PROCEEDINGS
OF THE
USSHER SOCIETY

VOLUME ONE

PART THREE

Edited by
M. R. HOUSE

REDRUTH, OCTOBER 1964
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THE USSHER SOCIETY

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CONFERENCE OF THE USSHER SOCIETY
HELD AT TORQUAY, 1964

At the kind invitation of the Torquay Natural History Society, the Society met for its conference at the Torquay Museum from the 1st to the 3rd of January. The Society was particularly appreciative of the generous hospitality shown to them. At the meeting Professor H. K. Erben, of the University of Bonn, gave the Invitation Address to a joint meeting of both societies on the evening of January 1st. His lecture is published in full in this issue of the Proceedings.

At earlier meetings of the Society, bad weather has limited field excursions. Such was not so on this occasion. On Saturday, January 4th, the morning was spent under the direction of Mr. N. E. Butcher and Dr. M. R. House in the Chudleigh area, and the Palace Wood Quarry and Kiln Wood Quarry were visited, then the sections near the Winstow Cottages and finally the succession of Devonian and Lower Carboniferous discernible on the hillslope at Mount Pleasant were examined. This was essentially similar to an excursion of the Devonshire Association reported by Mr. E. T. Vachell *(Trans. Devon. Ass.,* Vol. 95, p.58, 9).

After lunch in The Toby Jug at Bickington on the A38, Mr. C. M. Bristow led the party to the chert quarry beside the road on Ramshorn Down and then on to the top of the Down to an old quarry, unfortunately being filled in but formerly the source of type radiolariae. Then Mr. Bristow demonstrated the succession above and below the Rora Thrust (see his account in our *Proceedings,* Vol. 1, p.65-67).

The party crossed country through Rora Wood to near Colesworthy and finally to Ilsington where the party returned to Ramshorn Down and dispersed.

On Sunday 5th, Mr. C. T. Scrutton demonstrated the succession and fauna at Dyer's Quarry where *Mesophyllum (M.)* and *Macgeea (M.)* are abundant and Triangle Point where abundant *Acanthophyllum (Grypophyllum)* were noted. At Hope's Nose Mr. E. T. Vachell demonstrated the raised beach and the structures. After lunch, Dr. E. B. Selwood guided the party to Lummaton where he described the fauna of the Lummaton Shell Bed and the succession. Finally Mr. Vachell led the party to the Ogwell area where he showed members some of the structural problems regarding the disposition of the limestone masses.

PROGRAMME

Following the usual practice, all contributions to the conference are listed below, but only those marked with an asterisk are printed in the text.

1st January, 1964

54. Mr. J. E. Wright and Dr. E. R. Freshney: "A short account of the mapping of the Okehampton Sheet."
55. *Dr. W. R. Dearman : "Refolded folds in the Dartmouth Slates at Portwrinkle, South Cornwall."
56. *Dr. W. R. Dearman : "Some observations of boudinage structures in Cornwall."
57. *Dr. W. R. Dearman : "On deformed sun cracks in the Dartmouth Slates."
58. *Mr. R. G. Walker: "Some aspects of the sedimentology of the Westward Ho! and Northam Formations."
59. *Mr. D. M. Mackintosh: "The sedimentation of the Crackington Measures."
60. *Prof. Scott Simpson : "The supposed 690 ft. marine platform in Devon."
61. *INVITATION ADDRESS. Prof. H. K. Erben : "Facies developments in the marine Devonian of the Old World."

2nd January

62. *Dr. W. R. Dearman : "A comparison of minor structures at Lydford, Devon, and Boscastle, North Cornwall."
63. Dr. M. C. McKeown : "Structural history of the area between Polperro and Mevagissey."
64. *Prof. Scott Simpson : "The Lynton Beds of North Devon."
65. Major H. Wallace : "Ways in which the amateur diver can assist geologists as illustrated by recent work of the Bristol Sub-Aqua Club between Start Point and the Lizard."

3rd January

66. *Mr. B. Booth: “Petrogenesis of the Land's End Granite.”
67. Dr. K. F. G. Hosking : “Mineralization in the greisenised granite of Cameron Quarry, St. Agnes.”
68. Dr. K. F. G. Hosking : “The genesis of Cornish wood tin.”
69. Dr. C. S. Exley : “Clay formation in the south-western granites : notes on some of the factors involved.”
70. *Dr. M. R. House: “A new goniatite locality at Babbacombe and its problems.”
71. *Mr. F. J. Holwill : “Corals of the Ilfracombe Beds.”
72. *Mr. F. W. Sherrell “Some aspects of ground water geology in the South-west.”

55. Refolded folds in the Dartmouth Slates at Portwrinkle, south Cornwall : by W. R. Dearman.

Dartmouth Slates, of Lower Devonian age, are exposed on the coast at Britain Point (SX 352538) four hundred yards west of Portwrinkle, Whitesand Bay (Ussher, 1907). Bedding, picked out by thin beds of ripple-marked, cross-laminated sandstone in the purple and green slates, is steeply inclined to the south-west. The rocks are folded into tight and even isoclinal folds in which the inverted limb may be sheared out (Fig. la). A strong slaty cleavage is refracted through the sandstone beds and in any fold the intersection of bedding and cleavage is parallel to the fold axis. Wherever it has been possible to determine the way-up of the beds the folds are seen to face upwards.

Folds are plentifully developed in the reefs off Britain Point, an immediate impression of the structure over much of the area is of folds plunging evenly to the north-east at about twenty-five degrees, although local reversals of plunge to twenty-five degrees south-west would not escape notice. In both sets of folds the bedding maintains a constant strike whilst, in particular, the attitude of the fold axial planes remains constant.

Systematic measurement of the plunge of fold axes and indicatory lineations revealed first the extent of variation in the attitude of these structures, shown plotted on Fig. Id, and second a juxtaposition of folds as represented diagrammatically in Fig. lb. This latter is considered to be a critical exposure. It comprises two reefs, about ten feet apart, situated close to high tide mark. In the far reef in the illustration folds plunge at up to forty degrees west-southwestwards, whereas in the near crag the folds plunge more steeply at up to fifty degrees to the east-north-east. Thus the hinges of adjacent groups of folds change direction through a right-angle while maintaining a constant axial plane attitude. Indeed, the variation may be even greater if the fold in the foreground, with a plunge of seventy-two degrees to the west-south-west, is accepted as a member of the same group. Unfortunately it was not possible to determine whether this fold is an anticline or a syncline, but should the former be the case then in this small area the fold plunge has changed direction by as much as one hundred and fifty degrees. All the folds have the same shape and it is reasonable to assume that they arose in the same way and with the same attitude, reaching their present disposition by being folded again: they are refolded folds.

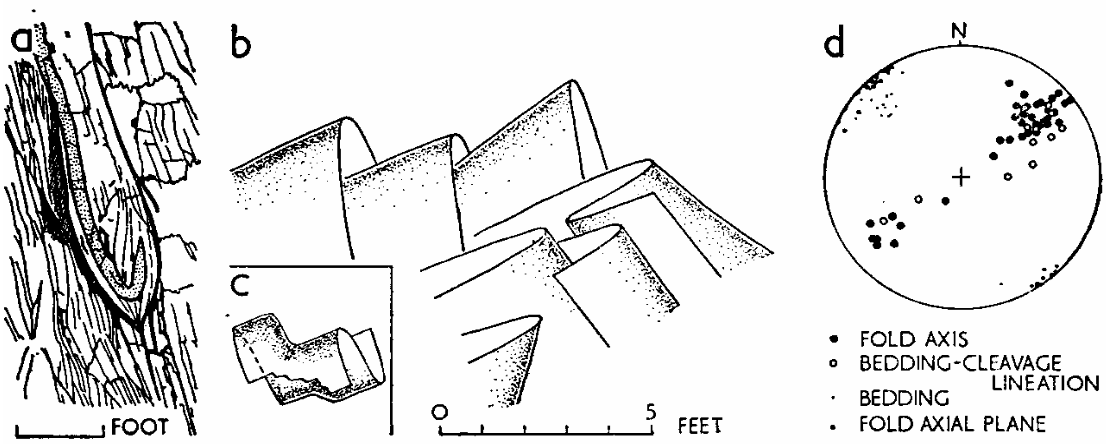

FIGURE 1. Minor fold structures in the Dartmouth Slates at Portwrinkle. (a) Profile, looking north-eastwards, of a typical isocline in which the inverted limb has been sheared out. Dotted bed crosslaminated sandstone, remainder slate in which an axial plane cleavage is strongly developed. (b) Surface diagram, looking to the north-west, of an actual exposure of fold groups with markedly different plunges. (c) Synthetic surface diagram showing probable relationships of the folds illustrated in (b). (d) Lineations and poles to planar structures. Equal area projection. Lower hemisphere.

Examples of refolding with smooth transition from one plunge direction to another have not been observed in these rocks. They are known to occur, however, in the rocks of the Southern Uplands of Scotland where this distinctive style of refolded fold has been called the " Eyemouth-type " of cross-fold (Dearman *et al.*, 1962, figs. 2, 4 and 5; Shiells and Dearman, 1963, p.214, fig. 4 and Plate 21, fig. 1). The ideal shape of a refolded fold is shown in Fig. lc and it is clear both from this and from the accompanying stereogram that the amount of refolding may be variable, although transverse arrangements of adjacent folds appear to be most common. Formation of these unusual fold shapes is visualized as having been penecontemporaneous with the generation of tight folds which later were to become isoclines. There must have been considerable stretching and buckling with intense shearing at the hinge of refolding. Lack of continuity in refolded folds may be attributable to these causes.

These inferred refolded folds represent structures and fold styles which have not been described before from Cornwall. It is known that such folds are not restricted to this particular outcrop of the Dartmouth Slates but are rather a ubiquitous element in the pattern of minor structures present in the Devonian rocks of Cornwall.

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SHIELLS, K. A. G., and W. R. DEARMAN, 1963. Tectonics of the Coldingham Bay area of Berwickshire, in the southern Uplands of Scotland. **Proc. Yorks. Geol. Soc.,** Vol. 34, p.209-34.

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

56. Some observations on boudinage structure in Cornwall :

by W. R. Dearman.

Purple and green Dartmouth Slates of the Lower Devonian form the core of the Watergate Bay antiform and are flanked to the north and south by the greyish slates with thin beds of quartzite and limestone characteristic of the Meadfoot Beds (Reid and Scrivenor, 1906). Recumbent folds occur in both groups, the distribution of poles to bedding planes in Fig. le reflecting both the small folds and the larger antiformal structure of the area.

Boudins are frequently found in beds of quartzite and limestone in the predominantly slaty succession. The dimensions of typical boudins can be gauged from Fig. 1, a marked separation being

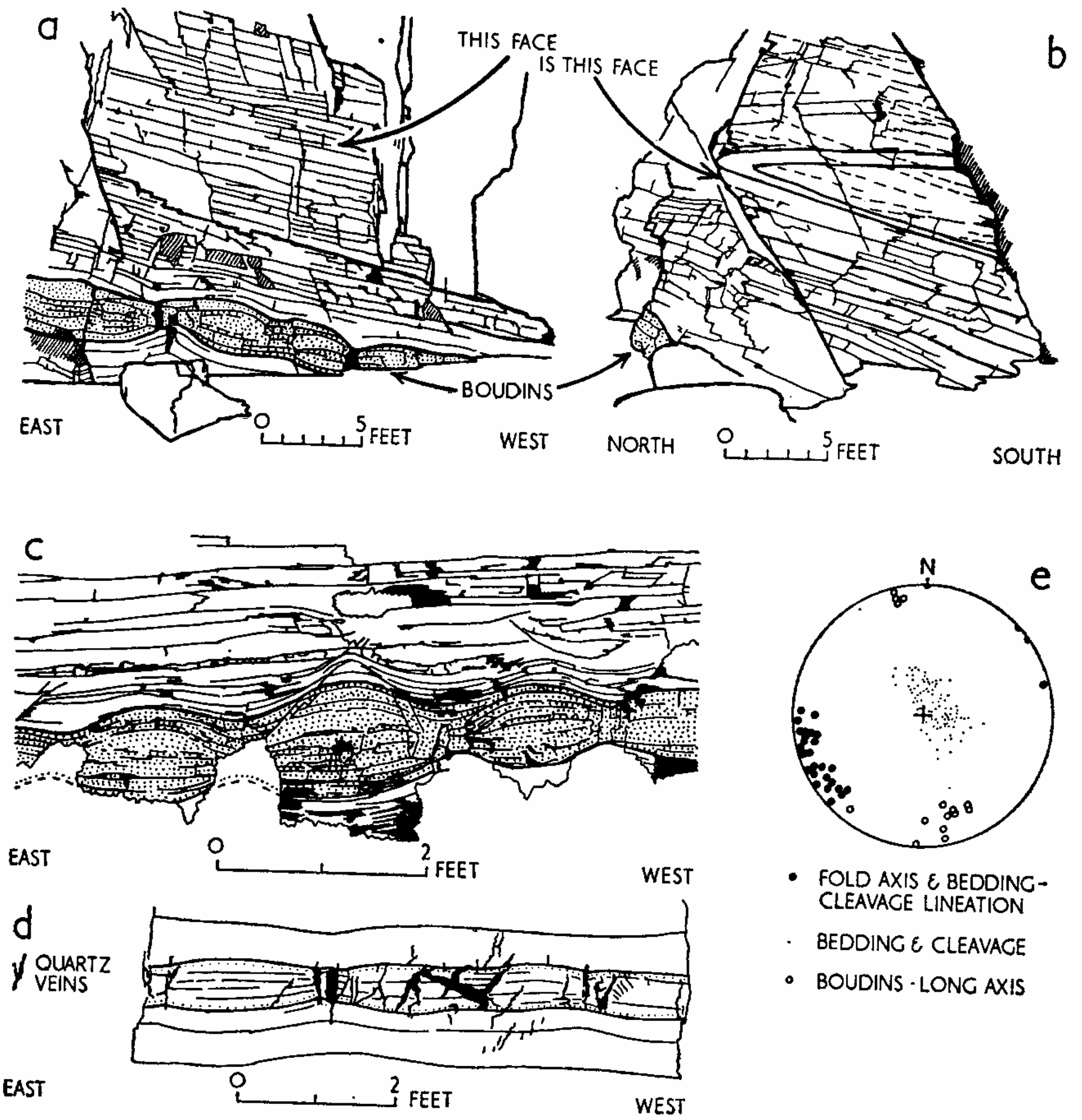

FIGURE 1.Boudinage structures in the Lower Devonian rocks of Watergate Bay, near Newquay, Cornwall. (a) and (b) Two views at right angles showing the relationship between folds and boudins in the Purple and Green Slates exposed in Fruitful Cove (SW 835638) 200 yards east of North Zacry's Island. Dashed lines in (b) represent cleavage. (c) Boudins in the cliff-top at the north-west end of Griffin's Point (SW 841664) south of Mawgan Porth. (d) Boudins 100 yards south of Otonna Rock (SW 843657) in Watergate Bay. (e) Relationship between the directions of the lengths of boudins and fold axes. Poles to bedding are also plotted. Equal area projection. Lower hemisphere. Illustrations of rock faces are drawn from photographs.

achieved by constriction aided in some examples by normal fault shearing. The length of the boudins is never very well exposed but, so far as can be seen, in the exposures there is no sign of a" transverse boudinage system, such as would yield a ‘tablette de chocolat’ structure (Wegman, 1932)." (Wilson, 1961, p.498). This is of particular importance as in a region where folds trend west-south-westwards the lengths of associated boudins are aligned north-north-west to south-south-east, that is at right-angles to the axes of the folds. The normal orientation of the lengths of boudins is parallel to the axis of folding.

The direction of extension of the folded slate mass, here in Watergate Bay as in Lanivet Bay on the south coast, was parallel to the axis of folding. It is worth noting, although the data are not plotted on Fig. le, that boudins have been found in which the direction of the long axis is west-south-west, but then the related folds trend north-north-west normal to the boudinage structure.

The apparently anomalous arrangement of boudins in the folded slates of Watergate Bay, together with other indications of extension parallel to rather than at right angles to fold axes, may have an important bearing on the interpretation of the tectonics of other areas in Cornwall.

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57. Deformed suncracks in the Dartmouth Slates :

by W. R. Dearman.

Typical slates and quartzites of the Dartmouth Slates are exposed in the cliffs of Lanivet Bay to the west of Polperro on the south coast of Cornwall (Ussher *et al.*, 1909). Fold shape, as defined by beds of cross-laminated quartzite from four inches to just over twelve inches thick, varies from truly isoclinal to structures with a limb divergence of forty-five degrees. The folds, which face upwards, are overturned to the north-east and plunge at twenty to thirty degrees to the north-west. One limb of an isocline may be sheared out to produce a hook-shaped fold. An axial plane slaty cleavage is refracted through the quartzite beds, the resultant marked lineation on the bedding caused by the cleavage is parallel to the local fold axis.

In the inlet just north-east of Sandheap Point (SX 163512) there is a fortunate exposure of a single bedding surface in slate which is marked with the elongate, roughly polygonal structures illustrated in Fig. la. The long axes of the polygons are parallel to the lineation on the bedding. From their shape these structures appear to be suncracks, an opinion supported by the presence of material coarser grained than slate outlining the pattern. If it is assumed that suncracks commonly assume a regular polygonal shape, then an estimate can be made on this basis of the deformation that the slates have undergone in the plane of the bedding.

The polygons are at least twice as long as they are broad, but it is a simple matter to measure lengths on the bedding occupied by the same number of polygons first in a direction parallel to the lineation and then at right angles to it. The ratio of the lengths, adjusted to take account of the foreshortening effect of the dip if the determination is made on the illustration, can be taken as a measure of the elongation suffered by the slates in a direction parallel to the lineation. This elongation amounts to one hundred and twenty percent.

In this simple computation the following assumptions have been made: first, that there has been no dimensional change in the suncrack pattern measured at right angles to the lineation ; second, that the mechanism of deformation involved simple flattening at right angles to the bedding accompanied by uni-directional elongation in the plane of the bedding parallel to the fold axis. The validity of the former assumption cannot be assessed, while the latter would appear to be unlikely in folded rocks in which an axial plane slaty cleavage is developed. Then the cleavage and presumably not bedding would be the dominant plane of deformation.

The interest of this exposure lies in the very clear demonstration of elongation parallel to the fold axis, that is in the b tectonic axis, rather than at right angles to it with the movement direction parallel to the a tectonic axis as has been described by Wilson (1951, fig. 5; 1952, fig. 3) in the Upper Devonian rocks of the Tintagel to Trebarwith Strand area on the north coast of Cornwall.

References :

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WILSON, G., 1952. The influence of rock structures on coastline and cliff development around Tintagel, north Cornwall. **Proc. Geol. Ass.,** Vol. 63, p.20-58.

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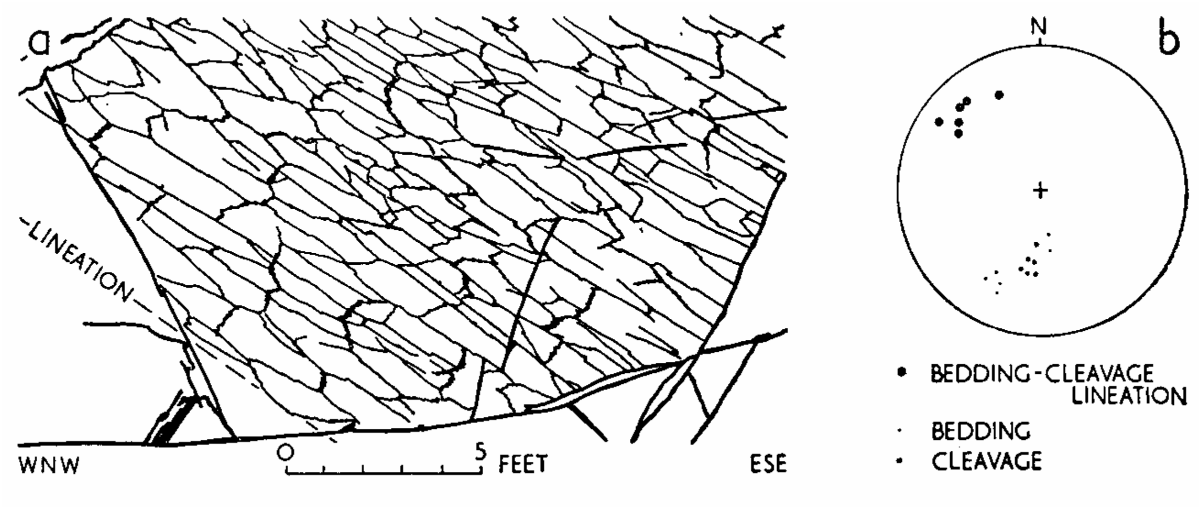

FIGURE 1. Deformed suncracks in the Dartmouth Slates. (a) Drawing from a photograph of a bedding plane covered with an elongated polygonal pattern. (b) Lineations and poles to planar structures. Equal area projection. Lower hemisphere.

58. Some aspects of the sedimentology of the Westward Ho! and Northam Formatiom : by R. G. Walker.

The interest in the Westward Ho ! and Northam Formations (Lower Westphalian of North Devon) is that they demonstrate a transition from turbidite to cyclic paralic sedimentation.

The stratigraphical sequence, with interpretations, was given by Prentice (1960) as :

3. Abbotsham Beds, with *A. lenisulcata.* — "coal measures", paralic.

2. Northam Beds, unfossiliferous. — "coal measures", paralic.

1. Instow Beds, with probably G_2 goniatites. — "greywacke", turbidite.

The stratigraphical nomenclature has been redefined (in de Raaf, Reading and Walker, in press) as:

4. Abbotsham Formation. — Equivalent to the Abbotsham Beds of Prentice.

3. Northam Formation
2. Westward Ho ! Formation — Equivalent to the Northam Beds of Prentice

1. Instow Beds

The Westward Ho! and Northam Formations, therefore, probably belong to the A, *lenisulcata* zone, the basal zone of the Westphalian. The Westward Ho! Formation is at least 1,660 thick, and the Northam Formation is 1,450 feet thick. They lie between the Instow Bed turbidites and the Abbotsham Formation, which de Raaf, Reading and Walker (in press) and Reading (1963) have shown to contain six paralic coarsening-upwards cycles.

The Westward Ho ! and Northam Formations include three groups of facies :

1. *Mudstone Group,* including a number of facies ranging from black mudstones with an exceedingly regular 1-cm. scale striping through very parallel and horizontally bedded siltstones into massive silty mudstones with occasional silt laminae. These facies are interpreted as having been deposited in rather quiet water, out of reach of bottom traction currents.

2. *Transitional Group,* consisting of muds, silts and fine sands, and characterised by wavy-lamination, rippling, cross lamination and small-scale scouring. These facies indicate variability of current strength, periods of quiet mud deposition alternating with bottom traction currents and sand deposition.

3. *Sandstone Group.* Four sandstone bodies, 40 to 105 feet thick, are allocated to this facies group. In their lower parts they are characterised by medium-scale cross-bedding. The upper parts are usually finer, rippled or wavy-laminated silty sandstone, and all have a burrowed horizon at the top. These sand bodies are interpreted as alluvial plain deposits.

In addition, turbidites are often present. They occur very frequently in the Mudstone group of facies, especially in the Westward Ho! Formation, although they are also found in the Northam Formation. At two horizons they are also sandwiched between Transitional group facies, suggesting that at times conditions were suitable for both turbidite deposition and bottom traction of sand by normal currents.

The Westward Ho! Formation consists of Mudstone group facies and interbedded turbidites, with three thin developments of Transitional group facies. Slump “tear-away” holes and turbidite-filled channels are also present. The Northam Formation starts with a sandstone body 105 feet thick (below which no cyclic sedimentation can be recognised) and continues through three cycles 500, 150, and 700 feet thick, similar to those in the Abbotsham Formation, and passing from Mudstone group through Transitional group into Sandstone group facies. The burrowed top of each sandstone is followed very sharply by the black mudstone of the succeeding cycle.

The current directions measured from ripples and turbidite sole-marks in the Westward Ho! and Northam Formations indicate a current flow from the north-east or north. The sole-marks on the Instow Beds turbidites measured by Prentice (1962) indicate a current flow from the south-west. This suggests that the Instow Beds had a different source area from the Westward Ho ! and Northam Formations.

Because the Westward Ho ! Formation consists dominantly of dark grey slightly silty mudstones with turbidites, it cannot be considered as a “coal measure” facies, as Prentice suggested (1960). The “abrupt” junction recorded at Hubbastone quarry (Prentice, 1960) is from dominant turbidites with thin beds of exceedingly fine black sulphurous mudstone (Instow Beds) to the greyer, more silty mudstones of the Westward Ho! Formation. The differences between these two formations, therefore, are (1) source area, (2) proportion of turbidites to mudstone and (3) the silt content of the mudstones. Although the junction between the formations may represent a change in environment, it does not represent a fundamental change in the processes of deposition.

Towards the top of the Westward Ho! Formation the mudstones-with-turbidites pass through Transitional group facies into the first alluvial plain sandstone (whose base marks the beginning of the Northam Formation). There is no “abrupt” change. The three cycles of the Northam Formation lack marine horizons, seat-earths and coals, and cannot be regarded as a true coal measure facies. Neither can they be regarded as southward extensions of the South Wales coalfield because, as Bluck and Kelling (1963) have shown, even the Lower Coal Measures of South Wales were partly derived from the south. The detritus of the Westward Ho! and Northam Formations may therefore have been supplied from the Bristol Channel area - an area which was positive, if not land at this time.

The author would like to acknowledge the help and advice of Dr. H. G. Reading, and of Dr. J. F. M. de Raaf and his colleagues from Shell International Research. The work was made possible by a grant from D.S.I.R. which the author gratefully acknowledges.

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59. The Sedimentation of the Crackington Measures :

by D. M. Mackintosh.

The Crackington Measures are formed of Namurian turbidite sandstones and shales outcropping on the coast between Rusey and Widemouth, North Cornwall. They contain horizons ranging from the Upper *Eumoyphoceyas* (E_2) zone to the *Reticulocevas bilingue* (R_2b) sub-zone. The Bude Sandstone formation, which is presumed to be entirely younger than the Crackington Measures, mainly outcrops from Widemouth northwards, but locally to the south of Widemouth it is infolded with the Crackington Measures. Owing to the tectonics, which involve complex folding and faulting (Mackintosh, 1963), it is impossible at this stage to give a thickness for the pile of strata, though it undoubtedly involves thousands of feet.

The Crackington Measures are divided into three main parts: -

Sandstones and shales	Upper :	Sandstones predominant
	Middle :	Sandstones and shales in equal amounts
	Lower :	Shales Predominant

The sandstones are fine grained and usually shew grading by having sharply defined bases and laminated tops. In the upper part of the succession some of the sandstones are poorly graded and flaggy ; they often form composite beds. There is a general increase in the prevailing thickness of sandstones upwards through the succession.

Current direction studies mainly using sole markings shew that the sandstones were for the most part emplaced by turbidity currents coming from between the west and north-west. This direction of flow is indicated by groove casts and flute casts. However, in the top of the shaly part and in the upper part of the succession, additional emplacement of sandstones by flow almost exactly at right angles to the main direction has occurred. The sedimentary structures which shew the flow at right angles include flow casts, ridge casts, prolapsed bedding, ripple drift bedding, drag structures and pellet beds. But groove casts also shew that turbidity currents flowed in this direction, and groove casts shewing the two directions of emplacement can be observed on adjacent beds. Consistent, unambiguous evidence shews that the flow at right angles is from between the south and south-west. The writer suggests that during the deposition of the Crackington Measures most of the turbidity currents flowed from approximately west-north-west, along the axis of the depositional trough, but currents at different times also flowed in laterally from the south-west.

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MACKINTOSH, D. M., 1963. Superimposed folding in Namurian turbidite sandstones near St. Gennys, North Cornwall. **Proc. Ussher Soc.,** Vol. 1, p.74-76.

60. The supposed 690 ft. marine platform in Devon :

by S. Simpson.

S. W. Wooldridge (1950) has demonstrated the existence of evidence in South-east England for an important marine transgression of late Pliocene or early Pleistocene age. A product of this transgression is an extensive erosional surface cut in the chalk downs which locally bears marine deposits and is now at a height generally over 550ft. and tending to a shore-line now at about 690ft. Wooldridge (1961) believed that this surface is also to be found at the same height in the west of England, and reference is made to it in a number of papers delivered to the January Conferences of Geologists and Geomorphologists in the South-west of England, and to the first Ussher Society Conference, including Brunsden (1962), Orme (1960), Waters (1960), Bradshaw (1960).

There is, however, one piece of evidence which seems utterly at variance with the sea ever having stood at much over 400 ft. in Devonshire since the Alpine earth movements, and this has not been discussed by any of the authors mentioned above. There is in central Devonshire and North Cornwall an extensive tract of country forming an east-west trending belt from Hatherleigh to Bude in which summit levels tend to lie between 500 ft. and 600 ft. This tract of country and a more extensive region bordering it, which tends to be only slightly higher, must have been inundated by a sea standing at 690 ft., and Wooldridge (1961) has a map which shows this wide mid-Devon gulf. On the retreat of this sea, the drainage of the area must inevitably have flowed westwards along the axis of the low-lying tract to the sea, and today there should be a major river following this line. But, in fact, the River Tamar flows from north to south across this tract and then continues generally southwards through ground which tends to rise much higher.

The drainage pattern of Devonshire as a whole is best understood as having been superimposed from an Upper Cretaceous cover and with its prominent north:south elements consequent on an early Tertiary uplift, which produced a slope which was continuously southwards from near the line of the present Bristol Channel coast to the English Channel. As O. T. Jones (1930) first showed, the present form of much of the summit envelope is best understood as the product of the warping by Alpine movements of the sub-Mesozoic plane of unconformity. The anomalous course of the Tamar in relation to this warped surface can be explained by the river having been able to maintain its course by down-cutting during the warping - so that the lower course is, in fact, antecedent.

On this interpretation, the supposed 690 ft. surface of, for instance, Plaister Down and Roborough Down, is merely the sub-Mesozoic surface (probably sub-Upper Cretaceous) where it happens to be near this height ; and the supposed 690 ft. shore-line break of slope is, in fact, the exhumed Upper Cretaceous shore-line.

If it is true that base-level in Neogene time has never been above, say, 430 ft. in Devonshire, it follows that any feature in Devon contemporary with the 690 ft. surface of South-east England must be at 430 ft. or lower. This would mean that the uplift of South-west England has been less than further east and that warping of high-level surfaces has been highly significant.

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61. Invitation Address.

FACIES DEVELOPMENTS IN THE MARINE DEVONIAN OF THE OLD WORLD :

by Professor H. K. Erben, Bonn University.

INTRODUCTION

To-day the facies concept is understood in different ways by different authors. This also holds true if we consider the facies terminology. The term "facies" was originally a geological one, but subsequently it has been used by petrologists, ecologists and even by structural geologists in ways which mostly do not correspond at all with the original definition. Furthermore, we have gradually become accustomed to using facies terms with genetic implications. We speak of "near-shore facies", "geosynclinal facies", "off-shore facies" and so on, in spite of the fact that we do not know whether or not the implied interpretation of a given facies is correct.

We have gone to the extreme of allowing our general facies classification to be based on interpretations - for terms such as "limnic", "littoral" ,"neritic" or "hemipelagic" imply most definitely an interpretation. We can never be certain, however, that a specific sedimentary body containing a certain type of fauna and declared as being "of hemipelagic facies" has actually been formed in a hemipelagic environment.

Thus, there is much confusion and inconsistency in our facies concept, our facies terminology and in our facies classification. In these circumstances, any attempt to clarify the situation should be highly welcome. One of the most encouraging contributions in this respect was made a few years ago by C. Teichert (1958), and I agree absolutely with him when he stresses the necessity to return to the original facies concept. If we do this, we would accept the following facies definition which is in accordance with the concept used by the Swiss geologist Gressly in 1838 : "*Facies is the total complex of all Primary lithological and paleontological characteristics of a sedimentary unit.*"

It follows naturally that there can be no such term as the "lithofacies" or "biofacies" although these names are quite commonly used. According to our re-established definition the facies concept is clearly dualistic one, the facies consisting of inseparably connected elements, the lithological *and* the biological one. It is true that we can distinguish “lithological characters” and “biological features” of a certain sediment and that both are used in the diagnosis of a facies. But they cannot be conceived as facies themselves for neither the so-called “lithofacies” nor the so-called “biofacies” alone covers completely the definition of a facies.

It is important, however, to notice that in many cases the biological and the lithological characters of a sediment may enable us to form a certain impression of, or even to draw certain conclusions concerning, the conditions under which the sediment has been deposited. These conclusions, or at least indications, may include bathymetric, ecologic, palaeogeographic or in exceptional cases even palaeoclimatologic data. But we should never forget that we are dealing with nothing more than with interpretations which always depend more or less on subjective feelings and opinions. Therefore, I suggested in 1962, that we should distinguish strictly between facies analysis and facies interpretation. *Facies analysis keeps to observable facts and phenomena and should be free from any element of interpretation. Its terminology should be of an exclusively descriptive type.* Facies interpretation, on the other hand, must always be kept separate from and must never precede or be included in, the procedures of facies analysis. Nowadays, unfortunately, this failure to separate the two phases is extremely common.

There have been many attempt to erect a facies classification. Some geologists use a classification based on lithological differences, others prefer a classification according to faunal assemblages. Both methods are questionable because their concept of facies is incomplete, at least according to the views expressed above. Still others, as for instance H. Schmidt (1935, 1956), classify the facies according to the degree of agitation of the sea water together with the amount of oxygen contained in it. Other authors use a classification referring to palaeogeographic elements, still others to bathymetric conditions, again others to degrees of salinity. But in each of these cases the genetic and environmental facies classification consists of subdivisions based on purely subjective interpretations. It is therefore difficult and commonly misleading when a particular sedimentary sequence is placed rather arbitrarily in one of these environmental subdivisions. That may be one of the main reasons why we have not reached until now a general facies classification that would be accepted everywhere and by everybody.

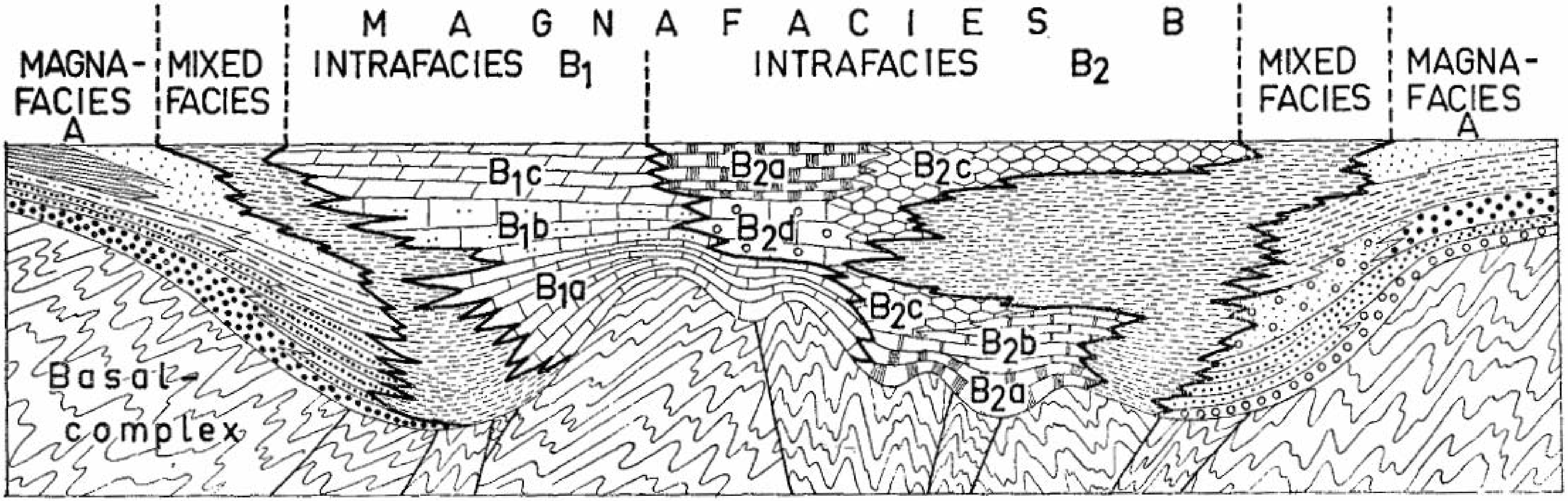

FIGURE 1. Schematic diagram of facies categories: B1a, B1b, B1c = different parvafacies of intrafacies B1. B2a, B2b, B2c = different parvafacies of intrafacies B2. B1, B2 = different intrafacies of magnafacies B. B, A = different magnafacies of Devonian deposits. (Magnafacies A has not been subdivided here. Both magnafacies are linked by mixed facies developments).

Fortunately there have been recent attempts to established a new facies classification completely free of any elements of interpretation. It was worked out by C. Teichert (1958) and I have tried, in 1962, to add certain details. This classification is based on the differences between “isopic” and “heteropic”- in other words between “isofacial” and “heterofacial” formations - and at the same time on the difference between “isochronic” and “heterochronic” origin of the concerned sedimentary units. Besides, it makes possible a distinction of lateral, vertical and latero-vertical facies groups, according to the different needs and viewpoints of geological research.

This classification resembles strongly the hierarchy of the zoological system. Each facies unit should be defined by a descriptive diagnosis and a corresponding type locality, the degree of resemblance or difference being the criterion of relationship between facies units of equal rank.

Facies categories of a lower rank are contained in higher categories, or - in other words - by building higher facies categories (fig. 1). In 1962 I suggested a classification containing the following facies categories :

Parvafacies (K. Caster 1934). The parvafacies is the unit of lowermost rank, more or less corresponding to a smaller stratigraphic unit.

Intrafacies (P. Cloud and Barnes 1957). This is a facies group consisting of a chronological and geographic sequence of several isopic parvafacies. They may be isochronic or heterochronic but they must be isopic, that means : they must be similar in their principal lithofacial and biofacial features.

Magnafacies. This term was established by K. Caster in 1934 and was amended by R. C. Moore in 1949 and by C. Teichert in 1958. It is a facies group consisting of a chronological and geographic sequence of several isopic intrafacies.

These are the terms used in the facies classification if we are applying it to a three-dimensional system. Since this is all we need for the purpose of our present study, we can disregard here the terms for the purely lateral or purely vertical aspects, terms that would be needed if we restricted our views to lateral geographic sequences or to purely vertical or stratigraphic sequences. We may safely compare the parvafacies with the rank of the zoological species, the intrafacies with the zoological genus and the magna-facies with the zoological family or any higher category of the zoological system.

FACIES ANALYSIS

In the following section the facies development in the Devonian of the Old World is analysed : namely in Europe, in Northern Africa, a part of the Near East and parts of Asia adjacent to Eastern Europe.

In this region since the end of the 19th century several authors have distinguished two main facies developments, first recognised in the Lower Devonian. In 1878 E. Kayser observed strong differences that become evident if we compare the Lower Devonian of the Rhenish mountains, the Rhine Valley and the Ardennes on one side, and on the other side the Lower Devonian in Central Bohemia (see also Kayser and Holzapfel 1894) as well as in the Harz mountains of Central Germany. He called the first type of facies the *Rhenish* facies of the Lower Devonian. The second one he named *Hercynian* facies derived from the ancient Latin name for the Harz mountains used by the Romans.

Both types were later identified in other countries, for instance in Russia by Tshernyshew, Mushetoff and Nalivkin. Furthermore, F. Frech (1889) discovered that the difference between the Rhenish and the Hercynian facies type is not restricted to the Lower Devonian but that it also occurs in the Middle Devonian. H. Schmidt (1956), myself (1962) and A. Rabien (1956) pointed out in more recent times that to a certain degree it is evident even in the Upper Devonian.

There have been several attempts to analyze the difference between the Rhenish and the Hercynian facies types. For their better understanding it may be advisable to study the sections present in the type areas, that is in the central Rhenish mountains, in Central Bohemia and the Lower Harz mountains (fig. 2).

In the central parts of the **Rhenish mountains** the Lower Devonian reaches a maximal thickness of approximately 6,000m. The Gedinnian sequence starts with phyllites containing some sandstone intercalations (1 = Grey phyllites) or with slates (2 = Silberg slates). In the Bergisches Land we find a series (3 = Huinghausen beds) consisting basally of a single limestone followed by shales with siliceous nodules, sandy shales, greywackes and sandstones, and a subsequent series of alternating thick-bedded sandstones, greywackes and shales (4 = Bredeneck beds). The upper

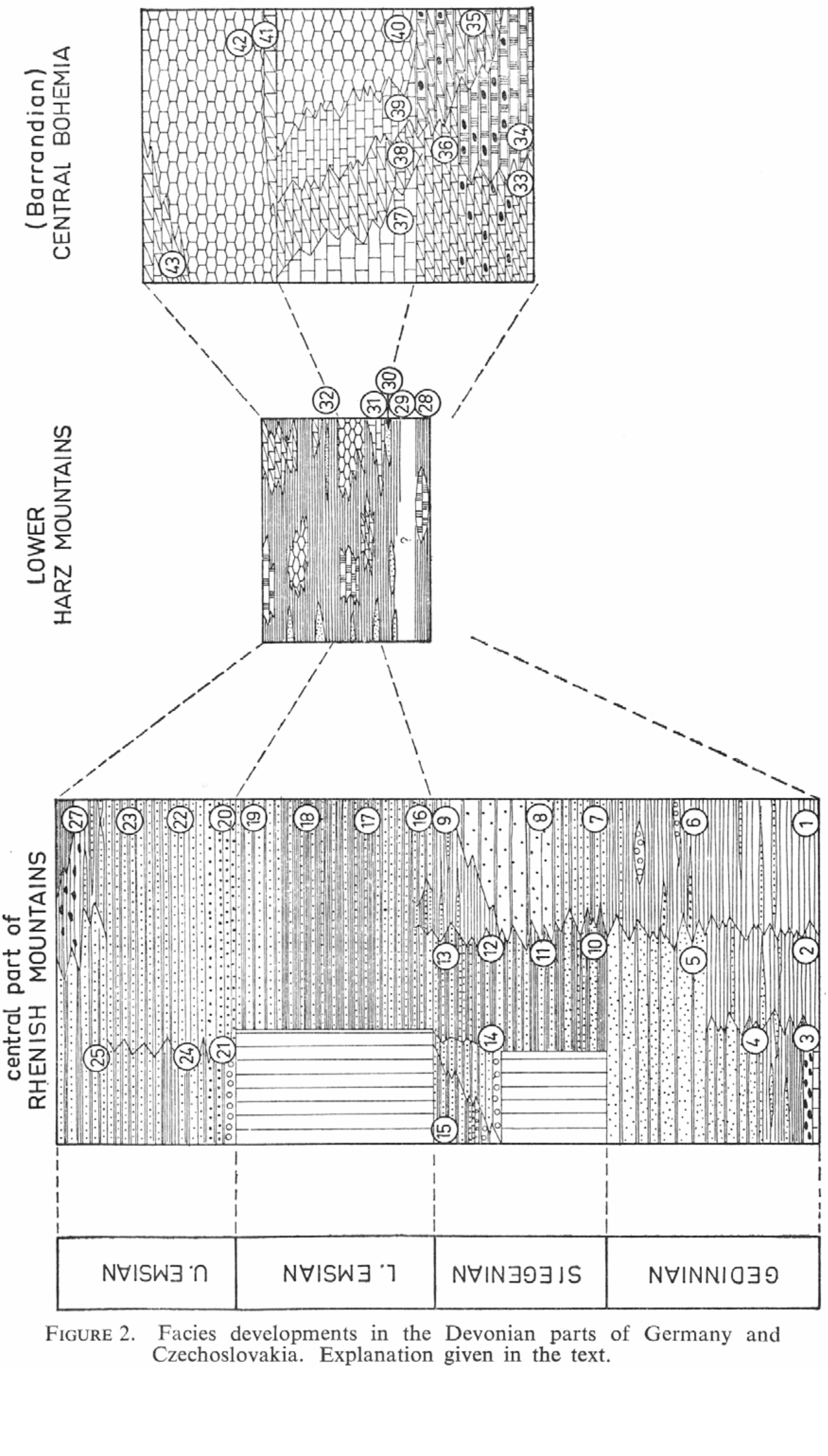

FIGURE 2. Facies developments in the Devonian parts of Germany and Czechoslovakia. Explanation given in the text.

Gedinnian is represented by a sequence of thick-bedded brownish to reddish sandstones and subordinate shales (5 = Bunte Ebbe beds) or by a series of phyllites or shales with interbedded quartzites and conglomeritic layers (6 = Bunte Phyllite).

In the Siegenian of the **Taunus region** we observe a sequence showing in its base alternating coarse sandstones, quartzitic sandstones and shales (7 = Hermeskeil beds) followed by the Taunus quartzite (= 8) and by the Hunsruck shale (= 9), a dark bituminous roofing slate with few intercalated sandy layers. The Siegen beds of the Siegen district consist of a thick series in which sandstones, greywackes and quartzitic layers alternate with varying predominance (10 = Tonschiefer horizon ; 11 = Rauhflaser horizon ; 12 = Herdorf beds ; 13 = Ulmen beds). In the Bergisches Land only the upper part of the Siegenian is developed containing a sequence of sandy shales with fossil land plants, intercalated sandstones and a basal conglomerate (14 = Wahnbach beds). It is laterally substituted by the Bensberg beds (= 15) consisting in their lower parts of greywackes, conglomerates and predominant arkoses while in their upper parts beside these rocks red shales are typical.

In the Lower Siegenian the same type of rocks persists, namely sand-stones, greywackes and quartzites alternating with more or less sandy shales. In the Taunus region the corresponding sequence is subdivided from bottom to top into the Spitznack beds (= 16), the Singhofen beds (= 17) containing layers of " porphyroidic tuffites ", the Vallendar beds (= 18) and the Nellenkopfchen beds (= 19).

The Upper Emsian begins with a rather constant horizon of thick quartzites (20 = Ems quartzite) or its equivalent, a series of quartzites, quartzitic sandstones and sandstones with a basal conglomerate (21 = Rimmert quartzite). In large areas these beds are followed by cleaved grey-wackes and predominant sandstones (22 = Hohenrhein beds) and a sequence of sandy shales, greywackes and sandstones (23 = Laubach beds). In the Bergisches Land both are replaced by sandy shales or more argillaceous shales alternating with quartzitic greywackes and sandstones (24 = Remscheid beds).

In the uppermost parts of the Upper Emsian the elastic rocks frequently become slightly more carbonatic. This is the case in the lower Hohenhof beds (= 25) and the lower part of the so-called " Cultrijugatus beds " (= 26), sequences of slightly sandy or argillaceous shales with interbedded fine-grained feably carbonatic sandstones. On the other hand, the Kondel group (= 27) starts with sandy beds which change into shales containing first sphaerosideritic and later siliceous nodules.

Within the whole of the Lower Devonian of the central Rhenish mountains fossils are generally rare throughout long stretches of the thickness. They appear accumulated, however, in occasional thin layers. The faunal assemblages appear to be rather monotonous consisting, as a rule, of certain groups of brachiopods, pelecypods and gastropods while trilobites are less frequent and restricted to but few families. Crinoids, corals and cephalopodes are rare.

In the **Lower Harz Mountains** the thickness of the Lower Devonian is strongly reduced reaching maximally about 150 m. The Gedinnian and Lower Siegenian is not known excepting a single occurrence of a black limestone with **Hereynella** and cardioconchs intercalated as a lens in dark argillaceous shales (28 = limestone of Harzgeroder Ziegelhutte). A thin layer of shales with siliceous nodules and single lenses of greywacke (29 = Kieselgallenschiefer) and a thin series of shales with a calcareous greywacke (30 = Kalkgrauwacke) belong to the Upper Siegenian. Both contain a mixed fauna of rhenish and hercynian elements.

The Lower Emsian is represented by argillaceous shales with subordinate lenses of greywackes and typically hercynian limestone lenses of different facies (31 = Older Hercynian : Princeps-, Zorgensis-, and Dalmanites limestones). The same lithology is present also in the Upper Emsian (32 = Middle Hercynian limestones). The faunal assemblages differ strongly from those of the rhenish series but they coincide with those of the Bohemian Lower Devonian.

In the **central Bohemian basin,** the so-called Barrandian, the Lower Devonian reaches a thickness of maximally about 400 m. It is composed almost entirely of limestones, sandy rocks being completely absent. Its lithology and stratigraphy according to L Chlupac (1957, 1962) is as follows :

The Gedinnian and large parts of the Siegenian (both :" Lochkovian ") are represented by grey organodetritic slightly nodular crinoid limestones with cherts of various colours (33 = Kotys limestone) or without chert (26 = Lower Koneprusy limestone). In their faunas crinoids and brachiopods are predominant. Another facies development consists of black well bedded to platy fine-grained bituminous limestones containing black chert nodules and alternating with dark calcareous shales (34 = Radotin limestone) In the following strata (35 = Kosor limestone) the lithology is similar but the colour is less dark, the grain coarser and interbedded shales as well as chert nodules are less numerous. In the faunal assemblages of the Radotin limestones cardioconchs, **Hercynella,** gigantostracans, monograptids and the brachiopod genus **Hwellella** are playing an important role while in the Kosor limestones tentaculitids are outstanding.

The Lower Emsian (" Pragian ") is represented by several isochronic but heteropic limestones. There is the Upper Koneprusy limestone (= 37), a poorly bedded to almost massive organodetritic crinoid limestone of whitish colour and a faunal assemblage of predominant corals, bryozoans and brachiopods. The Slivenec and Vinarice beds (= 38) are reddish to pink organodetritic crinoid limestones with rich trilobite and brachiopod faunas. The third type is the Dvorce-Prokop beds (= 40) which are represented by grey non-organodetritic argillaceous limestones with slightly nodular bedding surfaces, with subordinate intercalations of calcareous shales, and with a faunal assemblage in which cephalopods, cardioconchs and certain trilobites are characteristic. The Reporyje and the Lodenice limestones (= 39) represent, to a certain degree, the transition between the facies of the Slivenec and the Dvorce-Prokop limestones.

Most of these facies types are repeated in the Upper Emsian (="Zllchovian") of central Bohemia. Its basis is occupied locally by the so-called Kaplicka horizon (= 41), an organodetritic and even breccious limestone horizon rich in coral debris. It is followed by non-organodetritic grey fine-grained limestones with black chert nodules (42 = Zlichov limestones). Their upper parts may be substituted by slightly reddish organodetritic limestones (43- - Chynice limestones) with trilobites, bactritids and goniatites.

Kayser and Holzapfel have observed that there is a difference in lithology insofar as limestones are absent from the Rhenish facies and sandstones are typically of the Hercynian facies. They noted also a difference in the faunal assemblages, but they did not analyze it closely.

A more detailed analysis was made by H. Schmidt in 1926. As far as the lithofacial and biofacial features are concerned, Schmidt proceeded in a strictly descriptive way. But his study of the biological aspect remained incomplete, being restricted to ecological generalities only, without taking into account the distribution of taxonomic groups. Furthermore, he included in his definitions of both facies types, interpretations which will be discussed later .

When analyzing the two different facies Schmidt very aptly had chosen Lower Devonian formations as objects of his studies for in the Lower Devonian the differences between the Rhenish and the Hercynian facies are far more pronounced than in Middle or Upper Devonian beds. In 1953 and 1962, I did the same and completed the diagnoses and definitions.

Typical for the Rhenish or the Hercynian facies respectively, are the facts shown in table I. This analysis shows that each of the two facies has its own characteristic combination of features. There is a strong dependence between biological and lithological characters. In other words : the faunal elements of Rhenish type are always connected with the presence of sandy elastic sediments, and the faunal elements of Hercynian type occur always with pure limestones or pure argillaceous shales.

Experience tells us that both the Rhenish and the Hercynian facies can be identified in numerous regions of the Old World, a point which will be discussed later. Furthermore, it is evident that within the limits of their diagnosis give in the table I we can distinguish a certain number of different developments, each of these subordinate facies developments representing a sub-category. This means that there is a distinct complexity within the Rhenish and the Hercynian facies.

RHENISH MAGNAFACIES	HERCYNIAN MAGNAFACIES
LITHOFACIAL CHARACTERS:	
Sediments " impure " : conglomerates, greywackes, sandstones, quartzites, quartzitic shales, etc.	Sediments " pure " . mostly pure limestones and argillaceous shales.
Calcium carbonate content low or absent.	Content high, as a rule.
BIOFACIAL CHARACTERS:	
CORALS :	
Solitary corals almost absent.	Very common and typical.
Tabulates rare or absent.	Very common and typical **(Favosites, Chaetetes, Heliolites).**
Pleurodictyum typical.	**Pleurodictyum** absent.
BRACHIOPODS:	
Strongly ribbed forms predominant.	Considerably less common.
Smooth and rounded shells rare.	Typical (pentamerids, meristids, etc.)
Ribbed spirifers with long "wings" are typical and very frequent.	Smooth and rounded spirifers are typical and frequent.
PELECYPODS:	
Cardioconchs nearly absent.	Present and typical **(Panenka, Kralowna, Buchiola,** etc.)
Conocardium rare.	Sometimes very common.
Hercynella absent.	Present and typical.
Typical : **Grammysia, Phthonia, Leptodomus, Sphenotus, Limoptera, Dechenia, Modiomorpha,** etc.	All absent or very rare.
TENTACULITIDA :	
Tentaculties predominant.	Nearly absent.
All absent or rare.	**Nowakia, Guerichina and Styliolina** frequent and typical.
CEPHALOPODS:	
Nautiloidea rare.	Very frequent and numerous.
Arthrophyllum present.	Absent.
Bactritida always absent.	Present and typical.
Goniatites as rare exceptions only.	Present and typical.
ARTHROPODS:	
Ostracods generally sculptured.	Nearly always smooth.
Trilobites mostly poor in number of genera and individuals.	Rich in number of genera, species and individuals.
Typical : **Asteropyge** and related genera, **Homalonotus** and related genera.	All absent.
All absent.	Typical : Proetidae, Otarionidae, Harpidae, Scutelluidae, Odontopleuracea, Lichacea, Calymenidae, Cheiruridae, **Odontochile,** Phacopidella.

TABLE I

This complexity, as well as the wide geographic distribution seem to suggest a relatively high rank within our facies classification for the Rhenish and the Hercynian facies. These are the reasons for giving them the rank of magnafacies as has been suggested by Schmidt and myself.

If this is accepted, we can distinguish three types of magnafacies in the Devonian of the Old World : (1) the Hercynian magnafacies, (2) the Rhenish magnafacies and (3) for the same reasons of widespread occurrence and complexity, the well known Old Red Sandstone magnafacies.

I am not familiar enough with the Old Red magnafacies to form a detailed opinion concerning their subordinate categories. But I suppose that those who are studying the Old Red Sandstone of the different countries would be in a position to judge the different intrafacies and parvafacies which together compose what we call the Old Red facies. Speaking of the Rhenish magnafacies there, too, is no doubt about its complexity. Up to now, however, no detailed study has been made concerning its subordinate facies categories.

For the Hercynian magnafacies I have made an attempt myself, in 1962, the results of which agree fundamentally with the results of I. Chlupac (1962). It seems that there are at least four different intrafacies contained in the Hercynian magnafacies. These four intrafacies I have named after four typical localities, three of them situated in Central Bohemia, one of them in the Harz mountains. The differences in these cases are not so pronounced and strict as they are in the cases of the magnafacies. But they are still evident, as shown in table II.

Within each of these intrafacies numerous parvafacies of lateral occurrence and short stratigraphic range can be distinguished. To give an example : to the Slivenec intrafacies would belong : in Germany the *Zorgensis* limestone of the Lower Emsian, certain so-called Middle Hercynian limestones of the Upper Emsian, the Greifenstein Limestone of the Eifelian, the *Cheirurus* limestone of the Givetian and others ; in Bohemia the Vinarice Limestone and the Slivenec Limestone both of Lower Emsian age, the Upper Emsian Chynice Limestone as well as other limestones situated in the Eifelian. In Northern France we may mention the Upper Emsian Calcaire La Grange, in Southern France the Calcaire blanc du Pic de Bissous of Givetian age.

HERCYNIAN MAGNAFACIES

Koneprusy intrafacies	Slivenec intrafacies	Dvorce-Prokop intrafacies	Badeholz intrafacies
LITHOFACIAL CHARACTERS			
Coarse spathic lst.	Middle spathic lst.	Fine-grained crystallinic to compact lst.	Fine-grained crystallinic to nearly compact lst.
Organodetritic.	Organodetritic.	Not organodetritic.	Not organodetritic.
Mostly whitish to light grey.	Mostly light grey (rarely reddish).	Mostly middle to dark grey (rarely reddish).	Mostly dark to black (bituminous).
Mostly not phacoidal (thick-bedded to massive).	Mostly slightly phacoidal.	Strongly phacoidal to nodular.	Strongly phacoidal to nodular.
BIOFACIAL CHARACTERS :			
Calcareous algae :			
Frequent, typical.	Absent.	Absent.	Absent.
Corals :			
Abundant, typical.	Few only.	Almost absent.	Very rare.
Bryozoans:			
Abundant.	Present.	Absent.	Absent.
Gastropods :			
Abundant ; large size.	Present ; medium size.	Rare ; small.	Very rare ; small.
Brachiopods :			
Abundant ; shells ribbed and smooth.	Frequent ; smooth shells predominant.	Not frequent ; shells smooth and small.	Rare ; mostly smooth and small.
Nautiloids :			
Rather rare.	Present ; small.	Frequent ; mostly large size.	Present.
Ammonoids :			
Completely absent.	Present.	Frequent and typical.	Sometimes present.
Cardioconchs :			
Almost absent.	Sometimes present.	Frequent and typical.	Present ; small.
Conocardium :			
Frequent, typical.	Rather rare.	Absent.	Absent.
Triliobites :			
Typical : **Proetus (Proetus), Bojoscutellum, Harpes.**	Typical: **Cornuproetus, Eremiproetus, Cheirurus, Harpes, Scrabriscutellum,** etc.	Typical : Blind or micro-phthalmic Proetidae and Phacopidae. **Odontochile.**	Typical: Macrophthalmic, Phacopidae. **Odontochile.**
Crinoids :			
Plates of stems abundant ; sometimes connected.	Frequent ; plates isolated.	Rare	Rare

TABLE II

As far as Devon and Cornwall are concerned it seems not possible, at present, to give a full account of the chronological development and the geographic distribution of the different facies in the Devonian. It is possible, however, to quote certain examples for the mentioned facies category above.[1]

The Rhenish magnafacies is manifested in the Staddon grits and to a certain degree in the Meadfoot beds. Their slightly sandy shales with intercalated sandstones and quartzitic beds, all nearly without any content of calcium carbonate, correspond clearly to the definition of the Rhenish lithology. Their fauna, too, is of definitely Rhenish type, the only exception consisting in the single specimen of *IVlitvcosPhinctes sp.* reported by M. R. House in 1963.

Within the Hercynian magnafacies there are three intrafacies present in South England :

The Badeholz intrafacies is perfectly developed, among other places, in the Givetian series discovered by House (1963) at Trevone Bay. Dark to black argillaceous shales containing nodules of black limestones are quite typical and so are the high content in pyrite and the absence of sandy material. The fauna is almost entirely without crinoids, brachiopods, and coral colonies, and trilobite families typical for other intrafacies are absent. The occasional presence of *Phacops,* of goniatites and in certain levels of frequent " worm tracks " has been observed also in other occurrences of the Badeholz intrafacies.

The Dvorce-Prokop intrafacies is manifested in the Upper Devonian grey " kramenzel "-like limestones of the Chudleigh district (c.f. House 1963), for example in the sections of Mount Pleasant and of Kiln Wood Quarry. Their lithology and faunal assemblage agree perfectly with the definition given for this intrafacies.

Finally, the Koneprusy intrafacies may be quoted from the Lummaton Quarry near Torquay. Its light grey thick bedded to massive limestones rich in corals and stromatoporids and smooth-shelled brachiopods correspond to the typical development of this intrafacies.

(1) The localities mentioned in the following text have been kindly demonstrated to me by Dr. M. R. House and Dr. E. B. Selwood, in the course of excursions held during the annual meeting of the Ussher Association in January 1964. I am greatly indebted to the Society for their courteous hospitality.

[The Lummaton shell bed, however seems to hold an intermediate position between the Koneprusy and the Slivenec intrafacies. This fact is evident from the presence of certain trilobites typical for the Slivenec intrafacies *(Gvotalocephalus, Radiaspis, Radiolichas,* etc.) as well as the simultaneous presence of abundant coral colonies and rarity of goniatites, the latter both being typical for the Koneprusy intrafacies.]

The Rheno-Hercynian mixed facies, mentioned later, is well manifested in the Eifelian Calceola shales at Daddy Hole Bay and Triangle Point near Torquay.

So far the different facies have been discussed only in their typical development. In such cases they can be easily identified and distinguished. But in many cases we find Devonian series which show a combination of different facies elements at the same time, and where the facies actually is a mixed one. On the one hand mixtures of intrafacies are found, where no sharp boundaries can be drawn ; but on the other hand mixed magnafacies are also quite common. It happens quite frequently that in certain Devonian beds Rhenish and Hercynian elements occur together and that then we are dealing with an intermediate development which we could call the mixed facies.

In such cases it is interesting to observe that even in mixed facies the dependence between the types of sediment and the faunal assemblages still holds. As a rule, we may state that if the proportion of Rhenish clastic content is about 50 to 50 then the fauna will also be a mixture of Rhenish and Hercynian elements in about equal proportions. If in the sediments the Rhenish sandy elements increase, the amount of Rhenish faunal elements increases also while the Hercynian faunal elements become subordinate. And if the Hercynian calcium carbonate content predominates, also the Hercynian faunal elements predominate while the Rhenish fauna tends to withdraw.

In the following pages, I have tried to trace the magnafacies through time and space, that is, through the Devonian of the West and Central European geosyncline (fig. 3).

DEVONIAN MAGNAFACIES THROUGH TIME AND SPACE

In the SILURIAN there appears to be no clear distinction between the two magnafacies. It is true that we find Silurian sediments corresponding to the Rhenish lithological features and others answering to the description of Hercynian lithological characters. But the corresponding separation of faunal assemblages is not yet developed. As a matter of fact many faunal elements typical of the Rhenish magnafacies do not appear before the Devonian, as for instance the more typical Asteropygidae and related genera. The same is true with Hercynian elements as for example the very important goniatites. The differentiation of our two magnafacies begins suddenly in the early Devonian.

In the GEDINNIAN and LOWER SIEGENIAN we can already distinguish Rhenish sediments in the Ardennes and the Rhenish mountains, for instance the clastic and sandy beds of Mondrepuits, of Oignies, as well as the Huinghausen beds, the Taunus quartzite and others, containing among others already Rhenish trilobites such as *Acaste, Asteropyge, Rhenops, Homalontus* and others, as well as Rhenish spiriferids such as *mercuri, primaevus* and other species.

On the other hand, distinct representatives of the Hercynian magnafacies, according to their lithology and fauna are parts of the so-called *Halysites* limestone on the coast of the Turkish Marmora Sea, developed in the Badeholz intrafacies, and certain limestones of the Russian Ural mountains occurring in the Koneprusy intra-facies.

In the geosyncline extending from South England through Northern France, Belgium and Central Germany to Poland, there are two regions where the Hercynian magnafacies remains through almost the whole of the Devonian. Both regions could be regarded as two of the original areas of the Hercynian magnafacies and as two of the starting points from which its distribution begins. The first region is the Carnic Alps of Southern Austria, where all the strata from the earliest to the latest Devonian are of the Hercynian facies. The second region is the Central Bohemian basin, called the Barrandian, where the Hercynian facies remains from the earliest Devonian up to the early Givetian.

In the Carnic Alps the Gedinnian and Lower Siegenian is represented by black limestones called “e-gamma” limestone, and in Central Bohemia by the different members of the Lochkov lime-stones. Most of these strata should be grouped with the Badeholz intrafacies and all are very definitely Hercynian, not only in their lithology but also in their fauna which in Bohemia contains such typical Hercynian elements as the trilobites *Scutellum* and *Leon-*

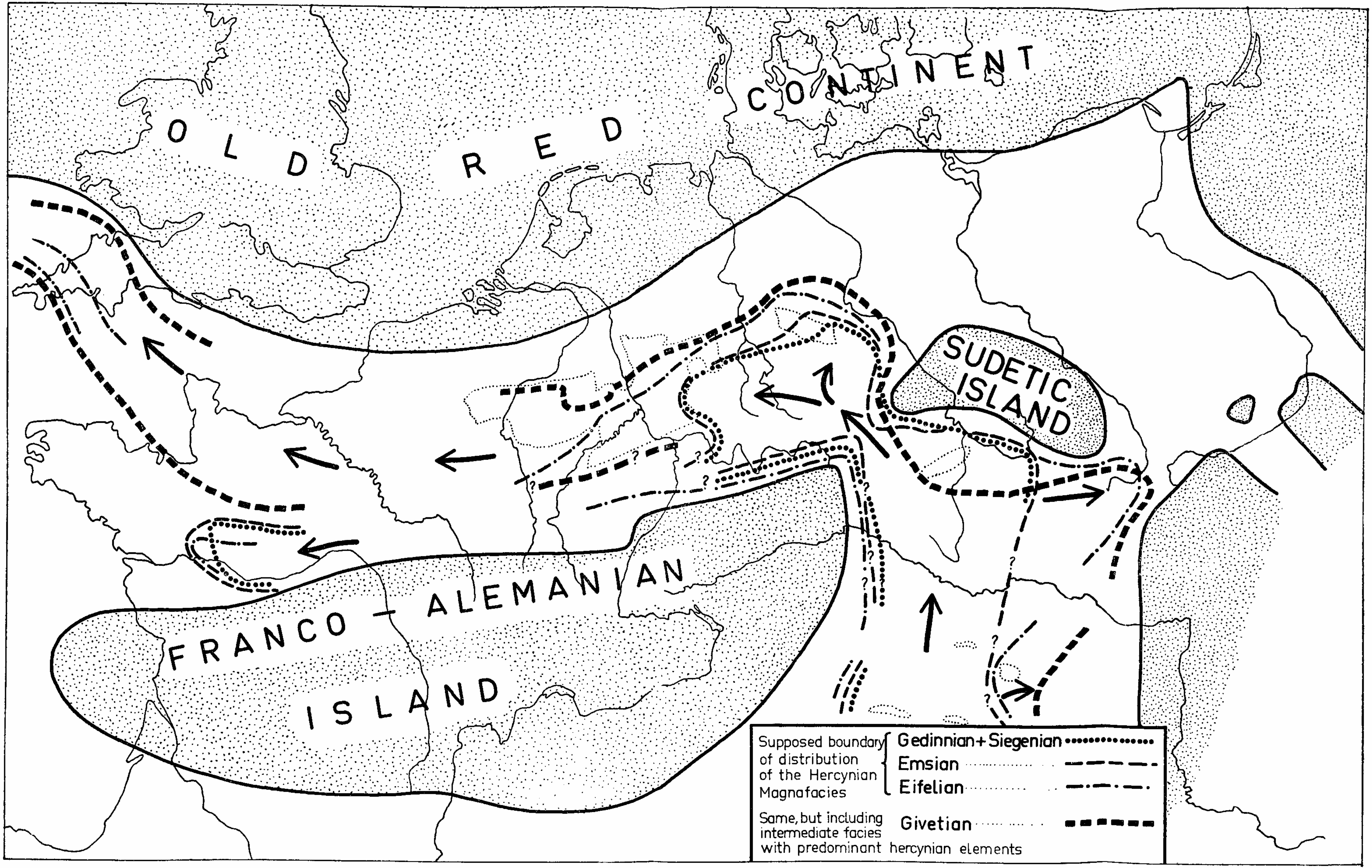

FIGURE 3. Distribution of the typical Devonian facies in Northern Europe during the Lower and Middle Devonian.

aspis, frequent cardioconchs, the typical genus *Hercynella* and others. Hercynian beds of the same age are found also in Thuringia.

This Hercynian development in the Gedinnian and Lower Siegenian extends in our geosyncline as far north as the southern parts of the Harz mountains with their *He-rcynella* bearing limestone of Harzgeroder Ziegelhutte and as far west as the very margin of the Rhenish mountains. It is represented in the Kellerwald mountains and the region of Marburg by *Monogyaptus heycynicus* bearing shales and in the region of Giessen by shales and limestones bearing *Howellela inchoans* and numerous cardioconchs. This magnafacies is absent in the other parts of the Rhenish mountains and it does not reach the western or the eastern part of the geosyncline.

Besides the typical Rhenish and the typical Hercynian magnafacies, the mixed facies is also present already, for instance in the Gedinnian and Lower Siegenian of the Spanish provinces of Asturies and Leon, in the Central Meseta of Morocco and several other areas.

In the UPPER SIEGENIAN, the Hercynian magnafacies recedes from the Harz mountains and the southern margin of the Rhenish mountains. Its northernmost occurrence is known from Thuringia. On the other hand, there is a sudden invasion of the Hercynian magnafacies into southern parts of the Massif Armoricain at least as far west as the synclines of Angers and St. Julien de Vouvantes, where it becomes manifested by lower parts of the Calcaire d'Angers and of the Calcaire d'Erbray.

A mixed facies with very strong Hercynian influence appears on the southern margin of the Rhenish mountains, that is the Hunsruck shale. It contains only few Rhenish faunal elements such as the tabulate coral *Pleurodictyum* and the trilobites *Astevopyge* and *Homalonotus,* but there occur numerous eminently Hercynian elements as goniatites, bactritids, cardioconchs and hercynian trilobite genera.

All other parts of the geosyncline remain occupied by the typical Rhenish magnafacies.

In the EMSIAN the difference between Rhenish and Hercynian magnafacies is well marked, at least in Europe. As a matter of fact, during this stage the difference between both marine magnafacies is as clearly expressed as never before or later in the Devonian.

In LOWER EMSIAN time the Hercynian magnafacies advanced again to the north, up to the central parts of the Harz mountains. It also invaded again the southeastern margin of the Rhenish mountains. In both regions there are all intrafacies of the Hercynian magnafacies present, represented by limestones with different names ; the *Princeps* limestone representing the Koneprusy intrafacies ; the *Dalmanites* limestone representing both the DvorceProkop intrafacies as well as the Badeholz intrafacies ; and the *Zorgensis* limestone the Slivenec intrafacies. Again the eastern and western part of the geosyncline remain under the influence of the Rhenish magnafacies, with sandy sediments and typical Rhenish faunas.

In the UPPER EMSIAN the situation more or less remains the same but with one exception. The Hercynian magnafacies in the southern parts of the Massif Armoricain remains represented in the synclines of Angers and of St. Julien de Vouvantes by the Calcaire d'Erbray and the Calcaire d'Angers belonging to the Koneprusy intrafacies. But in addition it now advances also into the syncline of Ancenis where it is now evident as the Calcaire La Grange of the Slivenec intrafacies, as unnamed coral reef limestones and as the Calcaire de Chaudefons. The faunas reveal only few relations to the south, that is to Northern Spain. But there are extremely strong faunal similarities pointing to the southeastern margin of the Rhenish mountains, to the Harz mountains and to Central Bohemia. Thus, we are forced to postulate a connection to these parts of the Upper Emsian sea, passing through the southern belt of the geosyncline. Unfortunately, the connecting Devonian strata are hidden under thick Mesozoic and Tertiary covers.

Again, the rest of the geosyncline remains occupied by the Rhenish magnafacies in its typical sandy development and with its typical Rhenish faunas.

In the EIFELIAN the Hercynian magnafacies seems to withdraw from parts of the Massif Armoricain, but it advances considerably in the Central and northwestern part of our geosyncline. It now reaches as far north as to cover the region of the Harz mountains completely, and also penetrates into the eastern, central and southern parts of the Rhenish mountains. In all these regions it is manifested now in the Wissenbach shales and associated limestones, belonging to the Slivenec, the Dvorce-Prokop and the Badeholz intrafacies. Only the northern parts of the Rhenish mountains remain excluded. They are governed by the mixed facies, in the Bergisches Land and in the Eifel mountains. The same is the case in the Ardennes and in central regions of the Massif Armoricain, for instance the synclines of Lire and of Laval. But within this mixed facies Hercynian influences are sometimes rather remarkable. In the northwestern part of the geosyncline, the Hercynian magnafacies now appears in South England, namely in the *Styliolina* and goniatite bearing shales near Padstow (c.f. M. R. House 1963). The *Calceola* shales of the Torquay district, however, should be included in the mixed facies.

While the Hercynian magnafacies advances, in Eifelian time the typical Rhenish magnafacies becomes restricted to only few places on the northern margin of the Rhenish mountains and the Ardennes as well as on the northern margin of the Vosgues in the Alsace.

Also in the eastern parts of the geosyncline, the Hercynian magnafacies advances considerably during the Eifelian. Coming from the Central Bohemian basin it now enters into northern Moravia and the border zone between Moravia and Silesia, being represented there by beds similar to Wissenbach shales with hercynian goniatites and trilobites. In Southern Poland, in the Holy Cross mountains, strong hercynian influence is evident in the mixed facies of Eifelian marly limestones with a fauna containing both hercynian and rhenish elements.

Subsequently, in the GIVETIAN, the mixed facies becomes influenced by hercynian lithofacial and biofacial elements to such an extent that rhenish elements become very scarce and the hercynian are pre-eminent. In these circumstances, sometimes it is very difficult to draw a sharp line between typical hercynian beds and beds of the mixed facies. If those Devonian beds which show only few rhenish relicts are included in the area of distribution of the Hercynian magnafacies, then it seems that the Hercynian magnafacies in the Givetian covers our geosyncline to a very large extent, at least in its central and western parts.

It is true that it recedes completely from the Southern Massif Armoricain and from the Central Bohemian basin, due to an uplift in late Givetian time and evident from the deposition of partially terrestrial sediments with fossil land plants of this age. But on the other hand, the Hercynian magnafacies and the almost completely hercynian mixed facies cover now not only the whole area of the Harz mountains but also very large parts of the Rhenish mountains and the Ardennes. In all these areas it is represented by coral reef limestones of the Koneprusy intrafacies and by trilobite, brachiopode and goniatite bearing limestones of the Slivenec intrafacies. Limestones of the Badeholz intrafacies are present also but less common.

A mixed facies with predominating rhenish elements is now restricted, in these parts of the geosyncline, to the central northern margin of the Rhenish mountains, particularly to the Bergisches Land.

The Hercynian magnafacies in the Givetian remains present also in the far west of the geosyncline, where many limestones in the neighbourhood of Torquay should be interpreted as manifestations of the Hercynian magnafacies.

In the eastern part of the geosyncline, that is, in Poland, a mixed facies is present, which also has hercynian elements to a very remarkable degree. But on the other hand, rhenish lithologic and faunal elements are still quite noticeable. According to the facies studies and paleogeographic reconstructions of Mrs. Pajchlowa (1959) it may be that the northeastern and southwestern borders are occupied by the Rhenish magnafacies.

In the southern adjacent parts too, the Hercynian magnafacies advances. It is well developed in Moravia, and in Austria it now penetrates towards the east, reaching and covering the region of Graz. Another invasion of the Hercynian magnafacies occurs in the Givetian of the Southern French Montagne Noire, particularly in the region of Cabrieres.

As a result, in the Givetian, the Hercynian magnafacies and the hercynian-influenced mixed facies became very wide-spread in our geosyncline. On the other hand, the area of distribution of the typical Rhenish magnafacies shrank very considerably. It is now represented only by a few sandstones, conglomerates and red shales restricted to the northern margins of the eastern parts of the Rhenish mountains and the northern margin of the Ardennes.

In the UPPER DEVONIAN, the situation is similar to the Givetian. Almost the whole geosyncline now shows sediments of the Hercynian magnafacies. It has frequently been pointed out that generally speaking and excluding other minor developments, there are two main types of Upper Devonian deposits in the Old World : The so-called *Clymenia* limestones which are developed as phacoidal " Kramenzel-" limestones or even as nodular limestones, and the so-called *Cypridina* shale.

The *Clymenia* limestones are definitely of hercynian type and they represent the Dvorce-Prokop intrafacies. They are wide-spread in Europe being present in South Devon (House 1963, p.16 : particularly in the Chudleigh succession). They also appear in the French Massif Armoricain and everywhere in the Rhenish and the Harz mountains. They occur in the Frankenwald mountains and in Thuringia as well as on the northern slope of the Sudetic mountains, in Poland and in Moravia. To the south the same limestones should be mentioned from the Carnic Alps, the marbre griotte of the Montagne Noire and the Pyrenees as well as other places.

Also the so-called *Gypridina* shales have been included in the Hercynian magnafacies which proves to be right in most of the cases excepting in those places where these shales become primarily sandy. Then they tend more to the mixed facies.

While the Hercynian magnafacies is very wide-spread in our geosyncline during Upper Devonian time, there are now only very few sediments which could be compared with the Rhenish magnafacies. Such examples are the sandstone of Condroz as well as sandy shales and sandstones on the northeastern-most margin of the Rhenish mountains and perhaps a few sandstones in the Sudetic and Polish part of the geosyncline. In all other places, the Rhenish magnafacies had been replaced successively by the Hercynian magnafacies.

During the course of time, however, this Hercynian magnafacies itself suffered a certain change. The lithologic features, of course, remained principally the same as in the beginning. But the fauna is now no longer quite the same as it was originally in the Lower Devonian. Many typical hercynian elements became extinct in the early Upper Devonian or even earlier. This is the case for most of the hercynian trilobites, numerous goniatites and many cardioconchs. On the other hand, new faunal elements had appeared, not known in the Lower Devonian. We may mention *Stvingocephalus* and its relatives, *Uncites*, dechenellids, cyrtosymbolids, clymeniids and others derived, however, from originally hercynian forerunners. Thus, while the general aspect of the hercynian faunal assemblages remains similar to the original one, it is no more the same faunal assemblage. The same is true in the case of the Rhenish magnafacies.

In the CARBONIFEROUS the original contrast between the Rhenish and the Hercynian magnafacies decreases to such an extent that now it becomes doubtful whether or not these names have any validity for this period. Actually, the original contrast between the faunal assemblages becomes now so obsolete that these names have lost their sense and that these magnafacies in Carboniferous times cease to exist.

FACIES INTERPRETATION

Up to now, the Rhenish and the Hercynian magnafacies have been studied by analyzing their lithologic and faunistic features, their complexity and especially their distribution in our geosyncline. Now the question concerning their interpretations may be considered.

It would be logical to expect that the conditions resulting in each of these magnafacies were not simple and uncomplicated. It is much more probable that we are confronted with a complex of palaeoecologic and palaeogeographic factors. Let us examine, therefore, these factors.

There is, in the first place, the degree of *agitation* of the sea water and its *content o f oxygen* depending on this agitation. H. Schmidt and A. Rabien interpreted the Rhenish magnafacies as the facies of strongly agitated waters rich in oxygen - and the Hercynian magnafacies as the facies of quiet waters poor in oxygen. This interpretation, however, is contradicted by the fact that large parts of the Hercynian are certainly not deposits of quiet waters with insufficient oxygen. As an example we can quote the Koneprusy intrafacies with its biostromes and bioherms as well as the Slivenec intrafacies with its fore-reef deposits and faunas. In these circumstances, the interpretation offered is not satisfactory.

In the second place, there are the *bathyvnetric conditions*. The Czech colleagues J. Svoboda and F. Prantl (1949) and L Chlupac (1957) interpreted facies differences in the Bohemian Devonian as manifestations of bathymetric differences, and to a certain degree this may be justified, particularly in the case of the differences between hercynian intrafacies and parvafacies. But we cannot apply this interpretation for explaining the contrast between the Rhenish and the Hercynian magnafacies. While it seems that the hercynian Badeholz and Dvorce-Prokop intrafacies have been formed actually in deeper parts of the sea than the Rhenish magnafacies, another part of the Hercynian magnafacies, namely the Koneprusy and the Slivenec intrafacies have been deposited in shallow waters, the same way as the Rhenish sediments.

In the third place, as far as the faunas are concerned, there are the *chemical and physical conditions of the sea-bottom.* We will remember that hercynian faunas always preferred areas of fine-grained purely argillaceous and extremely carbonate-rich mud which would be free of any sand or other debris coming from emerging land surfaces. (It is striking that this is true not only the benthonic but also the free swimming animals.) On the other hand Rhenish faunas preferred areas of the carbonate-free coarse-grained sandy sea-bottom. This seems to be a very important factor but it seems that it is not the only one.

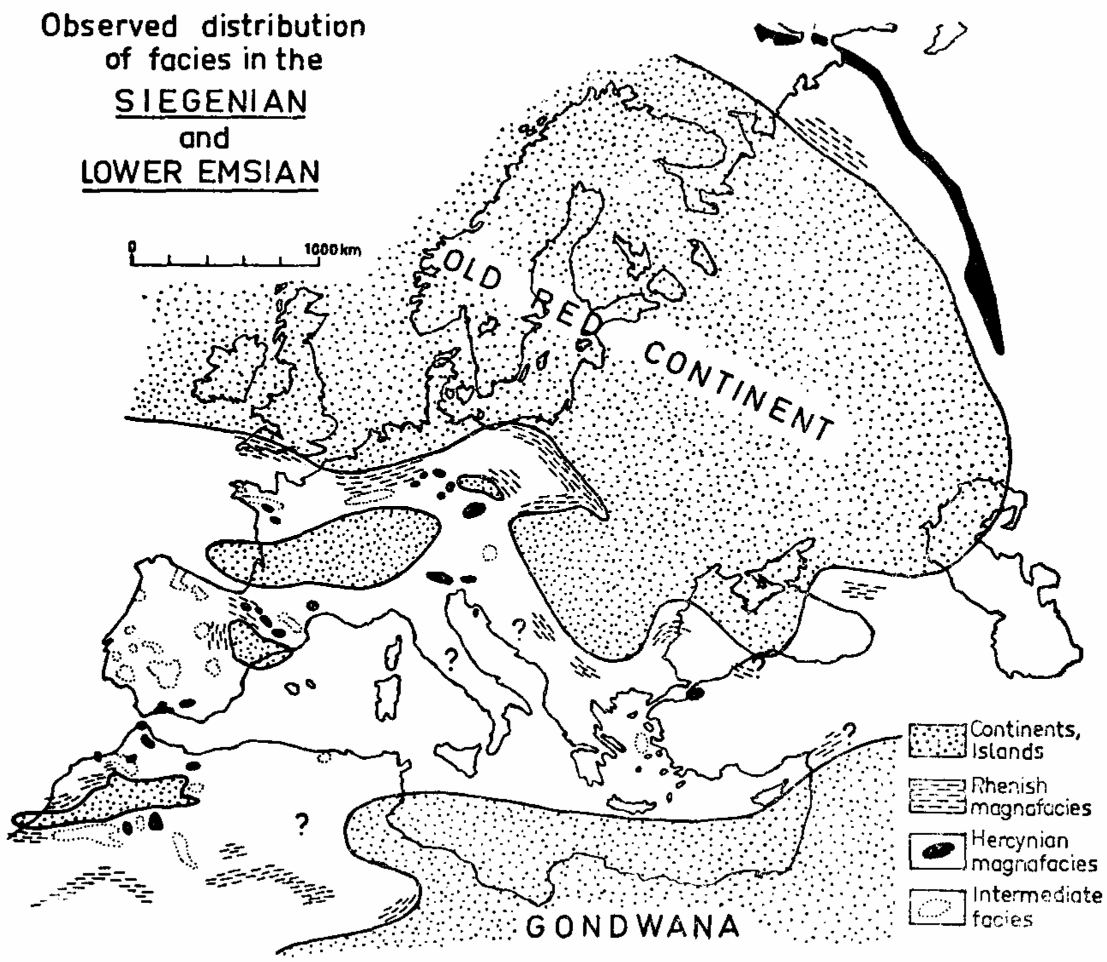

FIGURE 4.

The next point would be whether the deposition was on sub-marine *ridges* or in *basins.* Because of differences in thickness H. Schmidt (1926) and in a rather extreme way also F. Dahlgruen (1927) interpreted the Rhenish magnafacies as the facies of basins (in German : Beckenfazies) and the Hercynian as the facies of submarine ridges (in German : Schwellenfazies). There seems to be some truth in this interpretation but only in so far as most of our hercynian limestomes - if compared with Rhenish sediments - in this sense are sediments of restricted thickness and should be conceived as deposits on submarine ridges. But as is evident from the Wissenbach shales, the Upper Devonian Cypridina shales and the almost hercynian Hunsruck shales, in many places the hercynian shales have the same thickness as rhenish sandy formations. They must be interpreted therefore as deposits of subsiding basins, too. Therefore, also this explanation remains unsatisfactory.

The next possibility would be to interpret rhenish and hercynian faunas as representatives of two different zoogeographic provinces or realms. This was done by J. Shirley (1938) who pointed out that the distribution of hercynian faunas (he called them (" faunas of Bohemian type ") corresponds to the area of a" Lower Devonian Tethys ". This certainly is acceptable, but then, the interpretation as " Tethydian fauna " refers to a faunal province, and this term is of course not more than a circumscription of the effects caused by specific ecologic and geographic conditions.

It will be advisable to examine these conditions not only in our West and Central European geosyncline, as has been done, but to study the whole paleogeographic picture in the Devonian of the Old World, particularly the one of the period from late Lower to early Middle Devonian. In such a map (fig. 4) is shown the distribution of the two magnafacies and the intermediate mixed facies in the Emsian paleogeography of the Old World. On the basis of this map, one has attempted a generalised reconstruction of the distribution of facies at the same period in the late Lower Devonian, near the earliest Eifelian. Such reconstructions were published in 1962. The present one (fig. 5) is slightly improved by including some additional details. In this reconstruction, if it is correct, several regularities become evident :

(1) In the late Lower Devonian sea of the Old World both magnafacies form belts which extend east-west, more or less parallel to the shores of the suggested northern and southern continents.

(2) The Rhenish magnafacies appears always in a zone immediately adjacent to the coasts of supposed continents or islands. This is the case with both the northern Old Red continent as well as the southern continent of Gondwana.

(3) The next zone seaward is generally that of the mixed facies.

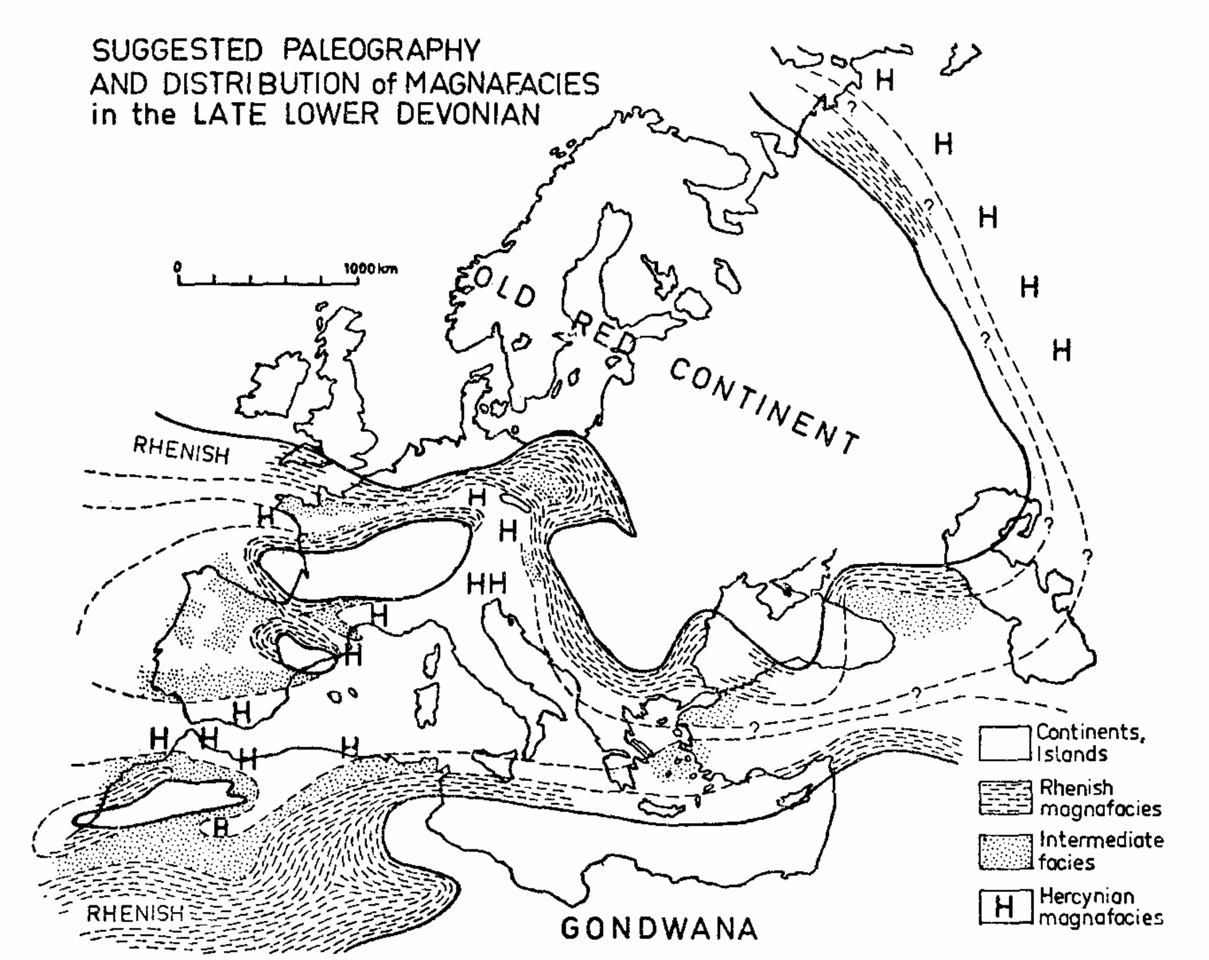

FIGURE 5.

(4) The Hercynian magnafacies, as a rule, is more or less offshore. Mostly it occurs in the centres of the basins. This is the case, for example, not only in the centre of our West and Central European geosyncline but also in the centre of the large general sea extension running east-west through the Old World. As far as the latter is concerned, the Hercynian magnafacies occurs in it in a belt the position of which would correspond more or less to a certain type of Tethys.

There are, however, a few exceptions, where between an island and the Hercynian facies the Rhenish facies and the mixed facies seem to be absent. On the other hand it may happen that a basin is filled up to its centre by Rhenish sediments, the Hercynian facies being absent. Such deviations from the rules, however, can be explained by the presence or absence of terrestrial debris in the sediment which in turn depends on the directions of transporting rivers on the adjacent land. These exceptional cases indicate that not only the position relative to the shore, but also the presence or absence of sedimentary materials derived from emerged continents or islands is responsible for the presence of the Rhenish or Hercynian magnafacies respectively.

Reconsidering all above-mentioned observations, a summarized interpretation may be suggested as follows :

The RHENISH magnafacies seems to depend on a near-shore position and it seems to be caused by the following factors : by intense accumulation of continental debris and therefore : by the presence of a coarse-grained, sandy bottom-sediment free of, or poor in, calcium carbonate : and by the faunal assemblage adapted to such type of bottom-sediment.

The HERCYNIAN magnafacies seems to be related, as a rule, to an off-shore position and it seems to be caused by the following factors: by the complete absence or scarcity of sedimentary debris coming from continental surfaces and therefore by the presence of bottom-sediments represented by fine-grained pure argillaceous and/or carbonate mud, and by the faunal assemblage adapted to such type of bottom-sediment and to the regions of open sea situated above it.

These relations and factors cause a distribution of the Hercynian magnafacies which corresponds to a Devonian Tethys Sea. But as we have learned from the continual increase in distribution of the Hercynian magnafacies in our West and Central European syncline, it is obvious that the ultimate causes for all these phenomena are represented by geotectonic events - by the continual subsidence of basins and geosynclines and by the uplifts of land masses.

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62. A comparison of minor structures at Lydford, Devon, and Boscastle, north Cornwall : by W. R. Dearman.

The beds at Penally Hill, Boscastle may be equated lithologically with slates cropping out in the valley of the Lyd on the north-west margin of Dartmoor. Strict stratigraphical correlation is not possible, but both groups of rocks are intimately associated with slate sequences of Upper Devonian and Lower Carboniferous age (Dearman and Butcher, 1959 ; House, 1960 ; Selwood, 1961). The rocks are slates or phyllites with lenticles and bands of siltstone and fine sandstone ; those at Boscastle are typically dark grey in colour whilst at Lydford this colouration is subordinate to a general pale green or grey-green hue.

At both localities two generations of minor structures have been impressed upon the slates : early folds, varying from tight to isoclinal, with well developed axial plane cleavage and later zig-zag folds with a strain-slip cleavage. The early slaty cleavage and the bedding are clearly deformed both by the zig-zags and by the strainslip cleavage so that there can be no doubt about the age relationships of the two sets of structures (Fig. 1).

The zig-zag folding at Boscastle has been described by Wilson (1951, p.399 and fig. 2) and his account fits the Lydford structures equally well apart from slight differences in trend. These might be attributable to the position of the measured Lydford structures within the contact metamorphic aureole of the Dartmoor granite.

Of much greater interest is the recognition of the wide variation in plunge of the axes of the early isoclines with respect to the fairly constant attitude of the axial plane slaty cleavage. This variation is particularly obvious at Lydford where, in a small group of crags on the banks of the River Lyd at High Down **(SX** 527848) fold trend varies from south-west to north-west. The folds have a moderate plunge of between twenty and thirty degrees and it is noteworthy that the extremes of plunge direction may be exhibited in two adjacent folds.

It has been known for some time that at Boscastle the early isoclines trend north or slightly west of north, that is normal to the axes of the zig-zag folds. There is a preponderance of isoclines with this northerly trend at Boscastle, but careful search has revealed a few examples of folds of the same generation in which the axial direction is westerly.

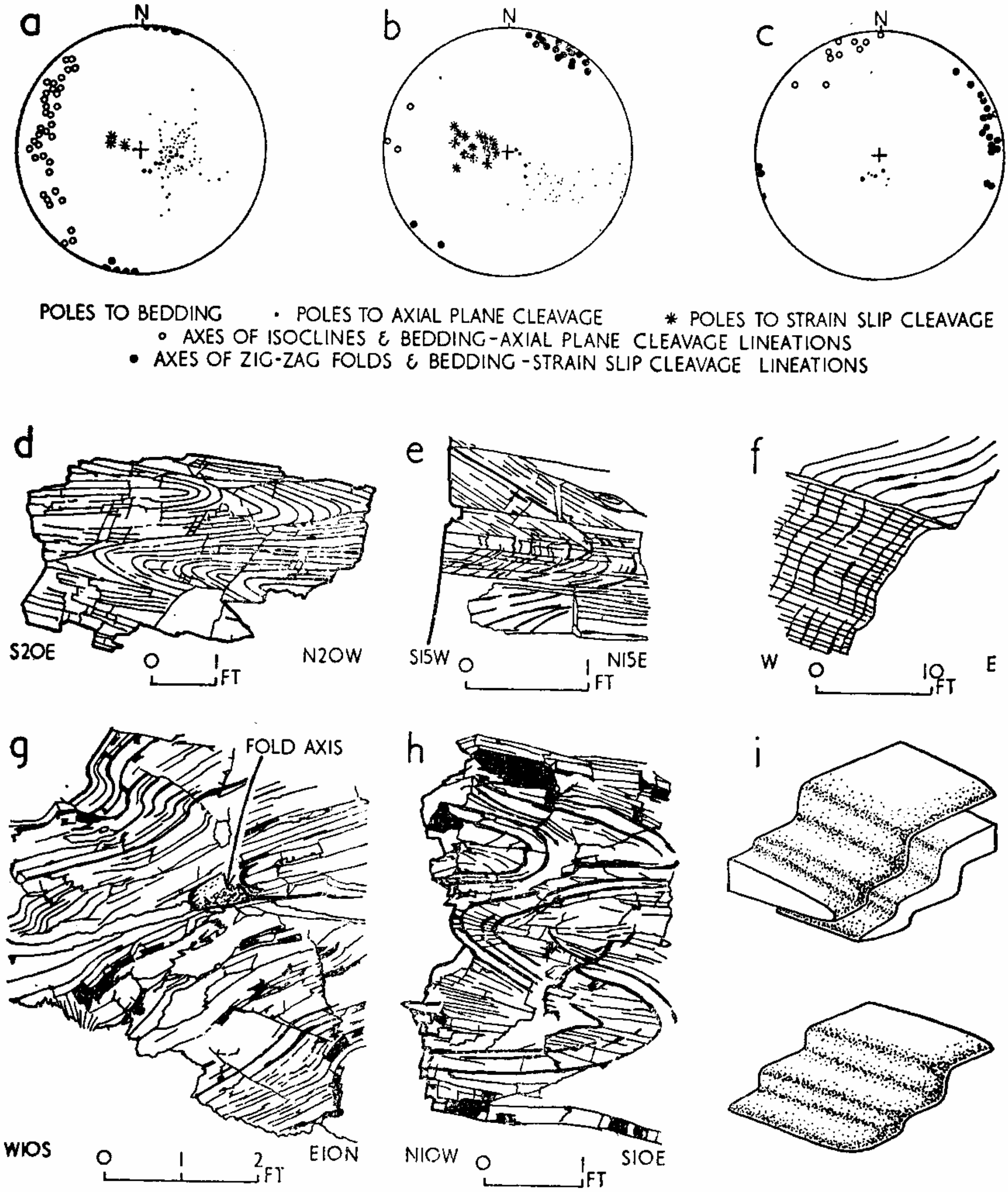

FIGURE 1. Minor structures at Lydford and Boscastle.

(a) Stereographic plot of structural data from one group of crags on High Down in the valley of the Lyd. Here the emphasis is on refolding in the early isoclines. (b) Stereographic plot of structural data from crags around Kitt's Mine, Lydford (SX 517846) with emphasis on zig-zag folding. (c) Stereographic plot of structural data from Penally Hill, Boscastle. (a), (b) and (c) are equal area projections, lower hemisphere.

(d) Very tight early folds, High Down, Lydford. (e) Early fold with axial plane cleavage, High Down, Lydford. (f) Two limbs of a large zig-zag fold with concentration of strain slip cleavage in the steep limb. Kitt's Mine, Lydford. (g) Early fold with crossing zig-zag fold, Boscastle. (h) View at right angles to rock face illustrated in (g) showing early folds crossed by axial plane cleavage. Illustrations of rock faces are drawn from photographs. (i) Synthetic surface diagram showing zig-zag folds superimposed on early isoclines. Lower half of diagram shows the presumed " refolded fold " form of the early isoclinal folds.

The correlation between minor structural detail at Boscastle and Lydford is now complete, and the interrelationships of the two generations of structures is illustrated schematically in Fig. 1i. It is inferred, although not yet demonstrated, that the two directions of early folds are related in the same way as the two limbs of refolded folds of "Eyemouth type" which have been described recently from the Southern Uplands (Shiells and Dearman, 1963).

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64. The Lynton Beds of North Devon : by S. Simpson.

The Lynton Beds are the oldest strata in North Devon. The Foreland Grits are not a distinct formation, but are the Hangman Grits on the faulted north limb of an anticline which runs from Lynmouth to Oar.

The age of the Lynton Beds is still not exactly known. Their fauna suggests that they may be of late Emsian or early Eifelian age. Though fossils are locally abundant, the fauna is an impoverished one. Pelecypods such as *Modiomorpha*, *Ptevinea*, *Limpoteya* and *Actinodesma* predominate. *Platyorthis civculayis* is a common brachiopod and species of the *Spirifer subcuspidatus* group are frequent. In the slate, fenestellid bryozoans are important.

Features of significance for the interpretation of the conditions of deposition are :

(1) the concentration of the fossils in thin shell bands (lumachelles) which sometimes become clastic limestone an inch or two thick ;

(2) the absence of thick current-bedded sandstones ;
(3) the great development of regular lamination of sand and mud, and
(4) the ubiquitous occurrence of the trace-fossil *Chondvites.*

The greater part of the exposed succession, amounting to about 1,300 feet, consists of sandstones. These form beds varying in thickness from 1 or 2 feet up to 10 or 15 feet. They appear at first sight to be fairly homogeneous but close examination shows them to be finely laminated, the laminae consisting of alternations, a few millimetres thick, of slate and sandstone. The lamination is however much disturbed by burrowing and also by the effect of cleavage. The two agencies have effected a considerable mixing of the arenaceous and argillaceous constituents, and hence the superficially homogeneous appearance of the rock. The sand generally predominates though all proportions of original sand and mud are present, so that it is often difficult to decide whether to call a bed a sandy slate or an impure sandstone. The sand is always of fine grain. There are occasional beds of pure slate or sandstone, but these are normally only inches thick. In the highest part of the succession, there are several thick packets of fairly pure slate.

Strongly disturbed water is implied by the evidence for repeated phases of pene-contemporaneous erosion (the concealed bedjunction preservation of *Chondrites* is common-see Simpson, 1957) and by the concentration of fossils in lumachelles. On the other hand, the fine-scale regular lamination of the sediment suggests settling out of suspension, which would imply quiet water.

Alternating periods of still and disturbed water on the sea bed might exist if the depth were such that wave action would only affect the bottom in stormy weather. The thick accumulation of sediment would further imply that erosion in stormy weather was on average less than deposition in periods of calm.

Reference:

SIMPSON, S., 1957. On the trace-fossil Chondrites. **Quart. Journ. Geol. Soc.,** Vol. 112, p.475-496.

66. Progress Report on the Land's End Granite : by B. Booth.

It is possible to conveniently represent areal mineralogical variation on a map by means of a trend surface, which depicts the modal values from which local fluctuations “noise” have been removed ; it can therefore be considered a smoothed “Response

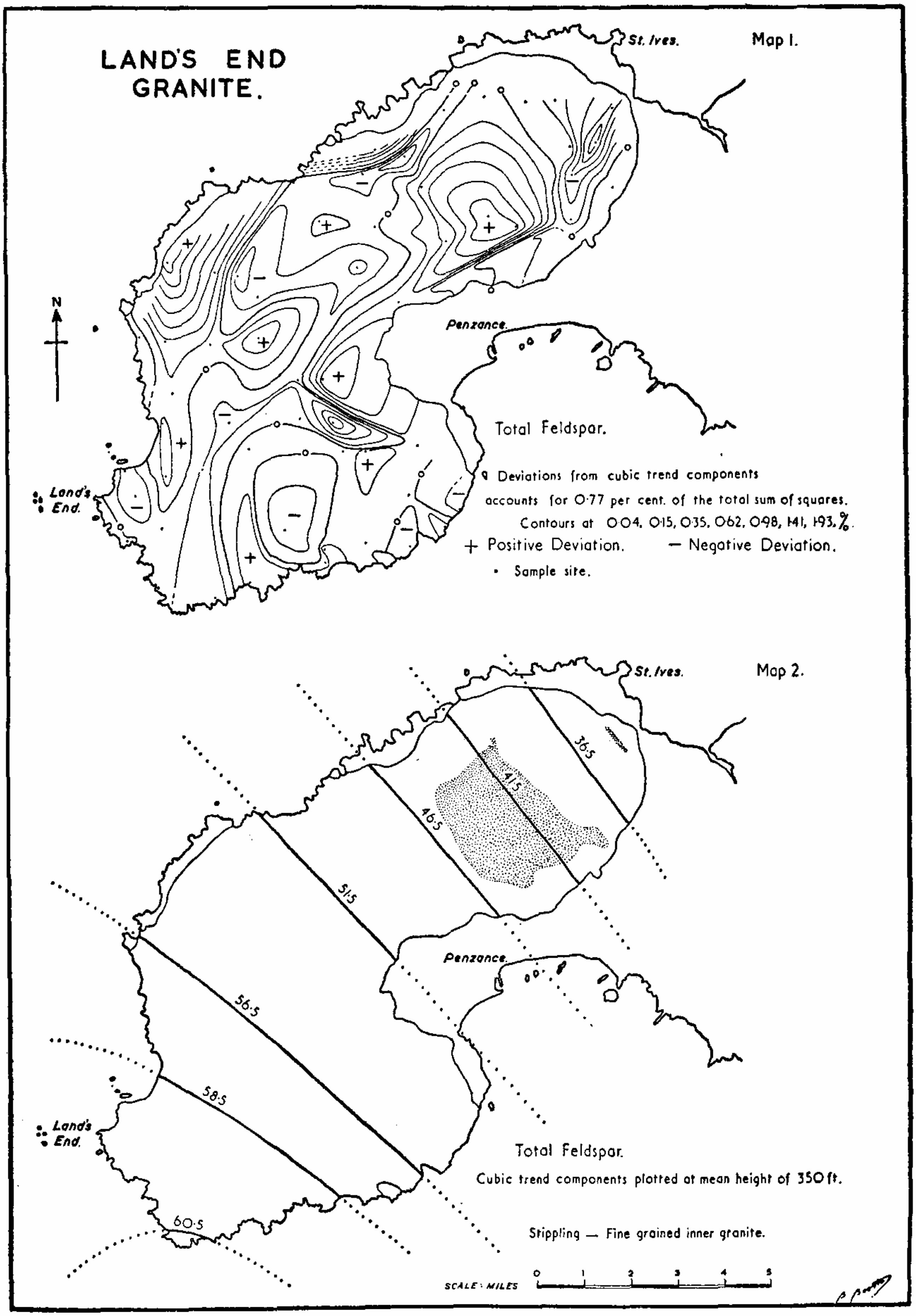
LAND'S END
GRANITE.
Map I.
St. Ives.
N
Penzance.
Land's End.
Total Feldspar.
Deviations from cubic trend components
accounts for 0·77 per cent. of the total sum of squares.
Contours at 0·04, 0·15, 0·35, 0·62, 0·98, 1·41, 1·93, %.
+ Positive Deviation. — Negative Deviation.
• Sample site.
Map 2.
St. Ives.
36·5
41·5
46·5
51·5
56·5
58·5
60·5
Penzance.
Land's End.
Total Feldspar.
Cubic trend components plotted at mean height of 350 ft.
Stippling — Fine grained inner granite.
SCALE: MILES
0
1
2
3
4
5

FIGURE 1

Surface". Before smoothing, the surface is made up of the composition and geometry of the rock body and may consist of both local and regional effects.

In order to test the "goodness of fit" of data to this three dimensional mathematical surface the total sums of squares are partitioned into :

(a) those accounted for by the regional trend components.

(b) those accounted for by the deviations from this regional trend.

A well fitting surface contributes more than the deviations to the total sums of squares.

In studying the mineralogical variations of the porphyritic biotite granite of Land's End, non-orthogenal sampling was employed to collect material from sample sites as objectively as possible while attempting to minimise the within-site variability.

Modes were based on a minimum count of 4,200 points which reduced the analytical errors (Barringer 1953) at 10 per cent. and 50 per cent. to 0.95 per cent. and 1.6 per cent. respectively. To substantially reduce these errors would involve a count of over 9,000 points ; this is not practicable. The area of rock section pointcounted was calculated in such a manner as to keep the error of reproducibility below 1.41 (Chayes 1956).

A stepwise polynomial surface regression programme has been written for the I.B.M. 1620 computer ; phase II of the programme gives a correlation matrix. When applied to U, V (geographical coordinates defining sample sites) and modal data, correlation coefficients are generally low. This is taken as an indication of the homogeneity of the granite.

Mineral		Correlation (V)	Coefficients (U)
"Colour Index"	…	-0.21	+0.01
Secondary mica	…	-0.28	-0.17
Muscovite …	…	-0.10	+0.25
K/ Na Feldspar ratio	…	-0.14	+0.15
Biotite …	…	-0.15	+0.08
Quartz …	…	-0.15	-0.03

With the exceptions of K/Na feldspar ratio and muscovite there is a higher correlation with V than with U so that variation is greater along the N.W.-S.E, direction than along the N.E.-S.W. direction.

The directional variability of total feldspar is shown (Map 2) where the correlation with U gives a low coefficient of -0.02. This trend surface suggests that the intrusion centre lies to the south. Surfaces depicting the deviations from trend components show concentric patterns in the north-east, while in the south-west " ridges " trending W.N.W.-E.S.E. and N.N.E.-S.S.W. occur (Map 1). Deviation maps for other minerals show a similar arrangement.

Acknowledgements. The author would like to gratefully acknowledge the help of Dr. T. P. Burnaby who wrote the I.B.M. computer programme, and Dr C. S. Exley for discussions and criticism.

References :

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CHAYES, F., 1956. Petrographic Modal Analysis. **New York.**

69. A new goniatite locality at Babbacombe and its problems:
by M. R. House.

On the foreshore and cliff at Babbacombe Beach, Torquay, (SW 929655) grey slates with thin mudstones are exposed intruded by a dolerite which forms Half Tide Rock. Just north-west of the Rock a footpath passes over a small bridge and from the mass of slate beyond, which rises vertically from the shingle of the shore, Mr. A. M. Honeyman of Nottingham University made a collection of small pyritised goniatites and the writer has collected others on later visits.

These slates are marked as Eifelian on the Geological Survey maps and are so regarded in the *Memoirs* (Ussher 1903, p.54 ; Lloyd 1933, p.47). It was with some surprise, therefore, that the fauna proved to be Frasnian.

Commonest in the fauna are *Pyobelocevas fovcipifeyum (G.* and F. Sandberger) and *Toynoceyas (Tovnoceyas) sp.*, but *Bactrites* cf. *gracilis* (G. and F. Sand.) and *"Pleurotomavia"* also occur. *P. forcipifeyum* is a typical Lower Frasnian fossil, and the only other place where it has been recorded in England is at Staverton where it is found with *Koenenites*, another guide to the Lower Frasnian Lunulicosta Zone (Middleton 1960, p.194, House 1963, p.7). The set of fossils noted here has been presented to the Oxford University Museum (D290-D305).

Above the slates exposed near Half Tide Rock, limestones form Babbacombe Cliff, and these are usually supposed to be Middle Devonian in age. There are many outcrops along the maize of paths in the undercliff. If the Middle Devonian age of these can be confirmed, then the sequence here is inverted. The occurrence of Lower Frasnian slates at Torquay is interesting in itself, for hitherto the oldest Frasnian fossils known have been the Cordatum Zone *Beloceras* and *Manticoceras* from Petit Tor Combe (House *op. cit.* p.8), and from this it has been inferred that part at least of the top of the massive limestones were Lower Frasnian. This may still be the case, and the new Babbacombe locality may represent a shale development rather higher in the Lower Frasnian. This find serves to demonstrate the danger of identifying Eifelian shales on lithology alone.

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USSHER, W. A. E., 1903. The geology of the country around Torquay. **Mem. Geol. Surv.**

71. The Coral Fauna from the Ilfracombe Beds of North Devon :

by F. J. W. Holwill.

Shearman (1962) suggested that the Ilfracombe Beds in North Devon could be conveniently divided into three parts - a lower and an upper arenaceous division and a middle division consisting of calcareous shales and limestones. It is from the limestones of the middle division that a coral fauna has been obtained, though there is a bed of coarse sandstone on the north face of Hamator Rock from which *Thamnopoya* has been obtained ; this bed lies within the lower arenaceous group.

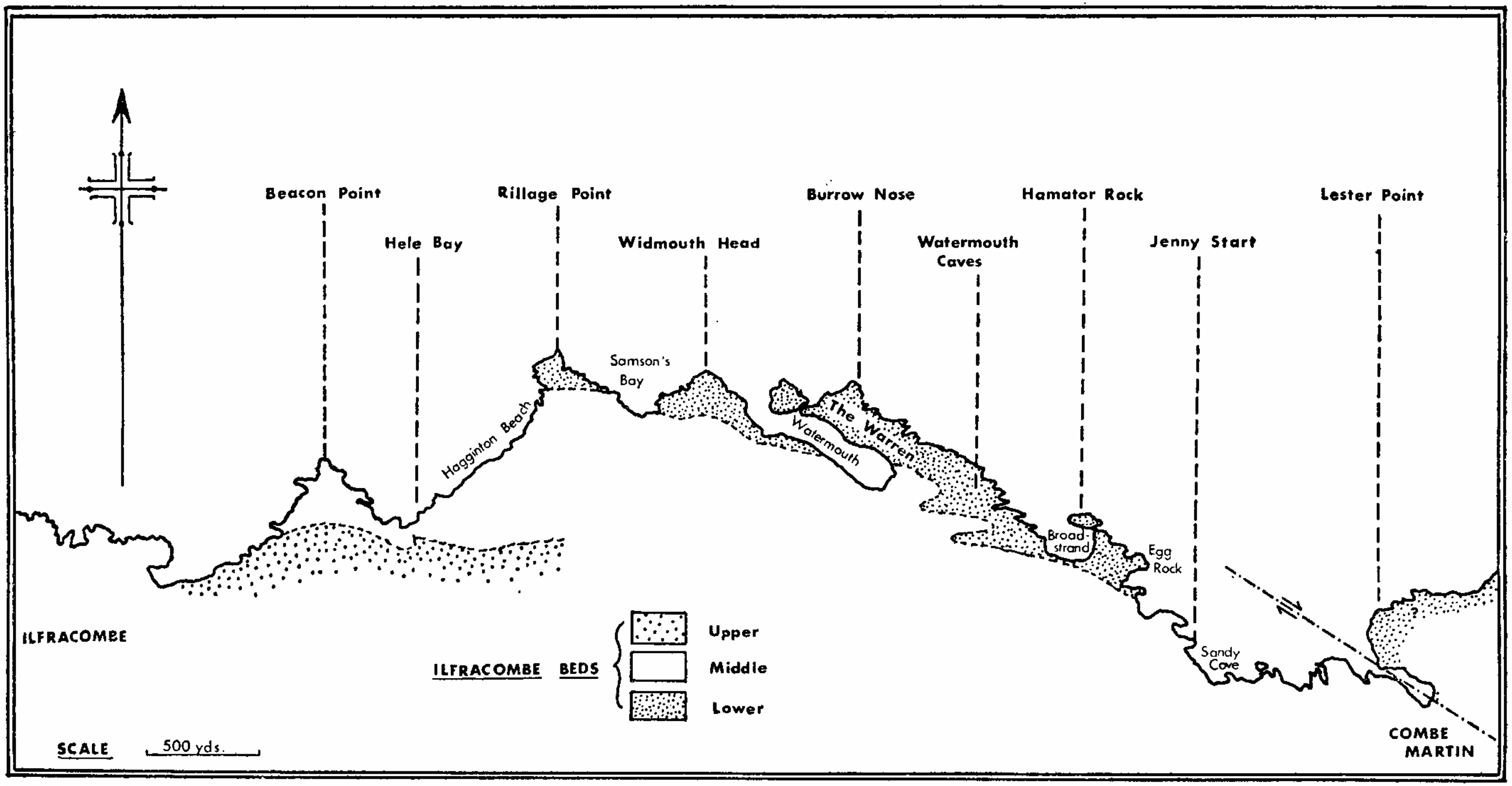

FIGURE 1. Map showing the distribution of the Ilfracombe Beds along the North Devon coast between Combe Martin and Ilfracombe.

There are four distinct limestones within the middle division and they are separated by variable thicknesses of slates:-

David's Stone Limestone	…	30 ft
Combe Martin Beach Limestone		3-5 ft
Jenny Start Limestone	…	30 ft
Rillage Limestone	…	6 in.-2ft

(The above thicknesses are approximations)

I regard the lowest and uppermost of these four limestones as defining the limits of the middle division, and its outcrop between Ilfracombe and Combe Martin is shown in fig. 1.

Rare fragments of *Thamnopora* occur in the Rillage Limestone, but much more abundant are brachiopods, crinoids, orthoceratids, bryozoa and algae with some unidentified fish fragments. It is possible that the Rillage Limestone is the lateral equivalent of the Holey Limestone (Evans 1922). If so, the lower division of the Ilfracombe Beds will be the equivalent of the upper beds of the Hangman Grits ; this possibility is also suggested by other lines of reasoning.

The Jenny Start Limestone is rich in corals many of which are found in their original positions of growth. The following coral genera have so far been identified (no account is taken of corals recorded in the literature as with only two exceptions, their precise location has not been recorded : *Disphyllum, Thamnophyllum, Endophyllum, Acanthophyllum, Cystiphylloides, Mesophyllum, Heliophyllum, Phillipsastraea, Hexagonaria, Heterophventis, Syringaxon, Stringophyllum, Trematophyllum, Thamnopora, Alveolites, Coenites, Favosites.* Associated with the above are stromatoporids crinoids, cystids, rare brachiopods and gasteropods. The fauna suggests an upper Givetian age and the corals listed above are almost identical to those recorded by Webby (1964) from the Roadwater Limestone of west Somerset. There can be little doubt that the limestones are developed at the same horizon without necessarily forming a continuous bed.

The Combe Martin Beach Limestone is packed with abraded fossil fragments, largely bryozoa (see Holwill 1962). The rugosa corals are all small solitary ones and are never complete. Tabulate corals are rare and only occur as small colonies. The following genera have been identified : *Metriophyllum, Syringaxon, Barvandeophyllum, Meniscophyllum, Amplexiphyllum, Alveolites, Thamnopora, Favosites, ? Pleuyodictyum.* Associated with the above corals are brachiopods, crinoids, gasteropods and algae in addition to the bryozoa mentioned above. The age of this limestone is considered to be lowest Frasnian.

The David's Stone Limestone contains few corals over most of its outcrop, but near Ilfracombe they become locally abundant and together with stromatoporids develop a small reef. The following genera have been identified : *Syringaxon, Baryandeophyllum, Phillipsastyaea, Favosites, Alveolites, Thamnopova, Coenites.*

The shales and limestones of the middle Ilfracombe Beds are thought to represent a deepening of the sea with consequent deposition of much finer material. All the limestones contain much argillaceous matter either as shaly partings or within the limestone itself, and there is frequent evidence of agitated waters; for example current bedding within the limestones at several localities and an oolitic limestone at Samson's Bay.

References :

HOLWILL, F. J. W., 1962. The Succession of Limestones within the Ilfracombe Beds (Devonian) of North Devon. **Proc. Geol. Ass.,** Vol. 73, p.281-293.

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WEBBY, B. D., 1964. Devonian corals and brachiopods from the Brendon Hills, West Somerset. **Palaeontology,** Vol. 7, p.1-22.

72. **Some aspects of Groundwater in South-West England :**

by F. W. Sherrell.

The problem of water supply on a small island is illustrated by Tresco, Isles of Scilly. Direct surface catchment-storage is limited, hence the supreme importance of groundwater and its method of abstraction.

A granitic island with bold topographical features is not ideal for groundwater storage or development. However, two basin areas exist, around Old Grimsby and the Great Pool. Head and gravels have accumulated in these, overlying weathered granite, thus creating two areas with small unconfined aquifers. What quantity of rain they receive and store is directly available to a suitably designed well system. The present main well abstracts from a portion of the Grimsby Basin

Both basins are near sea level and close to the sea. Small test bores in the seaward areas prove the absence of saline water, as does an existing but abortive bore immediately south of Grimsby Basin. Nevertheless, a well system here, must not cause or sustain a severe cone of depression, for risk of subsequent saline intrusion. A shallow system, “skimming” water from the aquifer is required.

In the case of the Grimsby Basin, it was considered that a further 5,000 gallons could be extracted per day, (water table 10 feet from surface) and at Great Pool a supply of 7,000 gallons (water table at c.3 feet from surface). In both, the specified yield per square foot of well surface is considered as 40 gallons per day.

To obtain these yields, large well chambers of five feet in diameter, will be constructed to depths of 15 to 20 feet. They will be installed as a cluster of three chambers in the northern part of the Grimsby Basin. In this manner, they will provide a maximum of storage and function in such a manner as to equal the output of a single, larger and more expensive well. This together with lateral feeding channels at a depth of 12 feet will permit the extraction of water over a maximum area, consistent with the hydraulic requirements.

Similar structures deployed along the northern margin of the Great Pool are envisaged in this basin.

Recent well-boring work in the valley between the Brendon and Quantock Hills is of interest. Between Bicknoller and Lydeard St. Lawrence the Lower Permian breccia-conglomerates and sandstones are found. Their great thickness, area of outcrop and favourable recharging conditions indicate that large volumes of groundwater may be available.

A recent borehole, six inches in diameter, was drilled southwest of Heddon Oak to a depth of 130 feet. Water was first encountered at 50 feet, increasing in quantity with depth. Pumptesting at 4,500 gallons per hour gave a drawdown of only five feet.

It would appear from this result and from other observation that an aquifer of considerable potential exists in this area.

Reference :

SHERRELL, F. W., 1962. Drilling and site investigation in Devon and Corn wall. **Proc. Ussher Soc.,** Vol. 1, p.37.

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