	<10	Hornblende-plagioclase	Newlyn, Gwavas
15	LE 39	33	<10	Garnet-plagioclase-diopside-hornblende	Tater-du
16	LE 62	480 (a)	96 (a)	Epidote-garnet-hornblende	Zawn-a-Bal
Average (b)		19	<10		
Average (c)		14	-		
Cummingtonite hornfelses					
17	LE 53	<5	<10	Biotite-cummingtonite	Kenidjack
18	LE 37	<5	<10	Cummingtonite	Tater-du
19	LE 32	<5	<10	Plagioclase-cummingtonite-biotite	Tater-du
20	LE 50	<5	<10	Cummingtonite	Kenidjack
21	LE 34	<5	<10	Plagioclase-grunerite	Tater-du
22	LE 35	<5	<10	Biotite-cummingtonite	Tater-du
23	LE 49	<5	<10	Pleonaste-chlorite-cummingtonite--biotite	Kenidjack
24	LE 36	<5	<10	Plagioclase-biotite-cummingtonite	Tater-du
25	LE 33	<5	<10	Plagioclase-cummgtonite-biotite	Tater-du
26	LE 61	17 (a)	<10	Biotite-cummingtonite	Zawn-a-Bal
27	LE 60	50 (a)	<10	Pleonaste-cummingtonite	Zawn-a-Bal
Average =		<5			
Anthophyllite hornfelses					
28	LE 54	<5	<10	Pleonasic-cordierite-anthophyllite	Kenidjack
29	LE 51	<5	<10	Cordierite--anthophyllite	Kenidjack
30	LE 52	<5	<10	Plagioclase-biotite-cordierite-anthophyllite	Kenidjack
31	LE 55	<5	<10	Plagioclase-cordierite-anthophyllite	Kenidjack
32	LE 56	<5	<10	Plagioclase-biotite-cordierite-anthophyllite	Kenidjack
Average =		<5	<10		
Calc-silicate hornfelses					
33	T 29/1	41	<10	Diopside-axinite--garnet	Tater-du
34	T 44	59	<10	Sphene-plagioclase-diopside	Tater-du
Average =		50	<10		

(a) Excluded from averages (probably represent ore "contamination")
(b) Excluding all values below detection limit
(c) Including all values below detection limit; values being counted as zero p.p.m.

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Consideration of the various hornfelsic groups shows that compared to the parental hornblende hornfelses, the Fe-Mg hornfelses (anthophyllite and cummingtonite-bearing) and the Ca hornfelses (calc-silicate bearing) exhibit lower and higher average contents of Sn, respectively.

The Sn^{2+}ion has an ionic radius comparable to Ca^{2+} and accordingly may be expected to proxy for this ion in Ca-bearing minerals (Ringwood 1955a). Whole-rock CaO increases in the various hornfelses as follows : anthophyllite hornfelses < cummingtonite hornfelses < hornblende hornfelses < calc-silicate hornfelses ; thus the different Sn values essentially reflect the availability of sites (as represented by the Ca content) in each hornfelsic group.

Sn occurs in magmas as Sn^{2+} and Sn^{4+} ions (Rankama and Sahama 1950), although Ringwood (1955b) suggests that the quadrivalent ion does not enter silicate lattices due to the formation of the large $(SnO_4)^{4-}$ complex. Thus Sn will occur in the hornfels silicates as Sn^{2+} and in cassiterite Ore as Sn^{4-}.

There is little doubt that Sn was added to the aureole hornfelses by the consolidating granite during contact metamorphism. This metasomatic Sn would be the Sn^{2+} ion which distributed itself according to the number of sites available. The Sn building up in the crystallizing granite as $(SnO_4)^{4-}$ would eventually be concentrated enough to form its own mineral species. This is now found as the late cassiterite-bearing lodes.

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Copper content of metamorphic and metasomatic basic hornfelses, Land's End aureole : by P. A. Floyd.

Early mine workers in the Land's End area were familiar with the association of Cu-bearing lodes with the metamorphosed basic igneous rocks ("green stones") and the slates ("killas") of the aureole (Dewey 1923). Sn-bearing lodes, on the other hand, appeared to be preferentially associated with the granite outcrop. Although exceptions can be found, the world-wide association of Cu mineralization with basic igneous rocks or their metamorphic equivalents implies some form of genetic relationship.

In view of this association and the apparent mobility of Cu under regional metamorphic conditions (Heier 1960), a series of metamorphic and metasomatic hornfelses of basic igneous rock parentage from the Land's End aureole, Cornwall, were spectrographically analysed for Cu. The object of this programme was to determine (1) the distribution and average concentration of Cu in the different hornfelsic groups (metamorphic and metasomatic) and (2) to see if any variation in Cu concentration could be correlated with the degree of metamorphism and metasomatism suffered by the original basic igneous rocks.

Some 34 samples were obtained from four traverse zones (Zawn-a-Bal, Kenidjack, Tater-du and Newlyn) around the aureole, these represent metamorphic hornblende hornfelses, metasomatic Fe-Mg-rich hornfelses and metasomatic Ca-rich hornfelses. The petrochemistry and mineral assemblages of rocks similar to those analysed has been described elsewhere (Tilley 1935, Floyd 1965). In an attempt to exclude any Cu deposited from migrating ore fluids, none of the samples were collected in the immediate vicinity of ore veins. Little chalcopyrites was found in any of the hand specimens.

TABLE 1. Distribution of Cu in various metamorphic and metasomatic hornfelses of the Land's End aureole.

Hornfelsic types	Cu (p.p.m) average	Cu (p.p.m) range	Number of samples
1. Metamorphic hornfelses			
Actinolite-bearing	147	-	1
Hornbende-bearing	85	6-180	15
2. Fe-Mg metasomatic hornfelses			
Cummingtonite-bearing	49	6-183	11
Anthophyllite-bearing	31	16-55	5
3. Ca metasomatic hornfelses			
Calc-silicate-bearing	69	59-80	2

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Table I shows the range of Cu concentration and the averages for the different hornfelsic groups. The results show a wide spread from 6-183 p.p.m. with an average for all samples at 67 p.p.m. On comparing the different groups (excluding the actinolite-bearing hornfels), the metamorphic hornblende hornfelses show a significantly higher average Cu content than the metasomatic hornfelses. As the latter metasomatic group were developed from the parental hornblende hornfelses by local Fe-Mg and Ca metasomatism, considerable Cu was released during their formation. That is, Cu appears to have been mobile during the phase of contact metasomatism of the aureole basic hornfelses. Local depletion of Cu from basic rocks during metamorphic processes may be of importance when considering the origin of Cu sulphide ores which often characterize low-grade metamorphic terraines.

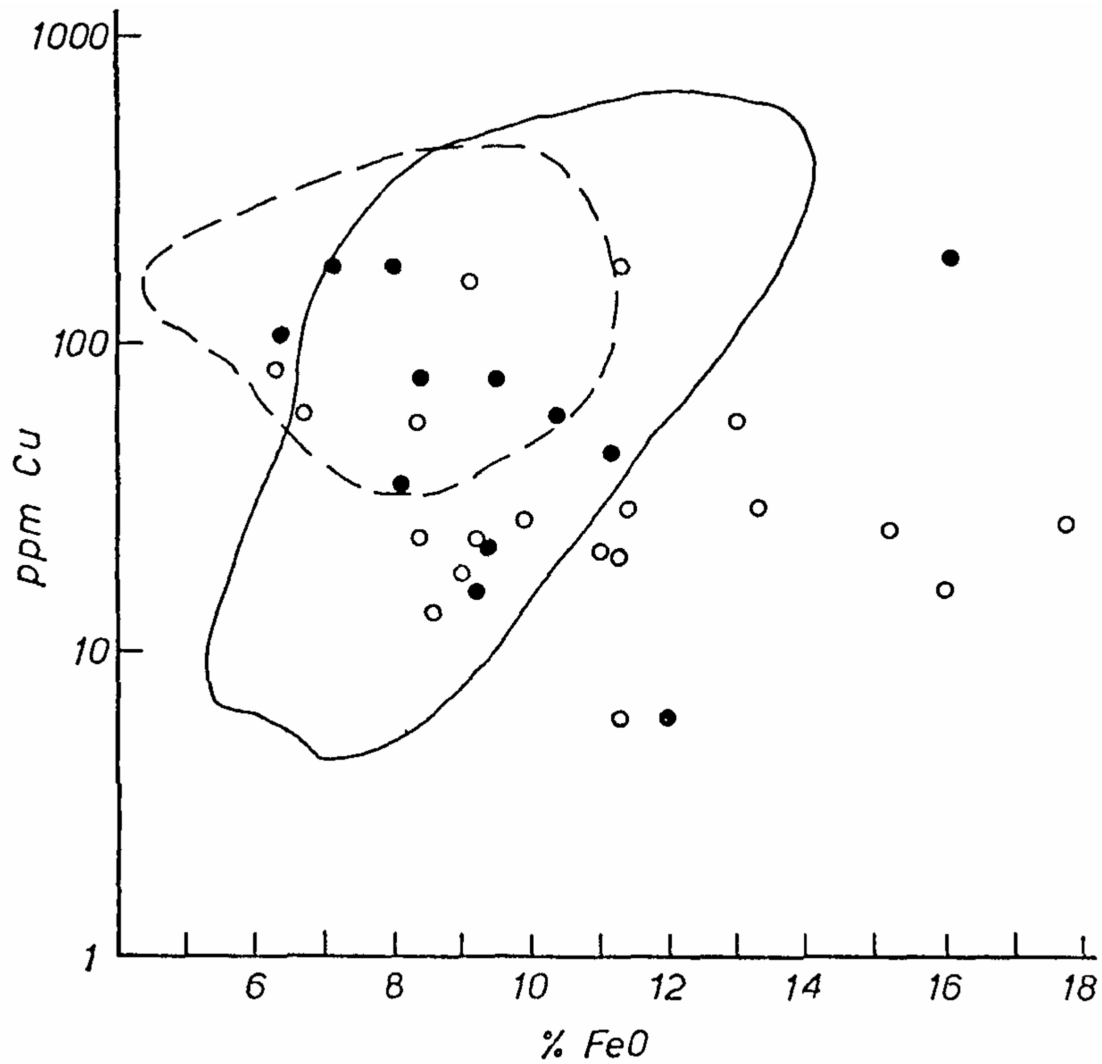

FIGURE 1. Distribution of Cu and FeO in basic igneous rocks (field enclosed by broken line) and ortho-amphibolites (field enclosed by solid line) compared with metamorphic hornfelses (dots) and metasomatic hornfelses (circles) from the Land's End aureole.

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Comparison of the average Cu content of the hornblende hornfelses (85 p.p.m.) of the Land's End aureole and similar basic igneous rocks (115 p.p.m. average) tentatively suggests that the original basic intrusives of the aureole underwent some degree of subtractive Cu metasomatism during contact metamorphism. If the Cu content of the original basic igneous rocks of the aureole was initially higher, then the metamornhic hornblende hornfelses and the metasomatic hornfelses have lost about 26% and 65% respectively of their original Cu content during contact metamorphism. On the other hand, the average Cu content of the hornblende hornfelses may represent the original Cu content of the basic intrusive magma. Few igneous basic rocks have average Cu contents below 100 p.p.m., although the above average (85 p.p.m.) can be matched in 150 unmetamorphosed basalts (87 p.p.m. average) analysed by Turekian (1956).

A plot (Fig. 1) of Cu against FeO for world-wide ortho-amphibolites (represented by the enclosed field) suggests a sympathetic relationship between these two elements, Consideration of the crystal-chemical characteristics confirms that Cu can proxy for Fe^{2+} (as Cu^{2+}) and also Na^{+} (Cu^{+}) in the silicates of basic igneous rocks. Note that a high proportion of the Land's End hornfelses fall outside the ortho-amphibolite field and do not appear to obey the general relationshin. That is, for relatively high values of FeO, the hornfelses are depleted in Cu relative to the ortho-amphibolites. The fact that these hornfelses are largely of metasomatic origin, underlines the mobility of Cu during the metasomatic phase of contact metamorphism in the Land's End aureole.

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Pleistocene episodes of the North East Celtic Sea trough :
by J. Dixon.

The southern portion of St. George's Channel, lying within the Celtic Sea, has been extensively explored by means of corer, Asdic, echosounder and Boomer. Profiles from the latter show a general absence of structures in the sediments for many miles around the channel. However, several irregular gently dipping interfaces are evident in the material beneath the present day feature. It is possible to trace three of these interfaces over a wide area and each interface itself forms a trough.

The mode of origin of these successive troughs is suggested by their geographical position along a major path of Pleistocene ice flow and by their morphology. The deepest interface seen on the Boomer profiles possibly represents the rock floor of the trough. However, it remains to be determined whether this rock trough was entirely cut by ice or was structurally controlled during its development by an earlier or contemporaneous feature. This deepest trough reaches over 700 ft below sea level at its deepest point and rises to the present sea floor along its eastern and western margins. During Pleistocene times the trough was probably partially filled with sediments and re-excavated during later glaciations, a morainic sill remains blocking the southern end of the trough at the present day. The 350 ft thickness of sediment in the trough is probably of Pleistocene age and the succession may be more complete than any found on the nearby land areas. The whole feature is thinly masked by late Holocene deposits (Belderson and Stride 1966).

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Water from the "Bunter" in West Somerset : by F. W. Sherrell.

The use of the term Bunter is here taken to include the Beds which, on the Geological Survey Maps are designated by the symbol f_2 and f_5 namely the Pebble Beds/Conglomerate, and the overlying Sandstone. Inasmuch as these beds have a common water table, they constitute a single aquifer unit.

The pattern of faulting in the Triassic Rocks to the north and west of Taunton, create what may be termed "groundwater compartments" in the area. These compartments are referred to as :-

			Catchment area of outcrop
Bishops Lydeard Compartment	…	c.	7 sq. miles
Halse Compartment …	…	c.	4 ,, ,,
Wellington Compartment	…	c.	10,, ,,

Lithologically, the Bunter in West Somerset differs from that to the south, for in addition to a different suite of pebbles, the beds are strongly cemented by calcium carbonate. Similar cementing is observed in the overlying Sandstone, in addition to which these Sandstones contain frequent marly or marlstone horizons and concretionary sandstones in a fine marly-sandstone matrix. These conditions conspire to give a significantly lower permiability for the aquifer than that which obtains in the south.

An exploratory programme, involving the sinking of a 12 in diameter borehole in the Bishops Lydeard Compartment and a similar borehole in the Halse Compartment was carried out, with provision for observation borings, for pumping-test observations. The two 12 in bores were located at Bishops Lydeard (ST 17953070) and Tylers Bridge (ST 12602895). The results obtained were very disappointing and it was decided not to proceed with observation bores. The main factors revealed by the two borings may be summarised thus :

i. Very low permiability was revealed in both Sandstone and Conglomerate.

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ii. Pronounced changes take place in a distance of little over one mile from the outcrop of the Pebble Bed Conglomerate. Conglomerates which are very readily recognisable at Coombe Florey, are almost unidentifiable one mile or so to the east, in the Bishops Lydeard Borehole. Similarly, massive conglomerate which may be seen in the escarpment to the north of Hillfarance Brook, is virtually unrecognisable in the succession at Tylers Bridge, a distance of less than one mile 'down-dip' from the escarpment.

iii. The Bunter was fully penetrated in both borings, and the underlying Permian Marl proven at depths of :

	- 166 ft O.D. at Bishops Lydeard
and at	+ 40 ft O.D. at Tylers Bridge.

Total depths of Bores	Bishops Lydeard	= 417 ft
	Tylers Bridge	= 200 ft

iv. Brief pumping-tests indicated a maximum safe yield of 5,000 g.p.h. at Tylers Bridge, whereas the maximum at Bishops Lydeard was only 3,500 g.p.h. Such yields were derived from a total penetration in Triassic material of 382 ft at Bishops Lydeard, and 180 ft at Tylers Bridge.

This contrast is significant, in that it shows a decrease in net permiability, as the aquifer passes to lower datum eastwards. It is suggested that the slower circulation, indeed almost ‘fossil water’ conditions, allow deposition of calcium carbonate thus reducing permiability even more, as the aquifer passes to greater depth under Keuper Marl cover.

These results, together with exploration in the Bunter at Washford (Borehole 350 ft deep, yielding c. 4,000 g.p.h.) and one at Minehead in ‘Keuper’ Sandstone (Borehole 275 ft deep yielding *c*. 5,000 g.p.h.) suggest that :

i. The Bunter of West Somerset, in the area north of Milverton cannot sustain yields to bores at a rate exceeding 5,000 g.p.h. (excluding freak or ‘chance’ conditions).

ii. Economical development by statutory water undertakings is not practicable with low yields of this order.

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Aspects of the raised beaches of South Cornwall :
by H. C. L. James.

Two distinct raised beaches, one at approximately 25 ft O.D. and the other at 15 ft O.D., were traced along the south coast of Cornwall from Cape Cornwall to Fowey. Neither beach shows any sign of warping. The upper beach is more widespread and in a better state of preservation than the 15 ft beach. The latter, being only 5 ft above H.W.M., is subjected to more rapid erosion, the deposits are often missing and the platform itself tends to be fragmentary.

From Cape Cornwall to Land's End, the average height of the base of the raised beach, which was always found to be in direct contact with the wave cut platform is 13 ft (above H.W.M.), and, as a result of levelling and interpolation, the height of the raised platform/cliff notch was found to be 33 ft O.D. Towan beach, two miles north-east of Zone Point, is a typical site of a raised beach in S. Cornwall revealing the following features :

1. The decrease in height of the raised platform from the headlands into the bay (8 ft above H.W.M. on the southern headland, decreasing to 2 ft along Towan Beach, then disappearing in the centre of the valley marked by the footpath leading to Porth Farm (SW 867329) before reappearing once more north of the footpath at a height of 2 ft above H.W.M., and, finally, in the north, rising once more to 6 ft).

2. The platform is cut across the local bedrock and has a seaward dip of 3-4°.

3. Stratified marine deposits, mostly of sand and pebbles, occur on the raised platform. These are formed essentially of quartz and local rocks ; exotic material, mainly flint, is rare.

4. Iron and manganese cementing occurs within the raised beach deposits, being particularly widespread near the base of valleys which open out on to the beach.

5. The marine deposits on the raised platform are overlain by thick sections of head which has often slumped on to the present beach.

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6. No shell or carbonaceous material was found within the raised beaches.

At present an altitudinal correlation appears to be the only possible method of dating the deposits. Both Clarke (1965) and Orme (1962) use the altimetric nomenclature of Zeuner (1959) and correlate the 25 ft platform with the Late Monastirian, while the lower fragmentary 15 ft platform is dated as Epi-Monastirian, a late still-stand in the last Interglacial. Zeuner's correlations of the former sea-levels are tentatively accepted here, for, apart from altitudinal similarities, the platforms and marine deposits, while not necessarily contemporaneous, clearly pre-date at least one glacial period. The comparatively fresh appearance of the 25 and 15 ft platforms suggests a late date, antedating the last major glacial period rather than pre-glacial.

CLARKE, B. B., 1965. The superficial deposits of the Camel estuary, and suggested stages in its Pleistocene history. TRANS. R. GEOL. SOC. CORN., Vol. 19, p.257-279.

ORME, A. R., 1962. Abandoned and composite sea cliffs in Britain and Ireland. IR. GEOGR., Vol. 4, p.279-291.

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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 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 shall be one pound, 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 Secretary, a Treasurer, an Editor and six 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 may be effected by simple majority vote at the Annual Business Meeting.

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