PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME ONE

PART TWO

Edited by
M. R. HOUSE

CAMBORNE, SEPTEMBER 1963
PRICE 7/6

THE USSHER SOCIETY

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CONFERENCE OF THE USSHER SOCIETY HELD AT EXETER, January 1963

CHAIRMAN'S REPORT

The Ussher Society was founded (if such a pretentious word can be used to describe the changes of organisation that took place) at the 5th of a series of January Conferences, which was forthwith deemed to be the first conference of the Society. Abstracts of its proceedings were duly published as Part One of the journal. As the Society does little else besides hold an annual conference, this report is concerned chiefly with the Second Conference held at the University of Exeter in January 1963.

The very heavy snowfalls that had been taking place since Christmas made the excursions, which were to have preceded and followed the conference, quite impossible. But otherwise the very difficult travelling conditions, which had partly isolated Exeter by road, though not by rail, affected the meetings very little. Only a handful of those who had intended to come failed to get through.

A notable absentee was Ronald Waters, who was one of the organisers of the initial Conference of 1956 and was actively concerned with all the subsequent ones. His departure to occupy the Chair of Geography at the University of Canterbury, Christchurch, New Zealand, is a real loss to the Society.

On the other hand, the Society has an accession of strength to record in several officers of the Geological Survey, notably G. Bisson, the new District Geologist based at Okehampton, and J. E. Wright, who was present at the conference.

The renewal of primary survey in the South West on the 6-inch maps of the Okehampton 1-inch sheet, 324, after a period of fifty years is most satisfactory, and will greatly forward the work in which the Society is interested.

Paid up members of the Society in 1962 numbered eighty-five, and there is good reason to suppose that membership will be maintained in the coming year. The next conference in January 1964 will be held at Torquay, the Society having gladly accepted an invitation from the Torquay Natural History Society to use their hall.

S.Simpson.

PROGRAMME

The lectures which were given to the conference are listed below and the numbers follow the sequence of contributions to the first conference. Abstracts and contributions which are printed here are marked with an asterisk on the list.

2nd January

33.*Dr. K. F. G. Hosking and Mr. P. Ong : “The distribution of tin and certain other heavy metals in the superficial portions of the Gwithian/Hayle Beach of East Cornwall.”
34. *Dr. A. T. G. Dollar: “The seismicity of the Cornubian peninsula in relation to its structure.”
35. *Mr. D. L. Jones : “The accessory minerals of the Scilly Isles granites.”
36. *Mr. M. Stone: “Lithium in the Tregonning-Godolphin granite complex.”
37. *Dr. K. F. G. Hosking : “Supergene galena and pyrite from Wheal Hope, Cornwall.”
38. Dr. A. T. J. Dollar: “Petrological and chemical evidence for the age of the Lundy dyke swarm.”

3rd January

39. GUEST SPEAKER, Dr. W. S. Mackenzie : “Laboratory studies on the origin of granites and related rocks.”
40. *Mr. B. Clayden : “The relationship of soil development to site on Culm shales.”
41. *Dr. E. C. F. Bird : “Coastal landforms of the Dodman district " (taken as read).
42. *The Rev. B. B. Clarke : “Erosional and depositional features of the Camel estuary as evidence of former Pleistocene and Holocene strandlines.”
43. *Mr. E. T. Vachell : “The structure of the Torbay region-the Marldon Beacon nappe.”
44. *Mr. M. J. Ripley : “The geology of the Watergate Bay area, Newquay, Cornwall.”
45. *Mr. A. H. Stride: “North-east trending ridges of the Celtic Sea.”

4th January

46. *Dr. J. M. Thomas: “The Culm Measures succession in North-east Devon and North-west Somerset.”
47. *Mr. C. M. Bristow: “The geology of the area between Ilsington, Bickington and Liverton.”
48. Dr. M. R. House: “Problems of facies changes in the Devonian of Devon.”
49. *Dr. H. G. Reading: “A sedimentological comparison of the Bude Sandstones with the Northam and Abbotsham Beds of Westward Ho!”
50. *Dr. M. H. Dodson : “Further argon age determinations on slates from South-west England.”
51. *Dr. J. M. Thomas: “Sedimentation in the Lower Culm Measures around Westleigh, North-east Devon.”
52. *Dr. B. D. Webby : “Structure of the Devonian rocks in the Brendon Hills, West Somerset.”
53. *Mr. D. M. Mackintosh : “Superimposed folding in Namurian turbidite sandstones near St. Gennys, North Cornwall.”

33. The distribution of tin and certain other heavy metals in the superficial portions of the Gwithian/Hayle Beach of West Cornwall : by K. F. G. Hosking and P. Ong.

The main object of this study was to test the possibility of using semi-quantitative colorimetric methods of analysis to supply data from which isopleth maps of various metals could be drawn which would not only enable the economic potential of a beach to be determined rapidly but would also be of value during other littoral zone investigations. In addition, the study was designed to determine to what extent rapid chemical and mineralogical examinations of such deposits could indicate the economic potential of those parts of the hinterland which were drained by rivers feeding the beaches. Finally, it sought to discover if the rapid methods, noted above, could facilitate an understanding of the heavy-mineral concentrating processes operating on beaches.

The Gwithian/Hayle stanniferous beach, which was selected as the study area, is gently shelving, wide, and c 3½ miles long. It trends c. N.N.E.-S.S.W., fringes a part of the St. Ives Bay, and is bounded by the Red River to the north and by estuarine reaches of the Hayle River to the south. The central portion is backed by dunes, whilst the extremities abut against cliffs of Lower Palaeozoic slates and grits from which occasional mesothermal lead/zinc veins outcrop. Tin-bearing lodes occur in the Black Cliffs to the south but are not exposed in the cliff face. Vast quantities of “tailings” have been transported to the Bay by the Red River from the major Sn/Cu/ W/As-mining area of Camborne/Redruth, and although the Hayle River also drains a mining area of some importance, the fact that it terminates in an estuary has precluded it from contributing significant amounts of heavy metals to the beach.

Field and laboratory work. Field work involved the mapping and sampling of profiles exposed in trenches and the collection of further samples along traverse lines. Laboratory work entailed, in addition to mineralogical studies, the analysis of various fractions of the 300, or so, samples collected for Sri, Cu, W, Pb, Zn, As, Ti and Fe.

Results. In general, the work confirmed that semi-quantitative analysis supported by field and mineralogical studies, enable the economic potential of beaches to be determined rapidly ; permit the construction of isopleth maps ; indicate the economic potential of the hinterland drained by rivers which contribute directly to the beaches, and facilitate the understanding of the ways in which concentration takes place in the littoral zone.

In particular, the investigation established that the heavy metals concentrated in the Gwithian/Hayle beach have been transported there, almost entirely, by the Red River. (This is indicated not only by the results of mineralogical and size-analysis studies, but also by the fact that the concentration patterns of Sri, Cu, W and As are virtually identical. The Pb and Zn patterns have been determined, to a considerable extent, by the presence of local primary sources.) The material, having been deposited by the Red River, is swept south-wards, and during north-west storms is piled up as a berm at the dune/cliff base. The berm constitutes the “stock-pile” which is beneficiated by successive tides which concentrate the heavy grains, largely by a tabling process, and in such a way that the values are distributed in elongate, crudely elliptical zones whose long axes parallel the dune; beach line. Considerable variation in the concentrating power of successive tides, causes, at any point, a series of dark, rich horizons to be separated by poorer grey and white bands. The black bands are very stable as the vertebral column of a seal embedded in one had not been displaced during the time necessary for the soft tissue to disappear.

In addition to tabling on a flat sand-surface concentration was also, in part, effected by processes akin to jigging and kieving, and to a minor extent by accumulation in ripple zones and in the channels of small distributaries. Concentration by wind is probably not of major importance, but dilution near the dunes due to "barren" sand being blown on to the beach, from the latter, and because of sand-slides, is appreciable.

34. The Seismicity of the Cornubian Peninsula in relation to its structure : by A. T. J. Dollar.

Within the Cornish Peninsula, its immediate submarine border and eastern continuation as far as the meridian of Bristol (longitude 2° 35' W.), an area of some 6,000 square miles, (c.15,540 sq. km) the regional seismicity is a function of many occasional and generally small rock-displacements manifesting stress relief across such planar discontinuities as faults and possibly high-angle thrusts, barren or mineralised fissures, master joints and contact surfaces of both major and minor igneous rock bodies of essentially E.-W., N.E. S.W. or N.N.W. S.S.E. strike, which are localised at about 26 relatively clearly defined single earthquake centres (seismic foci), and at a further small group of less clearly defined single foci, occurring chiefly at depths of 3 miles (5 km.) or less below the surface and associated more especially with the granite cupolas of the Peninsula, their immediate Palaeozoic sedimentary envelopes and the corresponding rocks of Exmoor, the Quantock Hills and the Vale of Taunton.

The pattern of the seismicity is similar to that shown elsewhere in the British sector of the deeply eroded Variscan Fold Belt, but differs from it particularly in respect of higher focal distribution-densities, and higher frequencies of activity but slightly lower intensities at the majority of the earthquake centres concerned, according to available records.

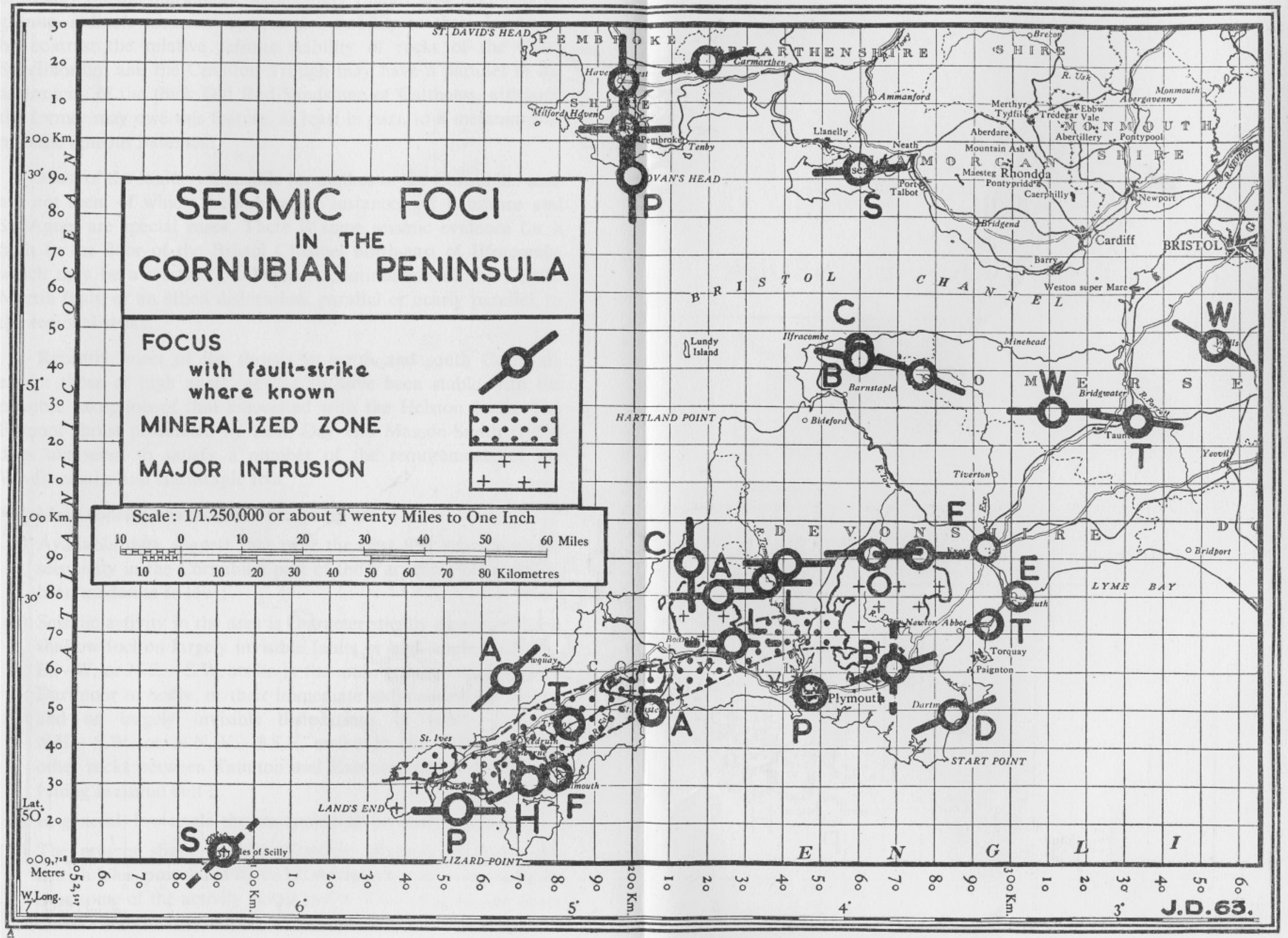
Most, if not all of the earthquakes are of tectonic type, as distinct from those of volcanic origin, and both instrumental and non-instrumental (questionnaire) information about them has been gathered by the late C. Davison between 1889 and 1924 and since 1935 by the present author through the British Earthquake Inquiry which he initiated at Emmanuel College, Cambridge, and now directs from Birkbeck College, University of London. These movements have to be distinguished from the occasional British tremors due to rock-bursts, cliff-falls, landslides, meteorite impacts and mine shakes, and explosions or gunfire which are also recorded by the B.E.I.

The foci, which are all single (i.e, not twin centres), fall into a northern group including Wells, Taunton, Wiveliscombe, Combe Martin and Barnstaple (two foci) ; a central group including Exeter, Exmouth, Teignmouth, Okehampton (two foci), Launceston (two foci), Altarnon and Camelford ; and a southern group including Dartmouth, South Brent, Plymouth, Liskeard, St. Austell, Truro, Falmouth, Helston, St. Agnes, Penzance and Scilly. Those near St. Agnes and Penzance are submarine, as may be that at Scilly. Between the northern and central groups is an aseismic zone elongate east-west and some 25 miles in width, coinciding with the axial belt of the Culm Synclinorium: a narrower one, 7-10 miles wide, extends between the central and southern groups from the mouth of the River Exe to that of the River Camel (see map).

The directions of major axes of isoseismal curves indicate that of the 26 well-defined foci, 9 are associated with dislocations of E.-W. strike and 5 with dislocations of N.E.-S.W. strike, while of the remainder, 4 dislocations strike N.N.W.-S.S.E., one strikes N.-S. and 7 are of unknown strike.

In terms of the C. Davison (modified Rossi-Forel) Scale of earthquake intensity the range of known Cornubian quakes lies between VI (Penzance 1757 July 15) and III (e.g. Launceston 1896 January 26) apart from the exceptional cases of intensity VIII at Wells on 1248 December 21 and Glastonbury on 1275 September 11

There is a close structural association between at least 12 ot the 26 Cornubian seismic foci and the zone of unroofed granite cupolas on the Cornubian bathylith. Further, there is a focus on or near the steep south-east contact of each of the main cupolas, where magmatic uprise and stoping seems to have occurred. Similarly, five of the foci lie within the Mineralized Zone of H. Dewey and all that this implies about fissure swarms there.


SEISMIC FOCI
IN THE
CORNUBIAN PENINSULA
FOCUS
with fault-strike
where known
MINERALIZED ZONE
MAJOR INTRUSION
Scale: 1/1,250,000 or about Twenty Miles to One Inch
60 Miles
80 Kilometres
ATLANTIC OCEAN
BRISTOL CHANNEL
ST. DAVID'S HEAD
PEMBROKESHIRE
CARMARTHENSHIRE
GLAMORGAN
MONMOUTHSHIRE
DEVONSHIRE
SOMERSET
CORNWALL
ENGLISH
Carmarthen
Ammanford
Llanelly
Neath
Port Talbot
Merthyr Tydfil
Tredegar
Ebbw Vale
Aberdare
Mountain Ash
Maesteg
Rhondda
Pontypridd
Caerphilly
Abertillery
Pontypool
Abergavenny
Monmouth
Newport
Bridgend
Cardiff
Barry
BRISTOL
Weston super Mare
Milford Haven
Pembroke
Tenby
Lundy Island
Ilfracombe
Barnstaple
Bideford
Minehead
Bridgwater
Tiverton
Yeovil
Wells
HARTLAND POINT
Newton Abbot
Torquay
Paignton
Plymouth
START POINT
LYME BAY
Bridport
St. Ives
LAND'S END
LIZARD POINT
Isles of Scilly
Lat. 50°
W. Long. 7°
Metres
J.D. 63.

Foci on the flanks, or at the intersections, of folds, and more especially on the margins of sedimentary domes now occupied by granite, indicate recurrent structural instability at these localities. by contrast the relative seismic stability of rocks of the Culm Synclinorium and the Crediton Trough may have a parallel in the aseismicity of the thick Old Red Sandstone of Caithness, although the former may owe this feature, at least in part, to a metamorphic or basic igneous basement.

Most of the faults responsible for quakes in the Cornubian area are not seen, of which the submarine instances off Penzance and St. Agnes are special cases. There is some seismic evidence for a fault in the floor of the Bristol Channel north-east of llfracombe which may be a westward submarine continuation of the Combe Martin fault, or an allied dislocation, parallel or nearly parallel, to the regional strike.

Recently, most of the thrusts in north and south Cornwall, except those of high angle, appear to have been stable with the possible exception of that associated with the Helston focus. The Exmoor thrust postulated by Bott, Day and Masson-Smith (1958) does not seem to satisfy a number of the requirements of the Wiveliscombe and Barnstaple foci.

Main conclusions from the foregoing are:-

(i) Available data suggest that over the past 989 years regional seismicity in the Cornubian part of the Variscan Fold Belt has been moderate to low ;

(ii) Seismic activity in the area is characteristically associated with shallow foci on largely invisible faults or high-angle thrusts of E.-W. or N.E.-S.W. strike in the main granite cupolas, from Dartmoor to Scilly, or their immediate sedimentary envelopes, and on largely invisible dislocations of nearly E.-W., N.E. S.W. or N.N.W.-S.S.E. strike in the sediments and other rocks between Taunton and Exmoor, with a wide intervening aseismic belt ;

(iii) In general, low-angle thrusts appear to be relatively stable ;

(iv) The present slight meridianal excess of pressure across the British Isles, postulated by E. M. Anderson, may account for at least some of the activity across faults of Caledonoid and near-Caledonoid trend in the Cornubian Peninsula.

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35. The Accessory Minerals of the Scilly Isles Granites :

by D. L. Jones.

The Scilly Isles is an elliptical group of essentially granitic composition lying 28 miles W.S.W. of the Lands End, Cornwall, with an elongation N. 53° E., and covering an area of nearly 50 square miles. Although Osman (1928) considered the main mass to be built of four distinct granite intrusions, recent work suggests there are only two, herein referred to as “G 1” and “G 2” respectively, of which “G 1” is the earlier.

From a statistical analysis of their accessory minerals (Table 1) there seems to be a significant difference between G 1 and G 2 in respect of iron ores, rutile, topaz, tourmaline, biotite and white mica. Since, however, it was not possible to separate all white mica by the bromoform method, the value for this mineral cannot be accepted as a reliable indication of difference between the two granites. Further, decrease in the amount of biotite in G 2 may be a result of its alteration to tourmaline by pneumatolysis, and this could also explain the relatively greater amount of tourmaline in G 2. Similarly, the different proportions of topaz, another pneumatolytic mineral, which occurs in both granites, may not indicate a real difference of composition between them. Also both rutile and iron ores, are in different amounts in the two granites, but their relationship is antipathetic and as much of the iron ore is ilmenite, which can be seen to have changed into the more stable form of rutile, and since both are probably derived from late-stage alteration of titaniferous biotite, too much significance should not be attached to the differing proportions of these minerals.

Of the accessory minerals shown in the tables only zircon, monazite and apatite are likely to be primary and none of these shows any significantly different proportions, as between G 1 and G 2. Thus, a statistical study of the main accessory minerals of these two granites suggests there are few if any differences between them which could not be accounted for in terms of secondary effects.

The modal analysis (Table II) indicates that both G 1 and G 2 are muscovite-biotite granites and further confirms the absence of any significant quantitative differences between either their primary or secondary minerals, except in respect of their felspars.

While G 1 proves to be a coarse porphyritic adamellite, with nearly equal proportions of oligoclase (An_{28}) and perthite, G 2, with its fine grain and generally non-porphyritic texture, shows a clear dominance of potash felspar over albite, (An_{6}) which demonstrates its higher content of potash and soda in relation to G 1. This alkali-enrichment of G 2 with its associated decrease in magnesia, is also accompanied by a slight increase in silica, as reflected by a greater content of quartz than is found in G 1.

These mineralogical and textural relations between the two granites afford part of the evidence for supposing that G I and G 2 resulted from differentiates of the same parent magma, as was suggested by Brammall (1927) in the Dartmoor granite mass, by Ghosh (1927) and Exley (1951) in the Bodmin Moor and St. Austell granite masses, by Subbarao (1960) in the Godolphin granite mass and by Dollar (1941) in the Lundy granite mass. In general terms these relations support the hypothesis of the consanguinity of the

SCILLY ISLES GRANITES

WEIGHT OF INDIVIDUAL ACCESSORY MINERAL PER 20 Grams OF GRANITE

	G.1		G.2			
MINERALS	**ARITHMETIC MEAN**	**STANDARD DEVIATION**	**ARITHMETIC MEAN**	**STANDARD DEVIATION**	**STUDENT 't' VALUE**	**CRITICAL Value = 2.00**
ZIRCON	**0.0536**	**0.03**	**0.0550**	**0.051**	**0.126**	
IRON ORES	**0.2695**	**0.219**	**0.4347**	**0.337**	**2.215**	✔
MONAZITE	**0.0073**	**0.012**	**0.0042**	**0.009**	**1.236**	
APATITE	**0.0751**	**0.033**	**0.0991**	**0.068**	**1.718**	
RUTILE	**0.0080**	**0.016**	**0.0016**	**0.004**	**2.302**	✔
ANATASE	**0.0068**	**0.016**	**0.0076**	**0.017**	**0.181**	
BROOKITE	**0.0072**	**0.012**	**0.0045**	**0.009**	**0.926**	
ANDALUCITE	**0.0219**	**0.017**	**0.0317**	**0.038**	**1.268**	
TOPAZ	**0.0944**	**0.041**	**0.0690**	**0.050**	**2.099**	✔
TOURMALINE	**0.3694**	**0.191**	**0.7942**	**0.834**	**2.672**	✔
BIOTITE	**2.8646**	**0.813**	**2.0033**	**1.199**	**3.202**	✔
CHLORITE	**0.2356**	**0.413**	**0.2008**	**0.309**	**0.354**	
WHITE MICA	**0.5298**	**0.304**	**0.2943**	**0.289**	**3.077**	✔
OTHERS	**0.0018**	**Not Recorded**	**0.0039**	**Not Recorded**	**-**	

TABLE I

MODAL ANALYSIS

MINERALS	ARITHMETIC MEAN	STANDARD DEVIATION	ARITHMETIC MEAN	STANDARD DEVIATION	STUDENT 't' VALUE = 2.048
ZIRCON	0.483	0.297	0.750	0.625	1.471
IRON ORES	0.050	0.100	0.175	0.250	1.890
MONAZITE	0.067	0.260	0.033	0.085	1.930
APATITE	0.667	0.488	0.825	0.499	0.860
ANDALUCITE	0.033	0.287	0.267	0.383	1.770
TOPAZ	0.050	0.187	0.050	0.100	0.000
TOURMALINE	0.300	0.459	0.667	0.925	1.350
BIOTITE	5.117	3.776	4.425	3.003	0.535
CHLORITE	0.317	0.414	0.650	0.843	1.310
MUSCOVITE	5.560	2.314	6.458	2.642	0.958
PLAGIOCLASE	25.983	4.043	11.633	4.842	8.520
ORTHOCLASE	32.317	9.284	39.258	5.228	2.441
QUARTZ	28.683	10.872	34.950	5.547	1.930

TABLE II

main granites of Devon and Cornwall (Bott, *et al.,* 1958) and the likelihood that the partial magmas of Scilly gave rise to an outer envelope of contaminated coarse-grained granite surrounding a core of alkali-rich and formerly volatile-rich finer-grained granite through differentiation (c.f. Dollar, 1941 ; Exley, 1961).

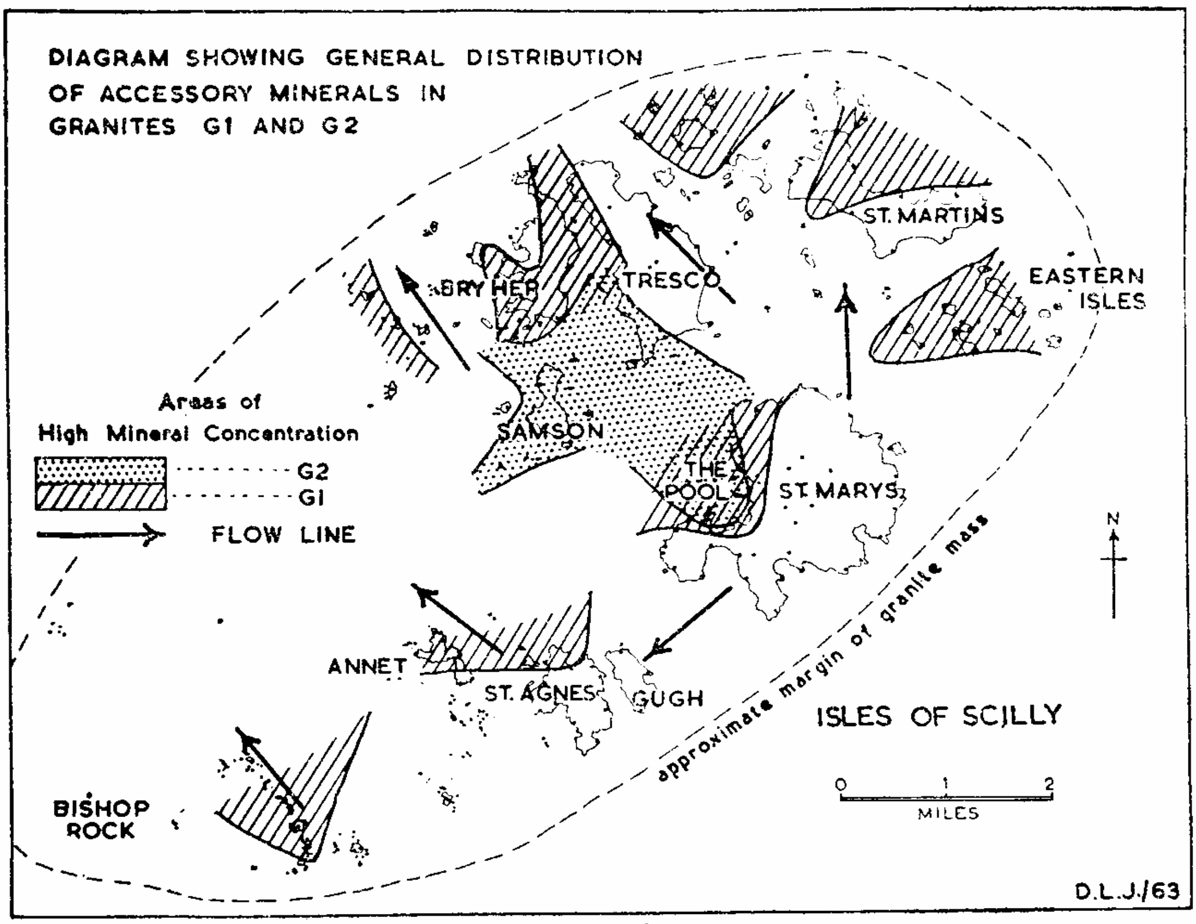

FIGURE 1

From a study of the weight-percentages of accessory mineral species in samples of G 1 and G 2 collected at 136 stations, it is evident that there are high concentrations, (a) about the periphery of the mass; (b) in a zone trending N.E.-S.W. from the Eastern Isles through The Pool to Annet and the Bishop Rock; and (c) in two and possibly as many as four nearly equidistant zones, apparently linked with the first and extending north-westwards from it, across the mass. These agree closely with regions of high radioactive intensity discovered by Dollar (1957). The intervening zones are characterised by markedly lower relative concentrations of the same accessory minerals, and correspond to magmatic flow-directions established in the course of a structural survey by Dollar

1958.

From this and relevant field evidence, it is believed by Dollar and the author that the magmas of G 1 and G 2 rose steeply through a fissure-like inlet, elongated N.E.-S.W. and passing through The Pool, St. Mary's, and then moved northwards and westwards in the directions indicated by the arrows on the map.

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36. Lithium in the Tregonning-Godolphin granite complex :

by Maurice Stone.

The occurrence of lithium-bearing micas in the granites of South-west England is well known. The biotites of the porphyritic granites contain appreciable lithium (Brammall and Harwood, 1932; Butler, 1953) whilst " lithionite " micas occur at St. Austell (Exley, 1958 ;

see also Cundy *et al.,* 1960, who describe zinnwaldite from St. Austell) and in the Tregonning granite and the associated aplite-pegmatite complex (Stone, 1960). This report describes the distribution and the behaviour of lithium in the rocks of the Tregonning-Godolphin granite complex.

Determination. Lithium was determined using an EEL flame photometer and a" lithium " filter supplied by the manufacturers. The procedures of Shapiro and Brannock (1956) and Riley (1959) were used to get the rocks into solution. Interferences due to other ions in solution were determined ; many of these are insignificant and cancel out the effects of one another or can be corrected graphically. Serious interference caused by potassium was overcome by adding 2,000 p.p.m. K,O (as K_SO,) to each solution (including standards and blank) and subsequently correcting residual interferences due to varying initial concentrations of potassium by graphical means. Results indicate precision errors of < plus or minus 10% in the 0.03 to 0.2°~.' Li,O range, and < plus or minus 5`%, in the 0.2 to 0.6% Li,O range.

Distribution. Twenty-eight analyses of Li_0 are given in Table 1. The main features indicated are as follows :

1. The granites show an increase in Li_zO in the time sequence porphyritic granite - Tregonning granite – leucogranite and aplite.
2. Lithium is removed during late-stage alteration.
3. Killas adjacent to lithium-rich granite is enriched in lithium.

Behaviour. The increase in Li_2O in the later members of the complex provides, by itself, some evidence for magmatic differentiation (Goldschmidt, 1954, p.134). However, textural evidence (the skeletal networks of “lithionite” in potash feldspar) demonstrates that the “lithionite” post-dated much of the already reconstituted fabric, but the loss of lithium in the altered rocks shows that “lithionite” development pre-dated the onset of kaolinization and greisening.

In general, increase in lithium accompanies increases in sodium and fluoride in the granites. Evidence has already been presented to show that the ratio K_2O/Na_2O is governed largely by metasomatic processes, Stone, 1960, 1961); therefore, by following sodium, lithium exhibits a metasomatic rather than a magmatic trend. The increase in lithium with fluoride results in the development of common hosts ("lithionite", amblygonite, and, to a lesser extent, tourmaline).

Elvans (Pre-Tregonning granite)	.07,	.05				
(Post -Tregonning granite)	.05,	.05,	.05,	.05,	.07	
Godolphin granite	.03,	.05				
Tregonning granite	.20*,	.31,	.29,	.19,	.33,	.04*
Leucogranites	.53,	.49,	.58,	.38*,	,39	
Aplites	.47,	.39,	.53,	.52		
Mylor slate. Dark band	.05					
Light band	.05					
Hornfels from contact	.09					
Inclusion in Tregonning granite	.62					

* partly altered
** highly altered

The mobility of lithium is shown by its ready removal with the onset of kaolinization (Table 1 and Exley, 1959) and by its enrichment in the killas (Mylor slate) adjacent to the granite. Examination of thin sections of inclusions in the "lithionite" granites shows that biotite in the inclusions is made over to "lithionite" at the margins. This would suggest an ion-exchange process, whereby Mg + Fe in the biotite is replaced by Li(+Al). Some of the magnesium and iron released is presumably fixed by boron to form tourmaline.

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37. Supergene galena and pyrite from Wheat Hope, Cornwall:
by K. F. G. Hosking.

Supergene galena after pyromorphite was recovered from Wheal Hope, Cornwall, during the period 1822-25 and has been briefly described by Collins (1871, p.49). Recent re-examination of the material has indicated that supergene pyrite also occurs in certain specimens. The latter mineral reports in the framboidal form (from which the hollow spherical remains of micro-organisms can be recovered), as polygonal masses (derived from a gel by dehydration, and in which framboidal forms sometimes occur), and as aggregates of small eu- and subhedral crystals : it predates the supergene galena.

The galena in part replaces the pyromorphite (which is virtually devoid of arsenate ion and is probably a calcian variety as collophane developed contemporaneously with galena), and in part it has been derived by the replacement of cerussite, and conceivably other secondary lead species, and possibly by direct precipitation. In addition, it locally replaces supergene pyrite, as relicts of framboidal pyrite occur in it.

It is thought that this curious mineral assemblage is due, fundamentally, to the intersection of the oxidised ore-body by a river valley which developed during the emergence of the land in Pliocene and subsequent times. During the estuarine phase foul bottom conditions prevailed, and pyrite-investing micro-organisms, which developed in the organic-rich deposits near the floor, were transported, together with water charged with biogenic hydrogen sulphide, into the cavernous oxidised zone of the lode. There the sulphide solution first reacted with iron ions, forming sulphide gel and crystals, and then, either because of the depletion of " reactive " iron, or because of subtle changes in the environment as estuarine conditions gave way to fluviatile, it reacted with free lead ions and lead oxy-salts, particularly pyromorphite, with the consequent formation of galena. At the same time some of the supcrgene pyrite was replaced by galena.

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40. The relationship of soil development to site on Culm shales : by B. Clayden.

Soil survey on Culm shales between Exeter and Okehampton has revealed a catena or hydrologic sequence of soils (Glentworth and Dion, 1949) in which both weathering and soil development are closely related to site conditions.

Well drained, acid brown earths, mapped as the Dunsford series (Clayden, 1960), are associated with steep or moderate slopes ; they are shallow and weakly weathered soils with little horizonation. The silty clay loam texture with 30-35% clay (< 2 p) shows little variation with depth and shale fragments occur commonly through-out.

By contrast, surface-water gley soils are found on flat or gently sloping sites. These soils are deeper and more strongly weathered with thick subsoil horizons of dense silty clay that cause severe drainage impedance. The strongly gleyed Tedburn series is particularly associated with lower slopes which receive water from higher ground. A thin surface horizon of grey-brown, silty clay loam overlies 2 ft. or more of plastic silty clay (50-60% clay) in which grey-faced fissures separate prismatic aggregates showing ochreous and red mottles when broken open. Soils with the same general morphology but in which gleying is less pronounced are known as the Halstow series and occur widely on gently sloping ridge tops. The mottled subsoil horizons are usually thinner and of lower clay content.

X-ray analysis of the clay fraction shows a similar suite of clay minerals in the three soils. In the subsoil horizons mica is the dominant clay mineral with subsidiary amounts of vermiculite, kaolin and chlorite, while in the surface horizons, vermiculite increases at the expense of mica. It appears that the clay minerals are directly inherited from the parent material and are little influenced by the drainage status of the soil.

It is unlikely that the clayey subsoil horizons were produced by a period of long continued weathering as they are not confined to soils of the oldest features of the landscape and are sometimes found on shaly Head in footslope sites. The overall profile morphology rules out the possibility of their development by clay eluviation and is substantiated by the absence of accumulations of optically orientated clay in thin sections prepared from samples of undisturbed soil.

It is suggested that weathering of the shale substratum and soil formation is strongly influenced by the quantity of water received at a site and its rate of loss. Clay formation or the release of clay material from the shale is considerably greater on subdued slopes than on steep slopes favouring rapid run-off. Thus surface-water gley soils are particularly widespread in Mid-Devon where there are extensive remnants of high level erosion surfaces.

A similar sequence of soils is not found on the Devonian slates of the South Hams where soils akin to the Dunsford series occupy both the gently sloping interfluves and the steep valley-sides. The re-crystallisation of these rocks led to the formation of new minerals from the clay minerals of the original sediments. The soils have less clay material to inherit directly from the parent rock and, at the present stage of weathering, the new minerals are relatively little altered.

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41. Coastal landforms of the Dodman district : by E. C. F. Bird.

The broad plateau (300-400 feet O.D.) south of St. Austell is a planation surface, truncating strongly-folded Lower Palaeozoic rocks and passing evenly across the phyllites of Dodman Point (373 feet) ; Clement Reid (1907) attributed it to marine planation in Pliocene times. It is incised by deep valleys, and terminates at the coast in steep 'slope-over-wall' cliffs.

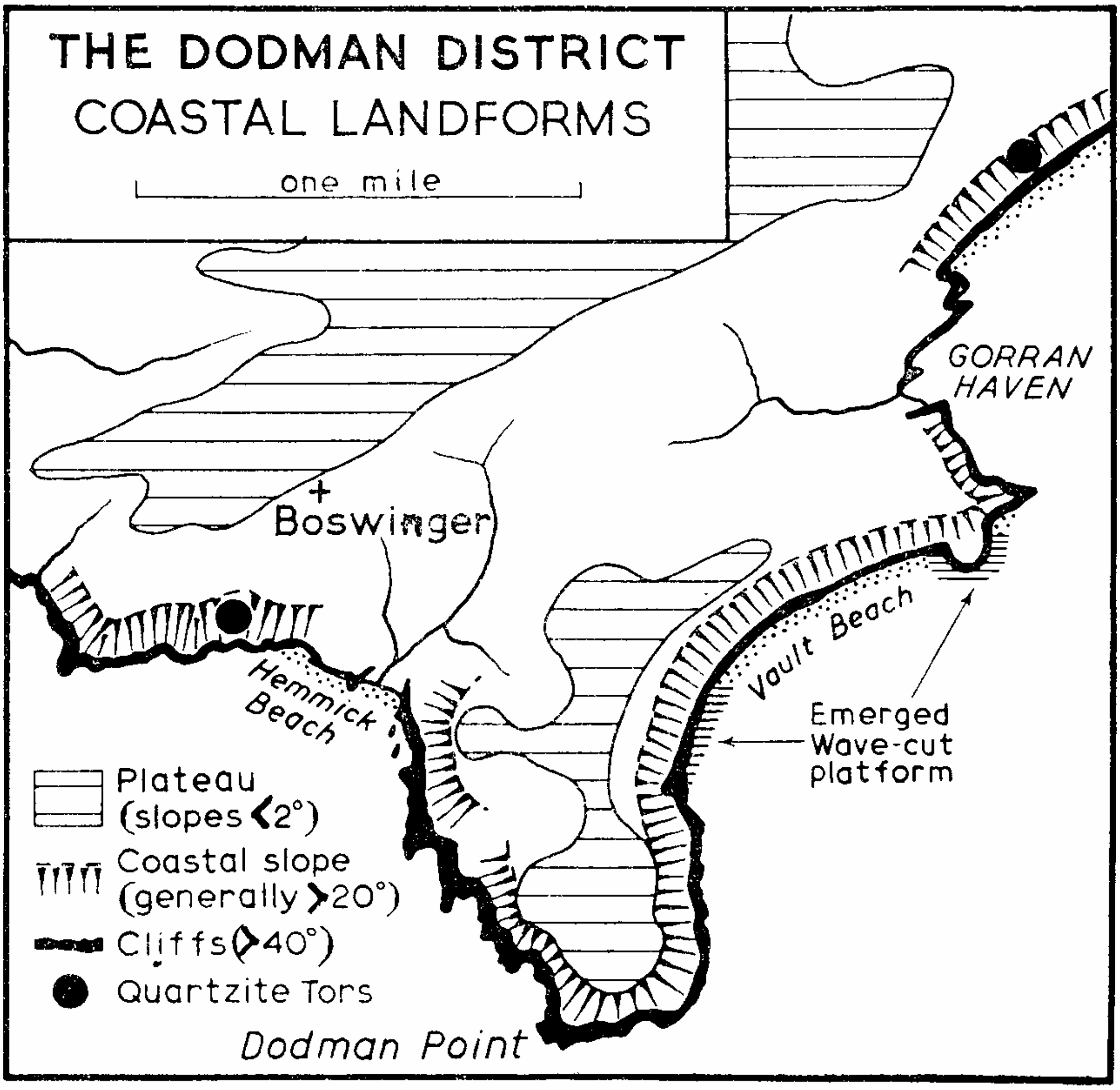

FIGURE 1

This is a periglaciated landscape, mantled by Head deposits. Angular pieces of local slate and quartzite in an earthy matrix extend across the plateau, down valley sides, and on to the coastal slopes.

Sections sometimes show traces of layering, indicative of repeated episodes of solifluxion or down-washing of frost-shattered material, associated with the thawing of frozen ground or the melting of snow. The coastal slopes (20°-30°) are former sea cliffs, degraded under periglacial conditions when sea level was lower. Slate, sandstone, lava, and much of the Dodman phyllite succumbed to periglacial wastage on these coastal slopes, but certain masses of rock proved more resistant, and these protrude as tor-like features (buttresses). Lenticles of massive quartzite, which are truncated by the plateau surface, protrude as buttresses on coastal slopes near Gorran Haven (at 20/018425) and Boswinger (at 10/987407). They are evidently analogous to tors on the periglaciated uplands of Bodmin Moor and Dartmoor.

As the sea rose during postglacial times (Flandrian transgression) these slopes were undercut, exposing a rocky wall, often with fragments of an emerged wave-cut platform bearing an older (interglacial) raised beach 12-15 feet above m.s.l. The proportion of relict slope to exposed wall increases on the eastern side of Dodman, which is sheltered from storms generated by prevailing S.W. winds. Vault Beach is backed by bluffs of Head, with rocky cliffs and the emerged wave-cut platform appearing at either end. The present wave-cut platform, exposed at low tide, is interrupted by sandy coves (Hemmick Beach) where valleys formerly passed beneath present sea level.

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42. Erosional and depositional features of the Camel estuary as evidence of former Pleistocene and Holocene strandlines: by B. B. Clarke.

The seaward slope is steep everywhere. At Padstow it descends from a near-level surface at 180 ft. O.D. down a 700 yard long slope in a series of worn steps with treads at 150, 120, 100, 88, 65, 50 and 25 ft to a flat terrace at 15 ft. O.D. on which the lower part of the town is built. Two of these treads, recently exposed, reveal near-horizontal surfaces suggesting that beneath the cover of head the sides of the estuary are sharply terraced. In occasional hollows in the 100 ft. surface were rounded beach pebbles of flint, stained deep brown, and quartzite. It is suggested these surfaces, cut in steeply dipping cleaved slates, are wave-cut platforms of former sea-levels of Pleistocene interglacials.

Erosion surfaces of which substantial areas remain are the top of Pentire head 200-250 ft., the high ground behind Padstow 180185 ft. and the bevelled top of Cant hill 150-160 ft. O.D.

Cliffs, especially Pentire head, exhibit a series of V shaped notches, the near-horizontal surface being the bench of the former sea level, the near-vertical surface the cliff line, and the point between the H.W.M. The notches in Pentire head suggest former sea-levels at 180, 125, 100, 50, 25 and 15 ft. Notches occur in neighbouring cliffs at 160, 80 and 65 ft. A close relationship exists between residual erosion surfaces, estuary benches and cliff notches.

The surfaces of the benches are usually almost horizontal though at Trebetherick the 25 ft. and 15 ft. slope seaward fairly steeply. The surfaces, unless well protected, are frost shattered. The 25 ft. bench is most complete and always present, the 15 ft. is fragmentary except in sheltered coves.

By projecting the cliff notches in a series of maps the estuary is seen to assume its present shape when the 100 ft. bench was cut, a level F. E. Zeuner correlates with the Great interglacial.

During the glaciations, with a sea-level at -60 to -360, the river cut a deep channel, probably to different levels in each glaciation. This is now buried, and there is probably a further series of benches beneath the present strandline.

On the benches are three periglacial deposits, frost shattered brash, main head (a downslope wash of slate in ochre clay), and brown solifluxion clay or younger head (a deposit left from melting snow and loess). Locally there are water worn gravels, and at Trebetherick a boulder bed. Above the periglacials on the east side is a hard sand, considered to be a storm-beach deposit, with broken marine shells, *Patella vulgata*, and complete land forms, *Pomatias elegans*, and above this dune sand with *Cochlicella acuta*. On the 15 ft. bench at S. Saviours point is an unfossiliferous well cemented beach shingle with rounded quartzite, flint and chert and angular slate.

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STEPHENS, N., 1961. Re-examination of some Pleistocene sections in Cornwall and Devon. **Abstracts Proc. 4th Conf. Geol. Geomorph. S.W. England,** Roy. Geol. Soc. Cornwall, p.21-23.

43. The structure of the Torbay region -the Marldon Beacon nappe : by E. T. Vachell.

Within the bounds of Torquay certain of the most prominent eminences are composed of Lower Devonian rocks. In the surrounding low ground younger Devonian rocks are invariably found; these are usually plicated and shattered, but on the larger aspect map as relatively flat sheets and behave as if they were passing into or under the Lower Devonian of the hills. The field evidence is against the widespread development of folds large enough to account for these anomalies.

Further detailed mapping showed that similar anomalous relationships occur between the younger rocks and the Lower Devonian which forms not only the high ground between Sharkham Point and Kingswear but also the ridges between Torquay and Berry Pomeroy and between Collaton St. Mary and Aish. Accumulating evidence indicates that in all these areas the Lower Devonian forming the eminences constitutes the remnants of a large nappe which has travelled for many miles in a northerly direction over a basement, not necessarily itself autochtonous, of younger Devonian rocks ; and that subsequently the whole complex, both nappe and basement, was subjected to block-faulting on a regional scale. This subsequent block-faulting largely obliterated the original and basic nappe structure and obscured the true tectonic relationships of the eminences, which now appear to be down-faulted klippen embedded in a decollement of the younger beds below the nappe-plane.

Usually the junctions between the rocks of the nappe and those of the basement are the block-faults, the nappe-plane itself being hidden at depth: but three localities have been found where deep erosion appears to have exposed the base of the nappe. These are:-

(a) In the valley of the Gatcombe Brook below Berry Pomeroy Castle (near Grid SX838622).
(b) In a small window through the nappe near Berry Pomeroy Castle Lodge (near SX838616).
(c) Round the upper part of the Longcombe valley (round SX8460).

Both in the nappe itself and in the basement below structural complexes develop :

In the Nappe. Subsidiary low-angle thrusts occur, for instance in Kilmorie Hill where Meadfoot beds overlie an arenaceous development in the Lower Devonion which elsewhere normally overlies them.

In the basement. Overthrusting and crushing is evident in the Orestone rock off Hope Nose and in the exposures round Union Street, and imbrication is developed in the Daddy Hole region and in Vane Hill - all near Torquay. Further afield complex structures in the Bishopsteignton-Kingsteignton area indicate overthrusting on a considerable scale. Overfolding has been inferred by Lloyd (Torquay Memoir) in the Walls Hill-Bishops Walk neighbourhood.

The nappe - which has been named the Niarldon Beacon Nappe, from the Beacon Hill, near Marldon which lies on it appears to be due to the Armorican orogeny, for Upper Devonian and Culm rocks are involved in the crumpling. The main blockfaulting was due to somewhat later epeirogenic movements of pre-Mid Permian age, for in a number of cases the Middle Permian breccias have been found to unconformably butt up against and overstep the fault-scarps. On some fault lines however the Permian is affected and here there must have been continuation, or a subsequent recrudescence, of movement.

44. The geology of the Watergate Bay area, Newquay, Cornwall : by M. J. Ripley.

The Devonian rocks outcropping in the coastal section between Newquay and Park Head, can be divided into well defined groups, based on the colouration of the slate horizons and the relative proportions of the arenaceous and calcareous constituents.

The occurrence, in many sections, of a non-comminuted neritic fauna, calcareous bands and shallow water depositional structures suggests that these sediments, although predominantly pelitic in composition, are of a shallow water marine origin, the only possible exceptions being the so called ‘red and green slate’ deposits of Watergate Bay (Reid and Scrivenor, 1906).

The coarsest sediments, which throughout the area are constant in both mineralogy and grain size, are fine grained impure sandstones. Typically they range from about 5 cm. to 1 m. in thickness and are composed of quartz grains (< 110p), set in a quartz chlorite and sericite matrix, which can form up to 50%. of the total volume. Apart from wash-out channels, sedimentary structures are characteristically absent from these sandstones bands.

Graded bedding, slump folding, load and flow structures and cross-bedding have however been recognised in many of the silt bands. From these features it is deduced that the dominant tectonic structure of the area is an anticline, the axis of which outcrops at the north end of Watergate Bay.

Three phases of folding have been recognised, which are possibly successive episodes of one movement system generated by a general north/ south compression. Evidence for phase I folds is very limited and restricted to the south of the area. Phase 2 folds are recognisable in most cliff sections. They are, in almost all cases, strongly recumbent and overturned (facing) to the north. Essentially they are cleavage folds. Many of the competent beds have however been deformed by flexural slip and in some instances the resultant concentric folds have assumed the geometry of similar folds, due to post-phase 2 flattening. The major anticlinal axis post-dates these phase 2 folds and consequently has been ascribed to a third phase of folding. North of the axis this refolding has caused the rotation of the axial planes of the phase 2 folds into sub-horizontal positions.

Minor tectonic structures, post-dating phase 2, such as knick bands, strain-slip cleavage, fracture cleavage and drag folds are common. Three genetically different types of knick band have been recorded. They are all restricted to the foliated rocks and are contemporaneous with the drag folds in the more massive sandstone horizons. No relationship has been established between these late stage structures and the major anticline.

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REID, C. and J. B. SCRIVENOR, 1906. The geology of the country around Newquay. **Mem. Geol. Surv.**

45. North-east trending ridges of the Celtic Sea : by A. H. Stride.

An examination of some of the north-east trending ridges of the Celtic Sea has been made with a Boomer (a seismic profiler ; see for example Bowers, 1963) operated from R.R.S. "Discovery II". It was found that the ridges are made of false-bedded deposits resting unconformably on gently dipping rocks. In Cockburn Bank (around 49 ° 52' N., 09' 10' W.) the beds are long and slope at about half a degree: they are approximately parallel with each other and also with the southern side of the ridge and probably outcrop on its northern slope. Similar but less ordered bedding was found in a single traverse over the unnamed ridge to the west and over the northern end of Great Sole Bank beyond it. In the cases of Labadie Bank (around 50° 35'N., 08° 05' W.), Jones Bank (mid-point 49° 50'N., 08° W.) and a number of smaller shoals, the uppermost deposits appear to mantle an earlier feature.

Sand is the commonest material to be found at the surface of the ridges, according to the numerous bottom notations on Admiralty surveys B 3013/l-4. Gravel and stones found on the lower half of portions of the northern slopes of Cockburn Bank and the unnamed ridge may indicate the nature of some of their oldest layers.

The origin of the ridges is uncertain. Their prevalently sandy composition, their profile, linearity, replacement *en echelon,* general parallelism with each other and with the strongest tidal currents, suggest that the ridges are sand banks. They differ from certain well-known sand banks in being up to one and a half times higher and up to twice as wide, and in their association with tidal currents of less than one knot instead of about two knots. Moreover, the ridges of the Celtic Sea are covered by a minimum of 34 fathoms (and generally by about 60 fathoms) of water, whereas the others referred to may partly dry out at low tide and occur off deltas, in estuaries and other enclosed seas where sediment is abundant (Off, 1963).

Accordingly, it is presumed that the ridges of the Celtic Sea are fossil sand banks, perhaps formed during Pleistocene or early

Recent times, with sea levels perhaps as low as 60 fathoms beneath those existing today. The ridges are unlikely to be as old as early Pliocene for silt was the prevailing grade, at least in the southern half of the Celtic Sea at that time. Nor are they Hercynian in age, as has been suggested (Le Danois, 1948).

A Pleistocene or late Pliocene age may be indicated by the presence of benches in the sides of some of the ridges (Stride, 1962). It is clear, however, that further work is required, for whilst the most clearly-defined internal structures do not control the location of benches. there may be structural control elsewhere.

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STRIDE, A. H., 1962. Low Quaternary sea levels. **Proc. Ussher Soc.,** Vol.1, p.6-7.

46. The Culm Measures Succession in North-east Devon and North-west Somerset : by J. M. Thomas.

The Carboniferous rocks of this area are the eastermost representatives of the Culm Measures, where this 'geosynclinal' facies most closely approaches the `shelf' Carboniferous of the Mendips.

The Carboniferous succession previously described around Bampton (Thomas, 1962) was mapped eastwards to the unconformable base of the New Red Sandstone near Appley (072211). The Culm Measure succession is similar to that previously described around Bampton, with a persistent basal group of hard black slates following conformably upon soft grey slates equated with the Pilton Beds (Goldring, 1955). The Bampton Limestone group (or Chert Formation, Swarbrick 1962) consisting of interbedded cherts, limestones and shales, overlies these black slates and was mapped eastwards as far as Ashbrittle, with the importance of limestones decreasing in this direction. This group is largely Visean in age, and in the region from HuntshaM to Staple Cross passes upward into a thin persistent group of black shales yielding Lower Namurian fossils. The highest Culm Measures exposed in this area are a thick group of turbidite sandstones which show a gradational contact with the underlying black shales. These sandstones are equivalent to the Instow Beds of North-west Devon (Prentice, 1960) and yielded *Gastrioceras subcrenatum* and *G. circumnodosaem.*

In the south-eastern quadrant of the area, the Upper Carboniferous turbidite sandstones and black shales overlie a different Visean limestone facies, which have frequently been called the Westleigh Limestones (see later paper). This facies of thick-bedded, often coarse-grained limestones when traced northwards meets the dark shaly Bampton limestone facies with an abrupt margin and no suggestion of lateral passage between the two equivalent limestone facies. At their contact the two facies remain distinct, and large masses of Westleigh Limestone up to 500 yards by 400 yards, containing over 50 feet of well-bedded limestone appear to be toreva blocks which moved into the deeper water to the north before black shale deposition began.

In the quarries near Westleigh the thick-bedded Upper Westleigh Limestones overlie fine-grained Lower Westleigh Limestones (Owen, 1957), whereas to the north west (around Hockworthy and Holcombe Rogus) and the north (near Kytton Barton farm) these Upper Westleigh Limestones appear to overlie the basal hard black slates which also underlie the Bampton Limestones. This suggests that the Lowest Westleigh Limestones around Westleigh may be the stratigraphic equivalents of the basal Culm Measures to the north and west.

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47. The geology of the area between Ilsington, Bickington and Liverton : by C. M. Bristow.

The succession in the area is summarised in the following table :-

Tertiary:	Bovey Beds	
Carboniferous:	Colesworthy Beds	
	Sigford Beds	
	Below Rora Thrust	*Above Rora Thrust*
	Posidonia Beds	
	Ilisington Cherts And Volcanics	Ramshorn Down Cherts
Upper Devonian:	Ilsington Slates	Liverton Slates

Due to a major thrust fault, the Rora thrust fault, different facies of the Devonian and Carboniferous are superimposed, so that different successions are encountered above and below the thrust.

The Ilsington slates are bluish-grey or greyish-green in colour. They are unfossiliferous except for one exceptional band just below the cherts which belongs to zone VI of the German Upper Devonian zonal system. These slates are similar to the supposed Upper Devonian slates of the Teign Valley. In the unit above the thrust, the Liverton slates are composed of purple and green slates overlying greenish-grey and bluish-grey slates with calcareous nodules. Fossils have been found at many localities in the slates of the upper unit, but few have provided useful stratigraphic information.

The rocks which overlie the slates are all presumed to be of Carboniferous age, apart from the Bovey Beds of Tertiary age. Different facies of the Carboniferous occur above and below the Rora thrust.

In the unit below the thrust the I'lsington cherts and volcanics are overlain by a group of siliceous slates containing *Posidonia sp.;* these are called the Posidonia Beds (after Ussher, 1913). The succession in the lower unit of this area shows a strong similarity with that seen in the Teign valley, where the Posidonia Beds are succeeded by the alternating sequence of turbidite sandstones and slates which make up the Exeter type of Culm Measures. In both areas the chert-volcanic group contains cherts of typical Lower Culm aspect as well as several other unusual types. The volcanic material is predominantly pyroclastic and contains deformed shard rocks which show a strong similarity with ignimbrites. It is possible that these rocks could have been produced under submarine conditions. Acid and basic lavas are also represented. The Posidonia Beds contain a well defined horizon rich in spirally striate goniatites at about the Pld/P2a junction. A limestone in the Teign valley yielded a rich conodont fauna from a slightly lower stratigraphic horizon (IIIa).

The cherts of the unit above the thrust are much more like the cherts seen elsewhere in the Lower Culm Measures. Volcanic rocks are noticeably absent, except some thin pyroclastic bands. Nothing is seen overlying the cherts in the unit which directly overlies the Rora thrust.

A north-south near vertical fault divides off the western quarter of the area, and in this unit a thick succession of blue-black rusty weathering pyritic slates are exposed, named the Sigford Beds. At their base they appear to overlie cherts similar to those of the unit above the Rora thrust. If these cherts are the same, then it indicates that the normal fault has a westward downthrow and that the Sigford Beds belong to the unit above the Rora thrust. However, the succession in the Sigford Beds shows similarities with the Teign valley succession where a thick group of bluish-black shales occurs between the cherts and the Exeter type of Culm Measures. Near the supposed top of the Sigford Beds thin silts and grey-wackes similar to those in the Exeter type of Culm Measures in the Teign valley are seen. If the Sigford Beds belong to the unit below the Rora thrust, then considerable tear movement would be necessary to explain their present position. A group of siliceous rocks composed of cherts, quartzites and breccias, is seen overlying the Sigford Beds.

The main feature of the orogenic movements is a low angle thrust which superimposes different facies of the Devonian and

Carboniferous. A flat lying cleavage sub-parallel to the bedding is developed and also a steep southward-dipping strain-slip cleavage. Studies of the E.-W. folds and faults in the cherts indicate that a N.-S. compression was followed by a N.-S. extension. N.S. faulting is also found.

The Colesworthy Beds appear to post-date the main orogenic movements. They rest unconformably upon the Devonian slates and the Carboniferous cherts and are folded along N.W.-S.E. fold axes. A weak cleavage is developed parallel to these fold axes.

The Dartmoor granite probably post-dates the Colesworthy Beds, as a recognisable easterly tilt affects the fold axes. The Sigford Beds, on the western side of the area, probably owe their present dip largely to this tilt by the granite.

N.W.-S.E. dextral tear faults cross the area, they are probably of Tertiary age. Their horizontal separation is not great.

The Oligocene Bovey Beds are the youngest strata in the area apart from the Quaternary head and gravels.

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49. A sedimentological comparison of the Bude Sandstones with the Northam and Abbotsham Beds of Westward Ho!:

by H. G. Reading.

It has been the custom to equate the Bude Sandstones of Cornwall with the Northam and Abbotsham Beds of Westward Ho! in north Devon. Both successions are almost barren sandstone-shale sequences of Lower Westphalian age, with Lower Coal Measure plants (Crookall, 1930), and the latter in addition has yielded non-marine lamellibranchs of the *lenisulcata* zone (Simpson, 1933). Thus, whilst the two successions are of roughly the same age, there is no palaeontological proof that they are exactly synchronous.

Owen (1950) summed up the lithology of the Bude Sandstones as “very like the Lower Coal Measures of other parts of the country”„ and he considered the same lithology was to be found at Westward Ho! Ashwin (1957) interpreted the Bude Sandstones

differently. giving evidence that they were an arenaceous greywacke succession deposited by turbidity currents. He did not examine the Westward Ho ! succession in detail, but he evidently saw no reason to suppose that they were a different facies from the Bude Sandstones. Prentice (1960), however, showed that the Northam and Abbotsham Beds were a paralic " coal measure " facies and suggested (1962) that the same lithology occurs in the Bude Sand-stones and reaches southwards at least as far as Widemouth, south of Bude.

There has therefore been a fundamental difference of opinion as to the processes of sedimentation, with the resulting contrast in palaeogeographical reconstruction.

Recent work has established that the Northam and Abbotsham Beds (de Raaf, Reading and Walker, in preparation) contain a succession of cycles of somewhat complex lithology, but each cycle starts with mudstone and passes irregularly upwards through siltstone into sandstone. At the top of the cycle there is a sharp contact, commonly burrowed, with the mudstone of the succeeding cycle. In detail the cycles are not identical and the amount of variability increases upwards in each cycle. The facies range from structureless or laminated mudstone, in which there may be a thin horizon of turbidites, through a silty and sandy streak facies suggestive of increasing current velocity and shallower water, into a variable succession of coarser strata showing ripple drift bedding, wavy lamination, medium-scale cross bedding and small "fining upwards" cycles, together with many channelled surfaces. The passage upwards is, in some cycles, through an oscillatory facies of approximately one foot alternations of sandier and muddier bands, the sands often extensively burrowed. A shelly fauna is absent except for small goniatites at one horizon (Prentice, 1960) and non-marine lamellibranchs (Simpson, 1933). The cycles are interpreted as the successive advances into a basin of a low coastal plain, possibly fronted by deltas, alternating with periods of reduced supply when basin conditions were re-established.

Work on the Bude Sandstones is at present incomplete, but to date it has shown that the bulk of the strata are made up of three facies, black shales, thick massive sandstones with few visible structures, and alternations of sandstones, siltstones and shales. The latter facies often shows grading and has internal structures and sole marks suggesting deposition by turbidity currents. There is an absence of medium scale cross-bedding, wavy bedding, fining upwards cycles and the oscillatory facies seen at Westward Ho !, and ripple-drift bedding is of a distinctive type (Walker, 1963). Channelling is common, but the bases of the channels are gently curved and not sharply erosive as in the Westward Ho ! succession. No cyclic pattern of sedimentation has been recognised, nor has any unequivocal evidence of shallow water or coastal plain deposition been observed.

The precise depositional environment of the Bude Sandstones is not easy to establish, but the facies is different to that of Westward Ho! The palaeogeographical conclusion is that whilst coastal plains reached into north Devon in Lower Westphalian times, there is no evidence that they extended into Cornwall.

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50. Further Argon age determinations on slates from South-West England : by M. H. Dodson.

Evidence has been given (Dodson, 1962) for an important 350 million year (Devonian-Carboniferous boundary) phase of folding in South Cornwall. Subsequent work in this area, on rocks from Gweek, Porthallow, Dodman Point, and Portscatho, support this figure.

Measurements on slates and mica schists from the Start-Bolt area now group closely round 300 million years (Upper Carboniferous). A comparable figure, 310 million, has been obtained from the Meadfoot Beds to the west at Porthpean, not far from their southern boundary.

Measurements from the Torquay area, from Portwrinkle, from inland exposures near Ashburton and Landrake, and from the Padstow area, suggest a broad east-west belt of Devonian slates with ages in the 320-335 million year range (mid-Carboniferous) running from Torquay to Padstow and Newquay. To the north of this belt lower ages are obtained : 280-300 million years from the phyllites of the Tintagel area, 270 million from the Boscastle Beds. These ages would correspond to the orthodox view of Hercynian folding in South-West England.

One obviously anomalous age (330 million years) has been obtained, from the Crackington Beds of the Culm Measures. This material appeared in a hand specimen to be a well-cleaved black slate, very similar to that from Boscastle. In thin section, however, it was seen to be hardly recrystallised at all, compared with the Boscastle specimen. X-ray diffraction studies on the two rocks supported this conclusion. The high age therefore is explained by incomplete expulsion of argon at the time of folding.

No other obvious correlation has been observed between the lithology of the samples and their argon age. On the contrary, the consistency of results in each region, is roughly what would be expected from the analytical uncertainties of around 10 million years : it therefore seems likely that systematic errors due to in complete expulsion of argon at the time of recrystallisation will not be greater than this.

On the whole a tectonic explanation of the pattern of results is to be preferred. Lowering of ages by post-Carboniferous losses

of argon is thought to be unlikely (Dodson, 1962). However, the possibility of argon losses caused by thermal effects during the later phases of orogenesis must be borne in mind in any detailed interpretation of the data especially the younger figures. These should therefore be regarded as minimum ages of folding and recrystallisation.

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51. Sedimentation in the Lower Culm Measures around Westleigh, North-east Devon : by J. M. Thomas.

Numerous quarries in the area of North-east Devon from Holcombe Rogus to Westleigh reveal a group of thick-bedded limestones which frequently have been called the Westleigh Limestones (Ussher, 1890; Owen, 1951; Prentice, 1962). Many authors, including Ussher (1891) and Hinde and Fox (1895), regarded these limestones as intermediate in character and position between the Carboniferous Limestone of the Mendips and the deeper water cherts and limestones of the Lower Culm Measures.

The Upper Westleigh Limestones, which are most extensively quarried, consist of the repeated interbedding of units of coarse calcarenite with units of fine-grained shale. These limestone and shale bands persist as discrete bedding units of constant thickness throughout each separate quarry exposure.

The shale bands range in composition from greasy clay-mineral mudstones (rare) to fine calcilutites, due to the varying amounts of calcilutite present in different bands, with a slightly calcareous mudstone occurring most frequently. They contain a large fauna of pelagic forms (goniatites; orthocones and *Posidonia* spp.) and a sparce benthonic fauna of productids : chonetids ; trilobites, and rare crinoids, all unabraded and some in position of growth. The shales show fine lamination and successive levels of burrowing activity within some units. All these features suggest that the shale units accumulated slowly as thin successive layers on a sea bed capable of supporting burrowing organisms and some benthonic macrofossils in quiet water conditions.

The calcarenites range from one inch to 20 feet in thickness, and occur as separate units, each with a sharp base against the underlying shale, a gradational top into the succeeding shale, and showing few internal bedding features. They contain much crinoid debris and oolitic material, and some rolled coral colonies and abraded brachiopod shells. Some bands show well-developed graded bedding. Ooliths are present in many limestone bands, including some less than one inch thick. The only worm burrows observed were in the uppermost parts of the limestone units.

Some thick limestone units contain may pebbles and blocks of the calcilutites which underlie them. These blocks may be angular or slightly rounded when consisting of calcilutites, but the platy shale masses also present are undulose and are thinned at the edges by squeezing as though deformed while somewhat plastic. These conglomerates show that limestone emplacement was accompanied by considerable erosion of the sea bed. The beds with more rounded blocks may be slide conglomerates. The material of these limestone units appears to have originated in a well-aerated `shelf' environment, and to have been transported to this area by powerful turbidity currents.

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52. Structure of the Devonian rocks in the Brendon Hills, West Somerset : by B. D. Webby.

The Devonian strata in the Brendon Hills consist of well-indurated sandstones, cleaved siltstones, slates, and cleaved to massive recrystallized limestones (Webby, 1962). Recent geological mapping has revealed that the rocks have been subjected to cleavage folding and flexure folding, on similar trends, and followed by a period of faulting. The cleavage folds are of different orders of magnitude (major and minor), and have associated axial plane cleavage, lineations, jointing and quartz-veining. In general the plunge of the cleavage folds is gently eastwards, but it is locally divergent. Cleavage strikes predominantly east-west, except in the Roadwater area where there is a conspicuous swing towards a north-east direction ; and the dip of cleavage gradually decreases from 60° south in the south of the area to 35° south in the north, and to 35' south-east in the neighbourhood of Roadwater. In contrast, the flexure folds are broad, open and symmetrical, such as the Croydon Anticline, referred to as the “great contortion” by De la Beche (1839). This anticline trends east-south-east and plunges gently eastwards.

An important series of faults cross the Brendon Hills in a northwest to northerly direction. The most important is the Timberscombe Fault System, already referred to by Ussher (1881 ; 1889) and Thomas (1940). The main displacements on this fault system predate the New Red Sandstone deposits in the Porlock depression, and consist of both dextral horizontal and vertical (downthrow to the west) movements.

The fanning of cleavage dip across the area is considered to post-date the development of the cleavage folds, and is thought to have formed with the development of the flexure folds. The parallelism in trend of the cleavage folds and flexure folds suggests that they represent folding during two separate phases of deformation in which the compressional forces acted constantly in a north-south direction, and built up in intensity on two separate occasions. The regional easterly plunge may have been initiated by block-tilting during the period of faulting. The development of the cleavage fan and the flexure folds may be linked with the possible major thrust beneath Exmoor (Bott, Day and Masson-Smith, 1958), which leads to the suggestion that the flexure folds may represent broad buckles produced in the over-riding thrust mass of Devonian rocks. Direction of thrusting is suggested by slickenside determinations, the overlying strata being transported north relative to the underlying. The period of faulting appears to have followed the periods of folding without a large gap in time, the fault movements being mainly Permian in age.

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53. Superimposed folding in Namurian turbidite sandstones near St. Gennys, North Cornwall : by D. M. Mackintosh.

All structures described here are found between Millook Haven and the north end of Cleave Strand. The area lies within the outcrop of the packet of strata called by Ashwin (1958) ' the Crackington Measures', which consist of a monotonous sequence of turbidite sandstones and shales. The main fold structures of the Crackington Measures are zig-zag folds on various scales, the axial planes of which range in orientation from horizontal to a northerly dip of 20 degrees. The axes of these folds trend generally towards 80 degrees in the area described.

Cross fold structures take a variety of forms within the area but achieve their greatest regularity of development in cliffs five hundred feet high between Sharnhole and Dizzard Points, a three-quarter mile stretch of coast which forms a structural unit bounded by N.W.-S.E. wrench faults. These faults are later than and unrelated to the fold structures described below. Within the Sharnhole-Dizzard structural unit, small monoclinal folds with generally westerly dipping axial planes refold the first folds. The amplitude of the monoclinal flexures is usually between one and three feet. Larger superimposed folds are found in. the low fore-cliff at Sharnhole Point, where second folds can be seen on the limbs of a recumbent first fold (shewn schematically in the block diagram). Cleavage is developed in the shales parallel to the second fold axial planes, and

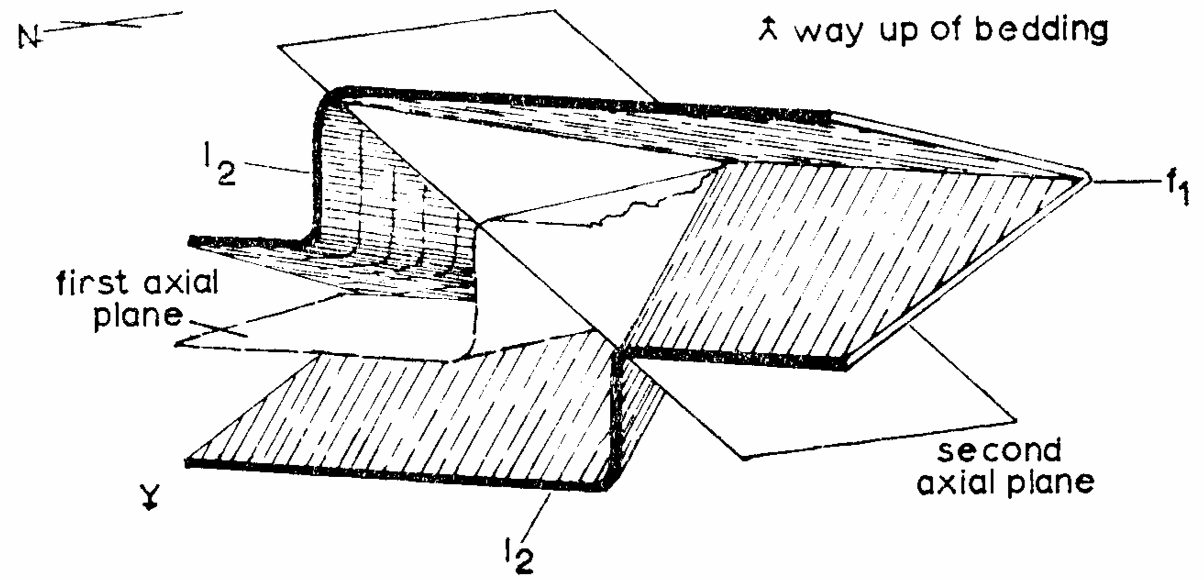

FIGURE 1. Diagrammatic representation of the relationship between first and second folds in the Sharnhole-Lizard structural unit.

clearly transects a first fold axial plane at Sharnhole. Refolded first fold axes are locally seen to plunge almost vertically. The refolding, which involves a mixture of concentric folding in the sandstones and similar folding in the shales, affects already dipping strata. Accordingly there is a marked divergence between the second fold linear structures developed on the normal and overturned limbs of the first folds.

Outside the Sharnhole-Dizzard unit isolated but spectacular examples of cross folding are seen, notably at the Stoneivy Rock and above the Scrade. A clear association, at the above places and at other localities within the area, between cross folds plunging down the dip of the overturned bedding and wrench faults parallel to the regional strike is observed. A similar relationship has been noted by Lillie (1960) in New Zealand. However, the wrench fault movements involve a dextral strike slip on low-angle northerly dipping planes which almost parallel the overturned bedding. An easterly transport of the upper layers relative to the lower layers after the main folding event would account for both the cross fold structures and the low angle strike slip movements in the area.

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