PROCEEDINGS
OF THE
USSHER SOCIETY

PART ONE

Edited by
M. R. HOUSE

CAMBORNE, SEPTEMBER 1962
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THE USSHER SOCIETY

Officers and Committee, 1962

Membership of the Ussher Society is open to all on written application to the Secretary and payment of the annual subscription of one pound due on January lst each year. Cheques should be made payable to the Ussher Society.

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The abstracts published in this part are those of papers delivered at a conference of geologists and geomorphologists who met at the University of Exeter at the beginning of this year. This was the fifth such conference, the first and second also having been held in Exeter, in 1956 and 1958 respectively, the third in Bristol in 1960 and the fourth in Camborne in 1961.

A very large part of the geological research in the South-West at the present time is being carried out by individuals working in relative isolation in a great many different institutions throughout the country. Moreover advances are being made along a very wide front in palaeontology, petrology, stratigraphy, structural geology and geomorphology. Thus there is a strongly felt need for special opportunities for contact both between people working within a particular field and between people working in different fields but having various points of common interest. Thus the conferences have been fulfilling a real need as is proved by their uniform success and the fact that all have been attended by the great majority of all the active researchers in the South-West on each occasion.

The conferences have been run with the minimum of formality on the same general lines from the start. There have been separate sessions in each of the main fields of work enumerated above, and since 1960 also in the submarine geology of the English and Bristol channels. Short papers, progress reports and discussions have made up the separate sessions and there has been much informal exchange of ideas and information in the evenings. One or two day excursions have preceded or followed the meetings and these are likely to become more important in the future.

For some time, however, the organisers of the conferences have been aware that some more formal arrangements would be needed if the conferences were to continue to be held annually as seemed desirable, and if abstracts of the papers were to continue to be published as had been done ever since 1958. The abstracts were published by the Royal Geological Society of Cornwall, to whom we are greatly indebted, and it was hoped that the Cornish Society might become associated with the organisation of the conferences Unfortunately this has not proved practicable and it was decided at the recent meeting in Exeter to set up a formal organisation to run the conferences and take responsibility for the publication of the abstracts. The organisation is to take the form of a society in order that there should be an assured income from membership fees and in order to have proper machinery for the election of officers.

At the same meeting the opinion was strongly expressed that the informal character of the conferences should not be sacrificed for the formation of an unwanted new regional geological society on traditional lines. Consequently the Constitution which was adopted makes it clear that the new society has no pretensions to emulate other societies and exists for the single purpose of carrying on the work of the conferences with the minimum of change in their character.

The name Ussher Society was adopted to commemorate W. A. E. Ussher (1849-1920), the only man whose life work has been in the geology of South-West England ; a man who, moreover, as an officer of the Geological Survey worked on nearly all aspects of the geology of the region, and who in establishing the stratigraphical succession in the Devonian and Carboniferous of South and Central Devon made the most significant single contribution to its understanding.

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CONFERENCE OF THE USSHER SOCIETY
HELD AT EXETER, 1962

The conference was held at the Geology Department, Exeter University, from the 10th to 12th January. The Society is indebted to Professor Scott Simpson and his department for the excellent facilities provided. The conference was preceded by an excursion to study the Upper Devonian and Lower Carboniferous rocks of the Launceston area on Tuesday, 9th January which was led by Professor Simpson. The conference was followed on Saturday 13th by an excursion to study geomorphological features of Dartmoor led by Mr. R. S. Waters.

The lectures given to the conference are listed below and the abstracts which have been received are printed in the same numerical order and marked with an asterisk on the list.

PROGRAMME

l0th January

Morning session

1. Professor W. F. Whittard :" Acoustic methods in sub-marine geology."
2. Mr. I. H. Ford :" Some equipment used in sub marine geology."
3. Dr. D. T. Donovan :" The Palaeozoic-Mesozoic boundary between Morte Point and Minehead."
4. *Mr. D. Curry :" Age determination of some rocks from the floor of the English Channel."
5. *Mr. A. H. Stride :" Low Quaternary sea levels."
6. *Mr. P. Floyd :" Petrochemical data from the Land's End aureole."

Afternoon session

7. *Mr. B. Marshall and Mr. J. Falla :" The mineral-isation at Hallsands, South Devon."
8. Mr. D. H. Green :" The high temperature aureole of the Lizard peridotite."
9. *Mr. M. G. Bawden :" The boron content of some Cornish rocks " read by Mr. M. Stone.

10. *Dr. M. H. Dodson : "Potassium-argon ages of some south-western slates and phyllites." Cornwall."
11. Dr. A. T. J. Dollar: "The age of the Lundy igneous intrusions : a revision."
12. Dr. K. F. G. Hosking : "The significance of the distribution patterns of trace and minor elements in the sediments of the Helford River and in the *Fucus* growing there."

11th January

Morning session

13. *Dr. J. E. Prentice : "The structural history of the Carboniferous rocks of North-West Devon."
14. *Dr. W. R. Dearman : "On some major lineaments in Cornwall and South Devon."
15. *Mr. N. E. Butcher: "The structure of Devon and Cornwall."
16. *Mr. P. Scott : "A gravity survey in South-West Cornwall."
17. *Mr. B. Marshall : "The small structures of Start Point, South Devon."

Afternoon session

18. *Mr. M. C. McKeown : "Structural studies at Dodman Point, Cornwall."
19. Mr. D. J. Shearman : "Minor structures in the Ilfracombe Beds."
20. Mr. D. J. Shearman and Mr. F. J. W. Holwill : "Strike faulting in North Devon."
21. *Mr. P. L. Hancock : "The late fracture phase of the Armorican orogeny in Southern Pembrokeshire."
22. *Mr. J. L. M. Lambert : "A reinterpretation of part of the Meneage Crush Zone."
23. *Mr. M. Stone : "Vertical flattening in the Mylor Beds, near Porthleven, Cornwall."
24. Mr. J. Barclay and Mr. E. D. Lacy : "The Land's End aureole between Pendeen and Kenidjack,"

12th January

Morning session

25. *Mr. S. C. Matthews : "A Middle Devonian conodont fauna from the Tamar Valley."
26. *Dr. M. R. House and Mr. N. E. Butcher : "Excavations in the Devonian and Carboniferous rocks of the Chudleigh area, South Devon."
27. *Mr. J. M. Thomas: "The Culm Measures in North-East Devon."
28. *Mr. E. E. Swarbrick : "Facies changes in the Chert formation of the Lower Culm Series of the Brampton area, North Devon."
29. *Mr. B. D. Webby : "The Devonian sequence of the Brendon Hills area, West Somerset."

Afternoon session

30. *Mr. D. G. Mead and Mr. D. Ingle Smith: "Some aspects of limestone solution on the Mendip Hills."
31. *Mr. D. Brunsden : "The erosion surfaces of the River Dart."
32. *Mr. F. W. Sherrell : "Drilling and site investigations in Devon and Cornwall."

4. Age determinations of some rocks from the floor of the English Channel : by Dennis Curry.

Professor W. F. Whittard of the University of Bristol has for the past five years carried out a systematic programme of sampling the solid rocks of the English Channel and Western Approaches between Longitudes 3° W. and 8° W. Samples have been collected by means of a drop-corer at the intersections of a grid whose meshes are 10' apart and at other points selected on a 1' grid where it has appeared that especially interesting information might be obtained.

Many of the samples are of fossiliferous soft rocks and a micropal aeon tological examination of these has produced some interesting results which are based for the most part on their content of small Foraminifera. A preliminary statement of some of these results follows. Nearly half of the samples recovered are of Chalk and it has proved possible in most cases to identify the stage of the Upper

Cretaceous which each represents and in some cases to identify the macrofossil zone. The great majority of the samples have proved to be of Santonian or Campanian age, but a very small number (collected near a known sub-Cretaceous unconformity) are Cenomanian or Turonian. No Coniacian has yet been certainly identified. There are in addition a few samples, collected from stations in the neighbourhood of 49° 35'N., 4° 20'W., which are clearly of Maestrichtian age, including some which contain *Racemiguembelina fructicosa* (Egger), the zone fossil of the so-called *Pseudotextularia* Zone of Denmark, which occurs near the top of the Maestrichtian of that country. Immediately to the south-east of this group of stations are several in cream limestone with a distinctive fauna which includes *Globigerina cf. Pseudobulloides* Plummer and appears to be Danian. The believed Danian beds are succeeded by glauconitic sands with a shallow-water marine fauna including many Miliolidae, also *Rotalia* cf. *lithothamnica* Uhlig, *Halkyardia minima* (Liebus) and *Linderina ovata* Halkyard. The age of these beds is tentatively placed as Middle-Upper Eocene. In the Western Approaches, a large area is covered with fine calcareous sands with many well-preserved Foraminifera. These include *Globigerinoides trilobus* (d'Orb.) and other planktonic forms, but few shallow-water species. These sands have yielded rare *Elphidiella hannai* (Cushman and Grant) (kindly determined by Dr. B. M. Funnell) and for this and other reasons are believed to be of Pliocene age. Of the larger Foraminifera, *Nummulites* (not yet specifically identified) has been found in glauconitic sands in the neighbourhood of 49° 20' N., 6° 00' W., and *Asterocyclina* occurs in a sample of Eocene age from 49° 10'N., 4° 40'W.

5. Low Quaternary sea levels : by A. H. Stride.

On the continental shelf between the south coast of Ireland and the latitude of the Scilly Isles the most obvious elements of relief are a series of north-west trending ridges. These are up to 50 miles in length, up to 5 miles broad, up to 180 feet high, and are separated from one another by distances of up to 10 miles (Admiralty Chart 1598). Information about the profile of the ridges has been obtained from 20 echo-sounding records provided recently by Captain E. F. Aikman.

At some places on the sides of the ridges there are benches up to 2 miles wide which are often flat and almost horizontal. The ground behind them can have a slope as high as 2 degrees while below them the slope is about 4 degree. Most of the benches occur at either 60 or 70 fathoms with a spread of about plus or minus 3 fathoms. While part of this scatter can be attributed to instrumental errors and to differences in sea level when the records were taken, the remaining differences are real.

The form of the benches, the considerable area within which they have been found and their presence in a region where littoral deposits have been taken (Godwin-Austen, 1850) suggests that they are near-shore features cut when the sea stood appreciably below that of today. The scatter about the two main levels would be in keeping with such an interpretation.

If the benches are approximately equivalent to the near-shore deposits taken from beneath 62 ½ , fathoms of water off western Mexico which are 19,300 plus or minus 300 years old (Curray, 1961), they will be late Pleistocene in age. Thus, a larger area of the European continental shelf may have been a land surface at that time than is generally supposed. For the moment the correlation between the two widely separated sites depends on the validity of the assumption that at neither place has there been any appreciable vertical movement during the last 20,000 years.

References :

GODWIN-AUSTEN R. A. C., 1850. On the valley of the English Channel. **Quart. Journ. Geol. Soc.,** Vol. 6, p.69-97.

CURRAY, J. R., 1961. Late Quaternary sea level, a discussion. **Bull. Geol. Soc. Amer.,** Vol. 72, p.1707-1712.

6. Petrochemical data from the Land's End aureole : by P. Floyd.

In this communication petrochemical data from the Tater-du area of the aureole is presented and discussed with regard to the rest of the Land's End aureole.

Meta-igneous hornfelses from Tater-du

(a) Petrology : The meta-igneous hornfelses (hornblende hornfels facies) were originally intrusive sill-like bodies as indicated by the presence of an adinole at the upper and lower contacts.

During contact metamorphism a variety of mineral assemblages were produced due to the effects of Ca and K metasomatism. Five main groups of hornfelses were recognized (revision of 1961), all of which may or may not contain plagioclase -- (i) amphibole hornfelses (hornblende and cummingtonite), (ii) biotite hornfelses (biotite), (iii) banded biotite-amphibole hornfelses (biotite with hornblende, cummingtonite or anthophyllite ; rare cordierite), (iv) banded calciferous hornfelses (hornblende and biotite with diopside and grossularite), (v) calc-silicate hornfelses (variable sphene, diopside, grossularite, clinozoisite, zoisite, anorthite, axinite, scapolite and calcite).

(b) Chemical data : Various triangular plots were used to illustrate metasomatic effects. On a Von Wolff diagram, incorporating chemical data from Tilley (1935), Reynolds (1947), Phillips (1876) and the author, a number of points were demonstrated ; viz. --- the presence of a large pelitic field becoming more undersaturated as biotite and cordierite develop ; a hornblende-plagioclase field (" parental greenstone ") not far removed from a meta-dolerite field - indicating the origin of the aureole hornfelses from doleritic intrusives by the development of amphibole (a process which is visible in thin section) ; and two major trends, one showing increasing Ca metasomatism and the other the development of ferromagnesians. The main chemical effects due to metamorphism are as follows : (1) Ca trend : coupled with the main process of Ca metasomatism, were the removal of Si, Al, alkalis, Mg and Fe ions which migrated out of the Ca rich areas, (2) K trend : increase in K in progressively biotitized hornfelses.

Metasomatism in the Land's End aureole.

Aureole rocks subjected to extensive internal metasomatism caused by the intrusion of the Land's End granite. Internal metasomatism consisted of :

(i) removal of Ca from hornblende hornfelses with the subsequent formation of Fe-Mg rich hornfelses (anthophyllite-cummingtonite-cordierite).

(ii) addition of Ca to hornblende hornfelses with the formation of Ca rich hornfelses (hornblende with diopside and grossularite, etc.)

(iii) coupled with Ca metasomatism the migration of other ions was effected, e.g. removal of Si, Al, alkalis, Mg and Fe ; although the main effect was a general desilification of the hornfelses involved. Migrating Si may have coupled with Al and alkalis to effect silification and felspathization elsewhere in the aureole (e.g. Avarak Reef).

There appears to be a crude zonal arrangement of ions in the highly metasomatized areas with irregular masses of Fe-Mg hornfelses near the granite contact and Ca hornfelses and Si hornfelses further away. All are set in a "background" of hornblende hornfelses.

7. **The Mineralisation at Hallsands, South Devon :** by B. Marshall and J. Falla.

Whilst mapping the microstructures in the Lower Devonian slates immediately north of the Start fracture zone, certain features noted regarding the nature of four ore horizons suggested that they might have a sedimentary origin.

The ore is pyrite, marcasite, quartz, ‘jasper’, hematite, limonite and carbonate.

The structurally significant features of the horizons are:

1. They are folded by F_1. (Marshall, 1962).
2. Their strikes and dips are slightly discordant with those of the cleavage, which either cleaves them, or forms a marginal shear zone.
3. The thickest horizon inosculates, suggesting incipent boudinage.

Thus they are pre-tectonic ; their paragenesis should reflect the structural history, and their mineralogy the metamorphic environment. Further, the depositioual conditions might be deduced from the original mineralogy of the sediment.

Thin sections and polished mounts were examined, and a summary of the paragenesis, and the conclusions reached, are now presented.

1. Pre-metamorphic pyrite was recognised. This was rotated during the cleavage formation, and was oxidised before the inception of the post-metamorphic cycle. The pyrite was the diagenetic modification of chemically precipitated iron sulphide.
2. Hematite and 'limonite', derived from the pyrite during folding, and included within segregating quartz, gave rise to `jasper'.
3. The passing of F_1 saw the iron that went into ‘solution’ during folding, reprecipitated as pyrite.
4. With falling temperature, pyrite / marcasite intergrowth occurred.
5. Finally marcasite formed by itself.

Three post-metamorphic cycles (Nos. 2-5) were recognised, and attributed to F_1 F_2 and F_3, respectively. The last cycle terminated with carbonate precipitation.

Metamorphic mobilisation of the pyrite resulted from Eh variation within the ground water, pyrite ceasing to be stable in the area of ‘acid solubility’. Figure 6.20 in Garrels' book, (1959), shows that a further increase in Eh might result in hematite formation. The end of the movements resulted in an Eh reversal and reprecipitation of sulphide. Which sulphide, probably depended upon a delicate balance of temperature and pH, (Allen *et al.*, 1914). The increasing marcasite/pyrite ratio in successive cycles indicates decreasing temperature, low temperature favouring marcasite formation. The trend within each cycle confirms this.

Reference to work by James, (1954), and Krumbein and Garrels, (1952), placed the Hallsands ore within the pyrite facies of the former, and below the sulphide fence of the latter. This suggests deposition within an offshore trough, sufficiently deep to be below the base of wave action, yet not cause continuous sulphide production. Possible reasons for its occasional formation are : an increased rate of trough depression relative to that of chemical precipitation ; an increased amount of iron and/or organic material. This reflects variations in the iron available for transport, the optimum conditions for which (Huber and Garrels, 1953), are large sluggish streams, rich in organic matter, and draining areas of carbonate free rocks.

The significance of this work lies in the information regarding the depositional and metamorphic environments, and in the correlation between the regional structure and the ore paragenesis.

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KRUMBEIN, W. C.. and R. M. GARRELS, 1952. Origin and Classification of Chemical Sediments in terms of pH and Oxidation Reduction Potentials. **Journ. Geol.,** Vol. 60, p.1-33.

MARSHALL, B., 1962. The Small Structures of Start Point, South Devon. **Proc. Ussher Soc.,** Part l, p.19.

9. The boron content of some Cornish rocks : by M. G. Bawden.

A colorimetric procedure using Carminic acid has been developed for the determination of boron in rocks. Only titanium causes serious interference. The rock powder is fused with sodium peroxide, the frit extracted with water, and the acidified solution passed through a cation exchange resin to remove titanium as a peroxy complex. The effluent is made alkaline and evaporated to dryness, and the residue is dissolved, in hydrochloric acid. The boron content of this solution is determined colorimetrically. Tests on boro-silicate glasses show that the overall error is less than plus or minus 10 per cent.

Fifty specimens from the St. Austell and Godolphin granite masses and the killas have been analysed.

The results for the Tregonning and Godolphin granite and the two porphyritic St. Austell granites agree with those obtained from petrological studies on the distribution of tourmaline (Exley, 1959 ; Stone, 1960). Both chemical and modal analyses show that the two non-porphyritic St. Austell granites have the same boron content, but the actual value for the concentration is nearly ten times higher from the chemical analyses than from the modal analyses.

The unaltered sediments contain between 60 and 460 p.p.m. of boron. Pelitic sediments have a higher boron content than psammitic sediments.

The boron content of the altered sediments near the Godolphin granite is reasonably constant to within a few inches of the contact. At this distance, where the rock is a tourmaline-rich hornfels, the concentration increases by a factor of four or five. This conflicts with Goldschmidt's (1954, p.288) findings, near Harzburg, that "the amount of boron decreases from the shales to the hornfels of the contact zone".

The origin of the boron in the tourmaline-rich hornfels is not known, but Goldschmidt's explanation that "the boron content of marine argillaceous sediments account excellently for the appearance of tourmaline in metamorphic rocks . . . and for ... tourmaline in the hornfels rocks formed in contact metamorphism" is not wholly adequate. Tourmaline in the metamorphosed rocks more than a few inches from the granite could be explained by a re-mobilisation of the boron in the original sediments, but the large increase in concentration at the contact suggests that boron has been added from the granite itself. Indirectly it may have been derived from sediments fused at depth, and subsequently concentrated at the contact.

Summary of Boron Analyses

Rock Type			*Mean boron content*	*No.of Samples*
Granite:				
Godolphin	…	…	520 p.p.m.	1
Tregonning	…	…	620	1
St. Austell,	(1) biotite-muscovite.		380	1
	(2) early lithionite.		1,270	2
	(3) late lithionite		300	2
	(4) fluorite	…	290	3
Killas				
Shales	…	…	140	4
Greywackes	…	…	140	5
Laminated shales		…	420	4
Slates	…	…	350	7
Mica schists	…	…	410	6
Hornfels	…	…	1,740	4

In the St. Austell granite varieties 1 and 2 are porphyritic, varieties 3 and 4 are non-porphyritic.

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EXLEY, C. S., 1959. Magmatic differentiation and alteration in the St. Austell granite. **Quart. Journ. Geol. Soc.,** Vol. 114, p.197-230.

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STONE, M., 1960. The Tregonning-Godolphin Granite. **Abstracts Proc. 3rd Conf. Geol. and Geomorph. S.W. England.** Royal Geol. Soc. of Cornwall.

10. Potassium-argon ages of some south-western slates and phyllites : by M. H. Dodson.

Whole-rock potassium-argon ages of fine-grained slates and phyllites have been shown in several instances to give the age of the metamorphism which produced the slaty cleavage, when this is known independently (Goldich *et al.* 1957, Hurley *et al.* 1959).

Two possible sources of error must be considered : the slates may contain " detrital argon " i.e. argon in detrital grains which survived the low grade metamorphism ; alternatively they may have lost argon during their subsequent history. These factors would affect the ages in opposite directions.

An attempt has been made to check loss of argon by comparing the age of slate from Lyd George, about 12 miles outside the Dartmoor granite aureole, with the age of the granite. The slate had an age of 300 million years, compared with 270 million years for the granite and for two hornfelses near the outer edge of the aureole. These results suggest that this slate would retain argon very well at low temperatures, though they are not conclusive.

Macroscopic detrital mica was not visible in any of the samples measured. It is thought that measurements on a variety of samples will show by their consistency or inconsistency whether or not this source of excess argon could be important.

The chief results so far are the following :

Formation	*Locality*		*Age (million years)*
Gramscatho Beds	½ ml. N. of Gunwalloe Cove	I	345 / 355
		II	348
Dodman "Phyllite"	Hemmick Beach …		356
Palaeozoic Slate	W. of Hemmick Beach …		349
Mylor Slate	Porthleven …		…less than 300

The analytical uncertainties correspond to about plus or minus 12 million years uncertainty in these figures. The Porthleven slate was probably heated by the Tregonning granite, losing most of its radiogenic argon when the latter was intruded. The close grouping of the other figures is strong evidence for metamorphism about 350 million years ago. This date approximates to the Devonian-Carboniferous boundary. It lies remarkably close to the independent K/Ar results obtained by Dodson (1960) and by Miller and Green (1961) on Muscovites from schists of the Old Lizard Head Series.

Work in progress suggests that a similar age may be obtained for Devonian slates over a wide area of South Devon and Cornwall. Ages from the Start-Bolt area, however, are more scattered and on the whole younger. The reason for this is unknown, but it may be connected with the difficulty of obtaining really fresh samples of the Start schists.

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DODSON, M. H., 1960. Isotopic Ages from the Lizard Peninsula, South Cornwall. **Geol. Soc. Proc.** No. 1591, p.133-136.

GOLDICH, S. S., BAADSCAARD, H., and A. O. NIFR, 1957. Investigations in A^{40}-K^{40} dating. **Trans. Am. Geophysic.** Union, Vol. 38, p.547-551.

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MILLER, J. and D. H. GREEN, 1961. Preliminary Age-determinations in the Lizard Area. **Nature,** Vol. 191, p.159-160, 14

13. The structural history of the Carboniferous rocks of North West Devon : by **J. E.** Prentice.

The folding of the Carboniferous rocks is a simple structure which could be produced by a single north-south compression. Two folding styles have been recognised : in a northern zone overturning accompanied by overthrusting is predominant, whilst in a southern zone simple folds with vertical axial planes are typical. The cleavage shows a simple relationship to the folding in the northern zone, but in the southern zone an irregular pencil cleavage is only poorly developed. The joint pattern shows predominantly a conformity with the stresses indicated by the folding, although there are a number of anomalies. The faulting, whilst displaying a simple wrench fault pattern of outcrop, displays many anomalies in displacement. In one case a north-easterly fault can be shown to have displaced the facies of the lower Carboniferous for more than a mile in a dextral direction. It is thus postulated that the wrench fault movements were imposed early in the history of the area, and have subsequently been rejuvenated on at least two separate occasions.

14. On some major lineaments in Cornwall and South Devon : by W. R. Dearman.

W. A. E. Ussher was the first to recognize that the Middle and Upper Devonian rocks near Plymouth were followed to the west, that is more or less directly along the strike, by beds of Lower Devonian age. His intimate knowledge of the Devonian rocks of South Devon had enabled him to disentangle the mass of factual evidence on the Devonian rocks of Cornwall given by De la Beche in 1839 and the results of this work were presented in 1891 as a geological map of Cornwall. This map clearly shows a single great fault trending in a general north-westerly direction from Cawsand Bay near Plymouth, past Menheniot and on towards Cardinham at the south-western margin of the Bodmin Moor granite. Later work (Ussher, 1907) revealed three major north-west to south-east faults, the Cawsand, Portwrinkle and Portnadler faults, affecting the out-crops of the Lower Devonian rocks between Plymouth and Fowey. These, together with other faults just east of Plymouth, have a combined dextral movement of more than eight miles.

It is reasonable to expect that such strong faults should have a great length, but on the Survey maps the fault lines are only drawn where Lower Devonian rocks are affected. The three faults could be expected to pass just to the east and to the west of the granite mass of Bodmin Moor and evidence in support of probable wrenchfaulting in these areas may be inferred from both the distribution and shape of selected outcrops. The western contact of the granite, for example, departs but little from a straight line which could be a continuation of the north-north-westerly branch of the Portnadler fault. A continuation of this line bisects the quartet of greenstone outcrops near Michaelstow and limits the extent of the metamorphic rocks around Tintagel. The eastern margin of the granite also has these linear elements. In a similar fashion the outcrop pattern of the lavas and Carboniferous rocks north-east of the contact contain an east-south-east element interpreted as a normal junction linked by north-north-westerly trending parts which could be wrench-faulted junctions. This explanation is strongly supported by the close agreement between the amount of fault offset affecting the outcrops near Plymouth and at the north-eastern margin of the Bodmin Moor granite on the presumed continuation of these faults.

The same approach to the recognition of wrench-faults in other parts of the peninsula suggests that the north-eastern and south-western parts of the other granite masses are affected by north-westerly or north-north-westerly trending fault zones. Fault zones have been mapped in north-east Dartmoor by Dearman and Butcher (1959) and Blyth (1957) who demonstrated that there has been a dextral movement of over one mile along the Sticklepath-Lustleigh fault zone.

An attempt has been made to assess the effects of wrenchfaulting on the geological structure of the peninsula. If all the faulted blocks are moved back on the assumption that the movments were entirely horizontal, then :

(a) The total movement between Land's End and north-east Dartmoor is at least 35 kilometres.
(b) The southern margins of the Bodmin Moor and Dartmoor granites were originally at the same latitude.
(c) The great arc of the Lizard-Start thrust is straightened into a linear tectonic break trending approximately east-north-east to west-south-west which is the axial direction of many minor fold structures throughout the peninsula.

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15. The Structure of Devon and North Cornwall :
by N. E. Butcher.

It is desirable to study the structural setting of South-West England in space and time. Variscan structures are dominant and these, in the orogenic belt, need to be related to the structures on the foreland to the north. Devonshire-type structures are not confined to South-West England -- for example, faulted folds involve the Coal Measures of Pembrokeshire. The Variscan structures of South-West England may well obscure Caledonian and earlier structures, especially in the Start and Lizard areas. They are themselves modified by Alpine structures. These latter seem to be mostly faults, but it is conjectured that locally the Palaeozoic basement may form the cores of eroded east-west monoclinal folds in the former Chalk cover, such folds being the westward continuation of those now seen in outcrop to the east.

The fossil evidence indicates a virtually complete Upper Palaeozoic succession in Devon and North Cornwall. Thus it seems that the Variscan orogeny in this region took place at essentially one time, at the end of the Carboniferous period (Butcher 1961). Evidence is accumulating that this orogenic deformation brought differing stratigraphical successions close together. How these are related, and therefore the nature of the major structure, is not yet known.

There is a pronounced change in the attitudes of the exposed folds across Devonshire. The Devonian rocks of North Devon and extreme South Devon show similar structures with folds overturned to the north. In between these two areas there is a north to south change through upright folds, folds overturned to the south and recumbent folds in the Carboniferous and Upper Devonian rocks. The belt of recumbent folds, in the region of the Bodmin Moor and Dartmoor granites, shows deformation increasing in intensity westwards.

Detailed work, using the evidence of goniatites, on a single section in the Upper Culm Measures at Bonhay Road, Exeter, proves the repetition of the local stratigraphical succession by folding and faulting. This section is thought to provide the key to a large part, at least, of the enormous outcrop of the Upper Culm Measures. It seems that a fairly thin stratigraphical succession, constantly repeated at the surface by folding and faulting, could explain this vast outcrop.

Indeed, it is suspected that the Upper Palaeozoic succession in South-West England may be generally thin compared with the considerable thicknesses of Old Red Sandstone and Carboniferous rocks known on the foreland to the north. This relative thinness may partly explain the intense deformation generally seen in South-West England.

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BUTCHER, N. E., 1961. Age of the orogeny and granites in South-West England. Nature, Vol. 190, p.253 ; Vol. 191, p.486-7.

16. A gravity survey in South-West Cornwall : by P. Scott.

The investigation of the structure of South-West England, using geophysical methods, was begun by Bott, Day and Masson Smith in 1958. This work has now been extended by means of detailed gravity surveys in selected critical areas, in continuance of their regional studies. In addition to a detailed survey carried out in South-West Cornwall, traverses of closely spaced gravity stations have been obtained over the granite masses of Dartmoor and Bodmin Moor, to enable a more accurate interpretation of granitic structure to be made.

Both Frost and Worden gravimeters have been used to obtain readings at 1,100 new stations, all of which have been referred to the observed value of gravity at Pendulum House, Cambridge. The Bouguer Anomalies, resulting from the reduction of the observed gravimeter readings have been primarily used to investigate the asymmetrical mass distribution within the granite bodies, first noticed by Bott et al. (1958). A correlation has been found to exist between the observed Bouguer Anomaly minimum over the Land's End granite, and the outcrop of a less dense, aplitic granite within the main mass. This indicates the existence of a density variation within the granite mass which could control the symmetry of the Bouguer Anomaly. The detailed survey in South-West Cornwall has enabled the investigation of the existence of subsurface ridges in the granite-killas boundary, postulated by Hosking (1957) to account for the distribution of mineralisation in the area. The presence of several of these ridges can be demonstrated, using the gravity results.

It has been possible to delineate the margins of the main Cornubian granite batholith in South-West Cornwall by means of gravimetric observations obtained at sea, using an underwater gravimeter. This instrument has also been used in the Bristol Channel, in order to investigate the structure of North Devon. continuing the earlier work of Bott et al. (1958).

References :

BOTT, M. H. P., A. A. DAY and D. MASSON SMITH, 1958. The geological interpretation of gravity and magnetic surveys in Devon and Cornwall. **Phil. Trans. Roy. Soc. London**, Ser. A..

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HOSKING. K. F. G.. 1957. Fissure systems and mineralisation in Cornwall. **Trans. Roy. Geol. Soc. Cornwall,** Vol. 18, p.9-49.

17. **The small structures of Start Point, South Devon** : by B. Marshall.

The area consists of Lower Devonian slates to the north and schists to the south of the "Start" Boundary (Phillips, 1961). The latter have been ascribed ages ranging from Pre-Cambrian to Devonian. The structures are now summarised :

Slates.

F_1. The folds progressively tighten and slightly overturn, both towards the S. Their regional, axial plane cleavage (S_1), strikes E.N.E.-W.S.W., and fans 30° either side of the vertical. The fold axes plunge around 15° at 250°, as does the bedding-cleavage lineation.

F_2. Similar in plunge to F_l, but folds and fans the slaty cleavage. A transposition cleavage (S_2), is formed, the resulting crenulation lineation plunging westward at 10-I5°. Associated with F_2, but cutting the crenulation, are :

1. A N.W.-S.E., N.E.-S.W. shear set, having dextral and sinistral movements respectively.
2. *ac*-joints, 90° to the lineation.
3. E.-W. sub-vertical dip-slip faults, the `Start' Boundary fault being an example.

F, The structural plane (S_4), is sub-vertical, striking about 20° in dextral movements, and 310° in sinistral ones. With increasing deformation it veers towards 50° and 280° respectively. The direction and plunge of the S_1, S_3 intersection, vary with the S_1 plane. Three stages are recognised :

1. 'Knitterung' (Hoeppener, 1955), or `Joint Drag' (Knill, 1961).
2. 'Schubklüftung' (Engels, 1960).
3. 'Shear Folding' (Mead, 1940).

It is stressed that they are progressively phases of the one movement.

F_4,. Similar to F_3, but only stage 1 is developed. The structural plane (S_4,), dips N. or S. up to 20°, whilst the plunge measured on S_1, is sub-horizontal. The `hanging wall', has moved `down dip' on both northerly and southerly dipping planes.

F_3; and F_4, are probably complementary to slips along the S_1 planes.

Schists.

F_1. Small recumbent folds, plunging 10-20° at 250-280°, were occasionally recorded. Their axial plane schistosity (S_1), dips slightly southward, but is generally destroyed by F_2.

F_2. The folds plunge gently westward, have vertical axial planes, and no axial plane schistosity. However, the `transposition' planes ($S_2$), bear `new' mica, and constitute a transposition schistosity. The S_1-S_2 intersection, paralleling the F_2 plunge, forms a mica crenulation, and quartz rodding, (Phillips, 1961). Associated with F_2 as in the slates, are:

1. A shear set.
2. *ac*-joints.
3. E.-W. faults.

F_3. Only Knitterung and Schubkluftung stages are developed otherwise, as for the slates.

F_4. Compared with the slates, F_4 is weakly developed, but has the same characteristics.

Conclusions. The antiformal distribution of the green schists results from F_2 and refolding F_1. Depending on the origin of the flat-lying schistosity, the concept of an upper and lower set of Mica Schists (Tilley, 1923), may be erroneous.

F_2, F_3, and F, are found in both schists and slates, and with equation of the flat-lying schistosity with the vertical cleavage, their structural histories become common. Thus, being part of the same orogenic cycle, for the schists to pre-date the slates, one must conclude that no major structural break exists between the Silurian and Devonian in S. Devon.

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18. Structural studies at Dodman Point, Cornwall :
by M. C. McKeown.

Dodman Point consists of well folded sedimentary rocks which are constant in lithology and which vary in amount of metamorphism from unmetamorphosed sediments (subgreywacke, banded silts, black slates) to phyllites. Graded bedding, slump folding and convolute bedding have been recognised within the subgreywackes, thus indicating their formation as turbidites.

Idiomorphic pyrites crystals (of up to 1 c.c. in volume) characterise the Dodman sediments, and provide the one distinguishing factor from the nearby Gramscatho Beds. Pyrites crystals tend to concentrate along bedding plane junctions between the subgreywacke and slate beds. Quartz pressure shadows surrounding each crystal are oriented parallel to cleavage.

Structure. The Dodman rocks have undergone repeated folding and two main phases of deformation can be recognised:-(a) First Deformation : Isoclinal minor folds have constant axial planes dipping 50° to 130°, and fold axes plunge at low angles (10°) to 40°. This phase was accompanied by the development of quartz veins parallel to bedding and cleavage. (b) Second Deformation : Minor accordion folding and disjunctive folding of the cleavage and quartz veining associated with the first deformation occurred within N.E./S.W. striking bands across Dodman Point. This phase was accompanied by quartz veins forming parallel to the axial planes of the second minor folds and to the second cleavage. The axial plane of the second folds dip at (a) 80° to 130° and (b) 80° to 40°, and the fold axes plunge at 25° to 310° or 20° to 40°. Vertical normal faulting, striking N.E./S.W., also formed.

Tectonic Styles : Three fold styles were formed during the first deformation : (a) Symmetrical isoclinal folds, (b) Asymmetrical folds. Both have fracture cleavage developed parallel to the axial plane and these fold types occur within thin subgreywacke and slate, (c) Oblique shear folding with axial planes generally parallel to cleavage. This folding occurs within the thick greywacke/thin slate unit and produces spindle-shaped lenses of slate within subgreywackes.

Three folds, formed during the second deformation, were: (a) Concentric folds, formed within the massive subgreywacke horizons. (b) Accordion folding, formed within the subgreywacke/

silt horizon. (c) Disjunctive folding, formed within the silt and slate horizons. From these observations it appears that fold style is related to the competency of the folded sediment.

Cleavage. The Dodman rocks were cleaved during both deformations with an overall schistosity developing during the first deformation, and fracture cleavage developing parallel to the axial planes of fold hinges. The second cleavage produced a strain-slip cleavage which varies in intensity, locally developing into knickzone folding.

The structures described show that Dodman Point consists of overturned folds, the product of the first deformation, cut by later belts of strain-slip cleavage. Cleavage-bedding relations show that the sediments generally young upwards. It is postulated that the folds achieved their present position by low angle N.W. to S.E. movements followed by horizontal E./W. compression.

21. The late fracture phase of the Armorican orogeny in southern Pembrokeshire : by P. L. Hancock.

The late fracture phase of the Armorican orogeny in southern Pembrokeshire essentially consists of wrench faults and equivalent joints cutting W.N.W.-E.S.E. trending folds. The wrench faults probably pre-date the joints and only in rare cases are the two systems parallel. The faults form a conjugate pair of near vertical shears, their departure from verticality is significant, for in most cases the line of intersection of the two shears is perpendicular to the plunge of the fold in which they occur.

The associated joints, which are related to the same major phase of deformation as the faults, depart even further from verticality. Their orientation on fold limbs makes them look as if they were a pre-existing pair of conjugate shears involved in the folding. They are however demonstrably younger. This orientation of the late fractures is probably due to their having been formed from a stress field which is the resultant of two residual stress fields, one remaining from the folding phase, the other from the wrench faulting phase. Tension joints which bisect the acute angle between the shears indicate the direction of minimum stress may have been an actual tension. Many undoubted shear joints have also been infilled and this presumably indicates an even later tensional phase. When local modifications to the orientation of the stress axes, due to folding, are allowed for, their regional orientation is basically that postulated by Anderson (1951) i.e., maximum compressive stress N.N.E.-S.S.W., minimum W.N.W.-E.S.E. and intermediate vertical.

The orientation of fractures in collapsed blocks of Carboniferous limestone, enclosed in Permo-Triassic cave breccias, shows that the late fractures formed prior to the breccias. Therefore this final phase, in addition to the folding and thrusting, can be regarded as part of the Armorican orogeny.

References:

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22. A reinterpretation of part of the Meneage Crush Zone:

by J. L. M. Lambert.

The rocks of the Meneage Crush Zone (Geol. Surv. one-inch Sheet 359) are poorly exposed inland and can only be examined in detail between Porthallow and Nare Head.

The bulk of the rocks are sedimentary, clastic and predominantly unstratified. Within these, stratified sediments comparable to the Gramscatho Beds are exposed near the Lizard Boundary at Porthallow and also in a few small isolated areas to the north.

Proceeding from south to north four divisions of unstratified sediment are distinguished (approximate outcrop widths in brackets):

1. Siltstone breccia (500').
2. Phakoidal sandstone (subgreywacke) in slate (1500').
3. Conglomeratic pebbly slate (500').
4. Conglomerate (2000').

1. Angular and lenticular fragments of siltstone and mudstone are contained in a matrix of variable, but mainly silty texture. The fragments lie with their long axes sub-parallel to a cleavage which cuts both matrix and fragments. It can be demonstrated that the

fragments are detrital and derived from a bedded deposit by a process which operated contemporaneously with deposition, probably sub-aqueous slumping. The only structures related to tectonic deformation are cleavage and the preferred orientation of the fragments.

2. The phakoids are asymmetric and pinch and swell irregularly. They range in size from wafers to masses three feet thick and ten feet long, generally dip gently south-east, with no apparent arrangement according to size. Slump structures are visible in the argillite at a few exposures. Cleavage is rarely evident, Since the form of the phakoids differs from the regular form of tectonic boudins, their formation is attributed to slumping of originally tabular beds.

3. Structureless black slate predominates, with rock fragments ranging from sand to boulders unevenly distributed within it. Though most are of quartzite, two boulders of limestone have been found, one calcarenite the other calcisiltite. The boulders lack any regular arrangement and none is represented by stratified deposits outcropping in the area. Boulders and matrix, unlike crush conglomerates, differ in composition. The characters of the division are attributed to slumping and mixing of conglomerate and semi-consolidated mud.

4. This division is stratified at its northern boundary and succeeded conformably by regularly bedded argillite with thin breccia lenses. A variety of rock types occurs in all grades including the coarse sandy matrix. Among the boulders sandstone predominates. A significant feature of the division is the presence of argillite clasts, especially in the smaller grades. It is inferred that the division is sub-aqueous slide conglomerate.

The most important conclusion is that previous interpretations are erroneous. The rocks are not tectonic breccias and it is no longer necessary to postulate northward thrusting of the Lizard Complex.

23. Vertical flattening in the Mylor Beds, near Porthleven, Cornwall : by Maurice Stone.

Complex minor folds in the Mylor Beds near Porthleven can be divided into two components: (1) A set of minor recumbent folds (F_2) superimposed on the limbs of (2) an earlier set of more upright subisoclinal folds (F_1). Both sets plunge gently to the east-north-east. Cleavages, S_1 and S_2 (corresponding to F_1 and F_2 respectively), belonging to each fold set occur. S_1 is sporadic and is folded by F_1. S_2 is the apical plane "shear cleavage" previously described (Stone and Lambert, 1956). A third, steeply dipping north-south cleavage (S_3) is responsible for a "crinkling" lineation on S_2; its significance is not understood, although it may be related to more widespread north-south structures in S.W. England.

Graded bedding in the sequence of alternating siltstones and pelites of the Mylor Beds, shows that whilst F_2, folds face north-west and south-east, when the direction of facing is projected on to the folded apical planes of the F_1 folds, the latter face upwards to the north-west.

It is believed that the F_2, folds have been produced by vertical or near-vertical compression acting on the steep limbs of F_1 folds. Evidence for vertical compression is as follows :(a) Although it is theoretically possible for recumbent similar (shear) folds which involve little or no vertical shortening, to form by subhorizontal slip along an apical plane cleavage, it is difficult to visualize how associated concentric folds could have developed in this way. The shortening indicated by the concentric folds in the silty bands is nearly vertical and is perpendicular to S_2. It follows that the associated pelites have undergone the same amount of vertical shortening, and that their similar geometry is not solely the result of slip along cleavage. (b) F_1 fold limbs which make a small angle with S_2 are generally not folded, but steeply dipping quartz micro-veins in such limbs are folded about S_2. and demonstrate vertical flattening. (c) S, is folded about S_2. (d) Quartz-vein boudins occur in S_2 and demonstrate stretching in S_2. (e) Tension gashes cutting fold limbs lie perpendicular to S_2. (d) and (e) indicate continued vertical compression after the formation of the F_2 folds and S_2 cleavage.

It is suggested that the vertical compression responsible for the formation of F_2 and associated structures was caused by an increase in superincumbent load due to large scale sliding. It follows from the information given, that the observation of isolated recumbent folds does not necessarily lead logically to the conclusion that they are congruous with a major structure.

Reference :

STONE, M. and J. L. M. LAMBERT, 1956. Shear folding in the Mylor Slates, near Porthleven, Cornwall. **Geol. Mag.,** Vol. 92, p.331-335

25. A Middle Devonian conodont fauna from the Tamar Valley : by S. C. Matthews.

Limestones are exposed on the Cornwall bank of the River Tamar at a locality some fifty yards north of Neal (Nail) Point (Grid ref. SX 437614). The one-inch sheet 348 of the Geological Survey (published 1907) shows that this limestone occurrence must lie within a broad belt of outcrop which extends from south-west Dartmoor westward to the Portwrinkle Fault and which includes rocks mainly of Upper Devonian age (although Carboniferous rocks may be more widespread than the one-inch sheet suggests). Proof of Middle Devonian age for these limestones brings the problem of explaining an occurrence of Middle Devonian rocks here, four and a half miles north of the Plymouth syncline.

Usher (1889, 1907) published two references to this locality the earlier suggested a Middle Devonian age for the limestones, and the later referred to re-interpretation of corals present there and proposed an Upper Devonian age for them. In neither account is it clear that three distinct limestone sequences are faulted together at Neal Point. One of the three is a tightly-folded succession of thin, dark-grey or light grey-pink calcarenites alternating or occasionally merging with slates, and abundant conodonts were obtained by dissolving a limestone from this succession. Rare highly deformed specimens may have been caught up in the calcite-filled cross-fractures. Seventeen “species” identified include *Polygnathus eiflia, P. linguiformis, P. webbi* and *P. xylus.* With one exception the conodont species present indicate a late Eifelian date (see Bischoff and Ziegler, 1957). Certain slim polygnathids must be referred to *Polygnathus vavca,* which according to the German authors should not appear until late in the Givetian. Rhodes and Dineley (1957) have also discovered *P. vavca* and *P. xylus* together so that there is a difference between British and German findings which remains to be explained. The Neal Point fauna includes distacodids and thus repeats a second “anomaly” apparent in Rhodes and Dineley’s results; but the genus *Belodus* is now considered to range properly into the Upper Palaeozoic and these distacodids may be discarded as evidence for derivation of Devonian sediment from a source in Ordovician rocks.

The occurrence of Middle Devonian limestones is to be explained structurally, rather than stratigraphically as Ussher suspected (1889). The limestones lie on a line of structural misfit recognised in the Tamar Valley, where north-south faults bring into juxtaposition a flat-lying, upward-facing succession of slates on the east and another, downward-facing, on the west.

These are regarded as portions of the two limbs of a major recumbent fold whose axis trends east-west. The north-south fault zone which brings an upper and a lower limb of the major fold to the same level may be expected to include elements from the fold core as fault-slivers. This is the structural setting proposed for the restricted Middle Devonian limestone outcrop at Neal Point. The continuity of the "Upper Devonian" slate-belt in west Devon and east Cornwall, as represented on sheet 348, is misleading.

References :

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USSHER, W. A. E., 1889. The Devonian of the Western Region. **Trans. Dev. Assoc.,** Vol. 21, p.440-451.

USSHER. W. A. E., 1907. The geology of the country around Plymouth and Liskeard. **Mem. Geol. Surv.**

26. Excavations in the Devonian and Carboniferous rocks of the Chudleigh area, South Devon: by M. R. House and N. E. Butcher.

With the aid of a grant from the British Association excavations have been made in the area around Mount Pleasant, Chudleigh, and a complete succession through the Upper Devonian and Lower Carboniferous has been established. The Famennian zones of Cheiloceras and Platyclymenia are represented as nodular limestones and the Clymenia Zone in shales with nodular limestones. The Wocklumeria Zone ammonoids occur as siliceous shales with limestone nodules. The Famennian thickness is about 170 feet.

This Upper Devonian sequence is followed by 75 feet of siliceous shales in the lower part of which a rich conodont fauna has been obtained which Mr. C. S. Matthews has identified as IIa. Near the top of the siliceous shales and cherts *Pyonorites* and goniatitids occur suggestive of B_2P_1 levels. The succeeding Posidonia Shales are at least 30 feet thick and contain goniatites, trilobites and abundant *Posidoniae*. The Ugbrooke Park Beds overlie these shales and the entry of coarser silty beds is first seen in the upper part of the Posidonia Shales.

The evidence shows that the main Chudleigh escarpment is a simple succession of flatly lying beds. The close juxtaposition of Middle Devonian and Upper Culm Measures is due, not to faulting or thrusting as has been supposed, but to a complete but very reduced succession in the Upper Devonian and Lower Carboniferous.

27. **The Culm Measures in North-East Devon :** by J. M. Thomas.

A continuous succession of Culm Measures was established around Bampton and proved by detailed 6 inch mapping eastwards from the town. The Culm Measures overlie soft grey fossiliferous shales equated with the Pilton Beds of N.W. Devon (Goldring, 1955), and presumed to straddle the Devonian-Carboniferous boundary. Hard, black, finely laminated shales appear to overlie the Pilton Beds conformably and are taken as the base of the Culm Measures, although Prentice (1960, p.264) suggests a black silty shale group ("D") forms the topmost part of the Pilton Beds in N.W. Devon.

A thick group of cherts with interbedded limestones overlie these basal black shales and is provisionally subdivided into Lower Bampton Limestones ; Middle Bampton Cherts ; and Upper Bampton Limestones on the relative abundance of the interbedded limestones in the quarries around Bampton. The cherts are frequently highly radiolarian black shales with a fine chalcedony matrix and are usually well laminated. They show some diapiric and flow structures formed after deposition, but evidence of current activity at the time of deposition, in the form of ripple-drift bedding and sole markings was only observed in the limestone bands. These limestone units are interpreted as turbidity current deposits interrupting the quiet accumulation of the radiolarian cherts. The lower part of the succession appears to become more argillaceous north-eastwards from Bampton.

Merocanites cf. sinzilis from Kersdown Quarry, Bampton, shows the Middle Bampton cherts to be of Zone II age. The Upper Bampton Limestones contain the thickest limestone units, and extend into Zone P_1 with abundant *Posidonia becheyi* at the top of the group, and Zone IIIb trilobites from quarries east of Bampton. The limestones die out near the top of P_1 and soft black shales with fine silts were deposited from P_1d throughout most of the Namurian. These black shales are very similar to the Limekiln Beds of Fremmington (Prentice 1960, p.266) and appear to be the lateral equivalents of the Exeter Grits in the Bonhay Road sections. Greywacke deposition began before R_2c times, but after at least part of R_1 and these greywackes have yielded numerous G_2 goniatites. No fossils younger than the Instow Fish Bed fauna have been found, and the whole of the greywacke group in N.E. Devon appears to be equivalent to the Instow Beds of Prentice (1960, p.278). The rocks are folded in large east-west asymmetrical folds with steep northerly dipping limbs and gentle westerly plunges. The intensity of the folding and the asymmetry of these folds increase northwards across the area, with the northerly dipping limbs becoming overturned and with some breaking along anticlinal axes accompanied by a swing of the axial trace from E.N.E.-W.S.W. to almost E.-W.

28. Facies changes in the chert formation of the Lower Culm Series of the Bampton Area North Devon : by E. E.Swarbrick.

The Chert Formation of the Bampton area is the approximate equivalent of the Chert Beds of the Bideford Region, (Prentice, 1960). Below the formation is a series of dark siliceous mudstones called the Basement Formation, and above are the black shales of the Black Shale Formation. Within the Chert Formation two major facies can be identified.

(a) Brushford Member. Above the Basement Formation in Hulverton Hill quarry ; m. south-east of Brushford, is a series, some 100 ft. thick, of alternating black and grey cherty mudstones containing many radiolarian tests. These Hulverton Hill Beds are quite thinly bedded -generally from ½"-l" and are characterised by a cross hatch system of cracks, filled with a white friable weathering product. Above these beds is a further series of cherty mudstones best exposed in Kents Hill quarry 750 yds. west of Hulverton Hill. These Kents Hill Beds are generally darker, more brittle due to a

higher chert content, and are much thicker - up to 4" - than the Hulverton Hill Beds. Upwards the succession, which is about 300 ft. thick in all, passes by transition into the overlying Black Shale Formation.

(b) Bampton Member. In the immediate vicinity of Bampton a rather different sequence of true cherts and dark calc-arenites some 300 ft. thick is seen. 600 yds. south of Bampton Station, the Basement Formation can be seen dipping below chert beds of the Chert Formation. The succession can be divided into a lower series, best exposed in Kersdown quarry, and an upper series as seen in Baileys quarry ; both exposures being immediately south and east of Bampton. The Kersdown succession is chiefly of cherts, generally pale and streaked with dark shale fragments, or darker and shaly. In the sequence are a few beds of dark calc-arenite. The upper series in Baileys quarry is composed entirely of dark calc-arenite, similar to those in Kersdown quarry. Indiivdual bed thickness increases upwards from 6" at the base to 5 ft. maximum, and the beds of calc-arenite are often separated by thin pale calcilutites. Upward the succession passes by alternation into the Black Shale Formation.

Thus between the Basement and Black Shale Formations are two roughly equivalent facies showing distinct lithological variance. The northern Brushford Member is predominantly argillaceous, and presumably pelagic, whilst the more south-westerly Bampton Member shows a mixture of true clastics - the limestones - and mixed elastic and colloidal material in the cherts. Furthermore the 120 ft. plus of limestone of the Bampton Member wedges cut completely in the three miles separating the two facies.

Related to the lithological distinctions are extreme differences in sedimentology. The Brushford Member is dominantly pelagic being evenly bedded, and shows no evidence of pene-contemporaneous deformation. The Bampton Member however displays a variety of current induced structures such as rippling, cross bedding, gouge channelling and other sole marks ; and evidence of plastic deformation in slumping and pull-aparts.

The situation in fact bears many resemblances to that described by Prentice in the Bideford area of a Northern and Central Facies of the Chert Beds, but in Bampton the distinction would appear to be even more finely drawn both lithologically and sedimentologically.

29. The Devonian sequence of the Brendon Hills area, West Somerset : by B. D. Webby.

The main stratigraphical divisions of the North Devon coastal section occur in the Brendon Hills area, namely the Hangman Grits, the llfracombe Beds and the Morte Slates. These units have been subdivided in the detailed mapping of the Brendons ; the local sequence, in upward stratigraphical order, being as follows :-

1. *Upper Hangman Grits :* the lowest beds exposed, consisting of predominantly quartz sandstones, often with lenticular bedding, sedimentary structures and plant fragments (probably *Psilophyton),* all suggestive of Old Red Sandstone depositional conditions. Towards the top of the formation there is evidence for a change of conditions, indicated by the occurrence of lamellibranchs.

2. *Avill Group :* subdivided into the following four units :-
   - (a) Mansley Beds : alternating grey slates and thinly-bedded siltstones. Only trace fossil *Chondrites* occurs in this formation.
   - (b) Walland Sandstone : sandstones interbedded with subordinate slates.
   - (c) Harwood Beds : grey and brownish-grey slates with interbedded calcareous siltstone and, locally, limestone. The calcareous horizons have yielded brachiopods, lamellibranchs, a gastropod, a stromatoporoid, Poiyzoa and crinoid ossicles.
   - (d) Oaktrow Sandstone : bedded, grey and reddish-brown sandstones with subordinate siltstones and slates ; often calcareous, and containing a similar fossil content to the Harwood Beds and a new species of crinoid (Webby, 1961).

3. *Cutcombe Slate :* grey slates, which are often calcareous and more arenaceous towards the middle of the formation. Fossils are few and include *Chondrites,* crinoid ossicles, indeterminate brachiopods and lamellibranchs. Laterally, there is a local development of limestone, known as the Rodhuish Limestone, containing rugose and tabulate corals, and stromatoporoids

4. *Roadwater Limestone :* contains a fauna consisting of rugose and tabulate corals, stromatoporoids, brachiopods, lamellibranchs, Polyzoa and crinoid ossicles.

5. *Leighland Beds :* this formation becomes progressively more arenaceous upwards, changing from grey slates to siltstones and then to sandstones with local limestone (Leigh Barton Limestone). *Cyrtospirifer* has been obtained from the limestone. The rest of the formation yields only indeterminate brachiopods, Polyzoa, crinoid ossicles and *Chondrites.*

6. *Sticklepath Slate :* grey, well-cleaved slates with only *Cyrtospirifer* and crinoid ossicles.

7. *Brendon Hill Beds:* greenish-grey, grey and brownish-grey siltstones with subordinate sandstones and slates. This formation has not yielded fossils.

8. *Upper Morte Slates :* grey slates and silty slates, lying to the south of the Brendon Hills and, therefore, not studied in detail.

Formations 2, 3, 4 and 5 belong to the Ilfracombe Beds, and formations 6, 7 and 8 to the Morte Slates. Tentative estimates of the thickness of the Ilfracombe Beds are 2,800 ft., and the two lower formations of the Morte Slates, a little more than 2,000 ft. ; both estimates being maximum values.

Correlation with Middle and Upper Devonian stages depends on brachiopod and coral evidence. Formations 1-4 are Givetian and, less confidently, the Givetian-Frasnian boundary is within formation 5. Formations 6-8 are probably Upper Devonian.

Reference :

WEBBY, B. D., 1961. A Middle Devonian Inadunate Crinoid from West Somerset, England. **Palaeontology,** Vol. 4, p.538-41.

30. Some aspects of limestone solution on the Mendip Hills:

by D. G. Mead and D. Ingle Smith.

Quantitative values for the amount of CaCO, dissolved by stream waters have been determined over the period December *1960* to December 1961*;* several hundred individual analyses having been made. For the majority of the springs discharging to the north and south of the Central Mendips (e.g. Cheddar, Rickford and

Wookey Hole) the $CaCO_3$ content was found to be of the order of 235 p.p.m, and did not vary by more than 10% throughout the year. It was not substantially affected by variations in the discharge of the springs. In marked contrast to these springs was Langford Rising (NGR: 466593), where the $CaCO_3$ content varied inversely with the spring discharge. Thus a randomly collected sample may not necessarily give an accurate idea of the $CaCO_3$ content of other springs in the same area, or even of the same spring at a later date.

The $CaCO_3$ content of the spring water is greatly in excess of that to be expected if the CO. necessary for the solution of the limesone were derived solely from the atmosphere. Additional CO_2 is probably obtained from the soil air. (Adams and Swinnerton. 1917). No readings for the CO_2 content of Mendip soil air have yet been obtained, but the figures for soils under similar climatic and vegetation conditions to those of Mendip suggest a value of some 1.6% CO_2. (Russell, 1958). Water in equilibrium with air of those composition would dissolve up to 280 p.p.m. $CaCO_3$. This figure accords well with the values obtained for the Mendip spring waters.

$CaCO_3$ figures have also been obtained for water samples from G. B. Cave (NGR : 477562). It was found that the $CaCO_3$ of the cave stream was higher at the terminal sump than at the cave entrance, and that the increase varied inversely with the stream discharge. This increase is thought to be due mainly to the addition of $CaCO_3$-rich percolation and tributary stream waters rather than the direct solutional activity of the main stream itself. The $CaCO_3$ content of the underground tributary streams varied widely with differing discharge conditions, but the water dripping from the cave roof varied only slightly with changes in the rate of flow. It is thought that the bulk of the water in the major Mendip springs originates as 'percolation water' rather than 'stream water'.

Other less numerous observations have been made upon the springs associated with the Cotswold escarpment and these show a mean $CaCO_3$ content of 290 p.p.m. in comparison with the 235p.p.m. of Mendip. This difference between these two limestone areas may be due either to the variations in the type of subterranean water flow *or* to differing soil types and therefore soil air composition.

Work on many of these problems is still in progress. The authors would like to acknowledge the help afforded to them by the University of Bristol Spelaeological Society.

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ADAMS, C. S. and A. C. SWINNERTON, 1937. Solubility of Limestone. **Trans. Amer. Geophysic. Union,** p.504.

RUSSELL, E. JOHN, 1958. Soil Conditions and Plant Growth. **Longmans, Green & Co., London.**

31. The erosion surfaces of the River Dart: by D. Brunsden.

The physical history of the River Dart is recorded in the landscape by the dissected remains of widespread erosion surfaces. Seventeen stages have been recognised which fall into two major groups. The upper six surfaces are developed within the moorland area and are believed to be sub-aerial in origin. The eleven surfaces at and below 690 feet are related to former coastlines which lay within the area and in the majority of cases both marine and fluvial components have been identified.

The highest surface recognised on Dartmoor lies at 1900-1700 feet in the north and 1650-1500 feet in the south. (Waters, 1960). It has relief of the order of 100-200 feet which is closely related to the structure of the granite. (Waters, 1957). This surface has been uplifted by the Mid-Tertiary earth movements and tilted to the south-east at an average slope of 40 feet per mile, and is suggested to be of Early Tertiary age.

Following the uplift of the summit plain the area suffered partial peneplanation which led to the production of the 1300-1100 foot surface. (Waters, 1960). The evidence is of three kinds : (1) broad basin floors on the West Dart and East Dart-West Webburn rivers, (2) residual hills, such as Bellever Tor, (3) youthful valley sections on the south flowing tributaries. The surface is separated from the summit plain by a youthful fringe ; steep reaches on the streams, bluffs on the interfluves and isolated hills which represent lowered parts of the summit plain. The development and extension of the youthful valley section into the northern moor reflects the southward tilting of the area.

Below this level four terraces are identified at 1000, 920, 800 and 750 feet O.D. These levels are preserved as valley side benches and narrow floodplains. No evidence of wave cut platforms related to these levels has been recorded. The surfaces between 1300 and 750 feet O.D., which are unwarped and were initiated by the MidTertiary uplift, are of Late Tertiary age.

The drainage pattern related to these six levels was eastward with a north-south pattern of subsequent streams. This was interrupted by the transgressive 690 foot sea, the shore of which has been mapped from Brent Hill to Holne and Ashburton Downs. The surface maintains a constant horizontal level at its back of 680 to 692 feet O.D.

Following the retreat of the 690 foot sea the Dart developed as a south-easterly stream across the emergent sea floor and was superimposed across the structural lineaments of the Palaeozoic rocks. The successive stages of development are recorded by a series of well marked terraces and wave cut platforms at the following heights :

590 feet	230 feet	25 feet
430-445 feet	180 feet	10 feet O.D.
325 feet	150 feet	
290 feet	50 feet	

The 690 foot surface is suggested to be of Early Pleistocene age and equivalent to the 600 foot platform of Wales, Dorset, the Bristol-Radstock area (Wooldridge, 1961) and South-East England. The lower levels represent the 'still-stands' of the retreating sea during Pleistocene time.

References :

WATERS, R. S., 1957. Differential Weathering and Erosion on Oldlands. **Geographical Journal,** Vol. 123, p.503-9.

WATERS, R. S., 1960. Erosion Surfaces on Dartmoor and adjacent areas. Roy. Geol. Soc. Cornwall. **Abstracts Proc. 4th Conf. Geol. Geomorph.** S.W. **England,** Roy. Geol. Soc. Cornwall, p.28-29.

WOOLDRIDGE, S. W., 1961. The Radstock Plateau. **Proc. Bristol Nat. Soc.,** Vol. 30, p.151-162.

32. Drilling and site investigations in Devon and Cornwall :

by F. W. Sherrell.

Drilling with particular reference to well boring was described. *Culm Areas.* By virtue of their geographical extent, most small scale boreholes have been sunk in the Culm. Although detailed mapping of these rocks over large areas is somewhat lacking, it is possible to make a reasonable prediction of the lithology (thus the groundwater potential) which may be encountered, in a borehole. Structure, particularly in depth is less predictable. Results indicate however that structure is of much less consequence than lithology.

The factor of the greatest single importance in the Culm is topography. The reasons for this are :

(1) The geographical catchment area controls groundwater recharge and thus the water available to a bore. The more reliable bores are thus on lower ground.

(2) In certain areas, the rocks carry a fairly extensive clay “head”. This head encourages run-off. Thus recharge is not encouraged on high or steep ground.

(3) Many Culm rocks, particularly the soft black shales are rich in iron. This high content creates a reduction in yield from a bore with time. The reason for this is that when drawdown or a '` cone of evacuation " is developed, air enters the aquifer. Oxidation of the iron in solution takes place and the resulting insoluble oxides are deposited, gradually infilling the joints, etc. Thus the yield is reduced. Drawdown is greater on the high ground for a given specific yield. Hence where drawdown is reduced as in the lower areas, oxidation is reduced. Normally bores are taken deep in order to minimise drawdown and thus the oxidation problem.

An average six inch bore in the Culm to a depth of 150 feet gives an initial yield of 1,000 gallons per hour. This soon reduces to about 4-500 g.p.h. Where the oxidation is very considerable, it may reduce to 200 g.p.h. Occasionally an artesian bore is obtained. A local thick clay head provides the "confining" bed.

Devonian Areas. Results obtained in the Devonian, particularly in S. Devon are much more variable. However, yields of about 200 g.p.h. are obtained from 150 feet in most of the slate formations. Improvement of yield is obtained in these rocks when the diameter of the bore is increased. Enlargement from 6" to 12" dia. will increase the specific yield by as much as fifty per cent. This results from the greater seepage area per foot of bore and the consequent reduction of “entry friction” into the bore.

Other Areas. Very good results are obtained from the PermoTrias, particularly the lower sandstone series. Bores in the Greensand areas are of interest, as they require very careful treatment in order to prevent “running sand” and silting up.

Site Investigations. Selected examples were described, together with the final results in relation to the structures.