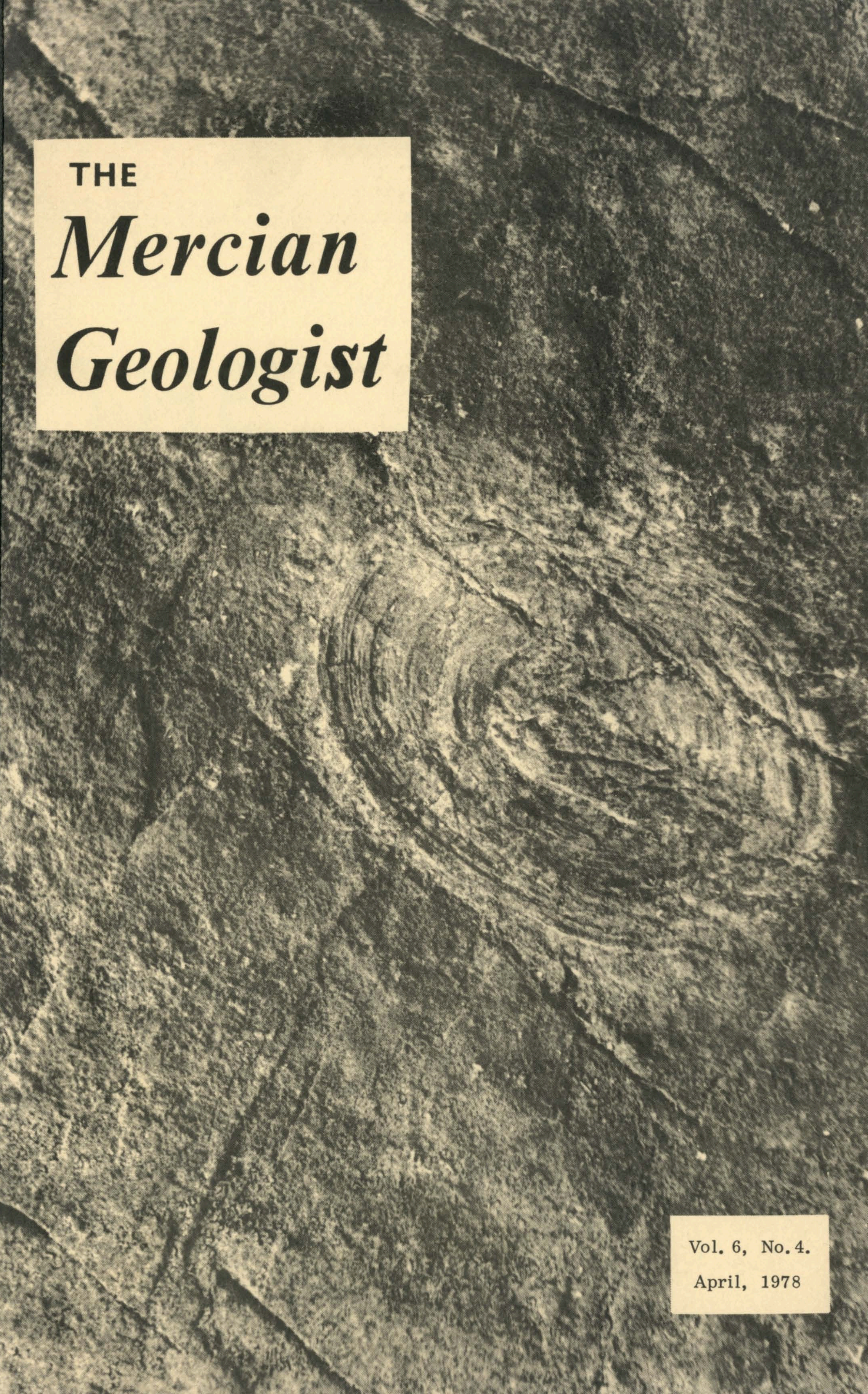
THE Mercian Geologist



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Front Cover: *Cyclomedusa* sp. Sprigg (X 0.5) Woodhouse Beds. Direction of cleavage shown by five broken lines parallel with the long axis of the medusa. Photograph by D. Boynton.

THE EMPLACEMENT OF A FLUORSPAR FLAT AT MASSON HILL, MATLOCK, DERBYSHIRE

by

R. A. Ixer

Summary

The fluorspar mineralization at Masson Hill is a discontinuous flat deposit with rich ore next to barren carbonates. The fluorite, quartz, barite, sulphide and calcite mineralization is a combination of metasomatic replacement of limestones and infilling of available open spaces.

Detailed mapping, structural and chemical analyses of the south-eastern half of the Masson Hill flat show that the mineralizing fluids encountered a complex sequence of rock-types, which were themselves the result of the interaction of a number of diagenetic and structural processes, the most important being dolomitization and silicification, faulting and jointing. The major controls on the emplacement of the ore included the distribution of replaceable limestones, together with the associated dolomites, basaltic lavas and ash bands. The juxtaposition of the various rocks produced porosity and permeability interfaces, often parallel to the original bedding and these controlled the horizontal movement of the ore fluids, whilst the faulting and jointing channelled vertical migrations. Locally, emplacement was influenced by the presence of premineralization solution cavities within both the limestones and dolomites.

The economically significant ore, found mainly within coarse-grained limestones at the base of the Matlock Lower Limestone Formation, was the result of the entrapment of mineralizing fluids above the thick Matlock Lower Lava, below a 0.60 m volcanic clay horizon and down-dip of a clay filled fault.

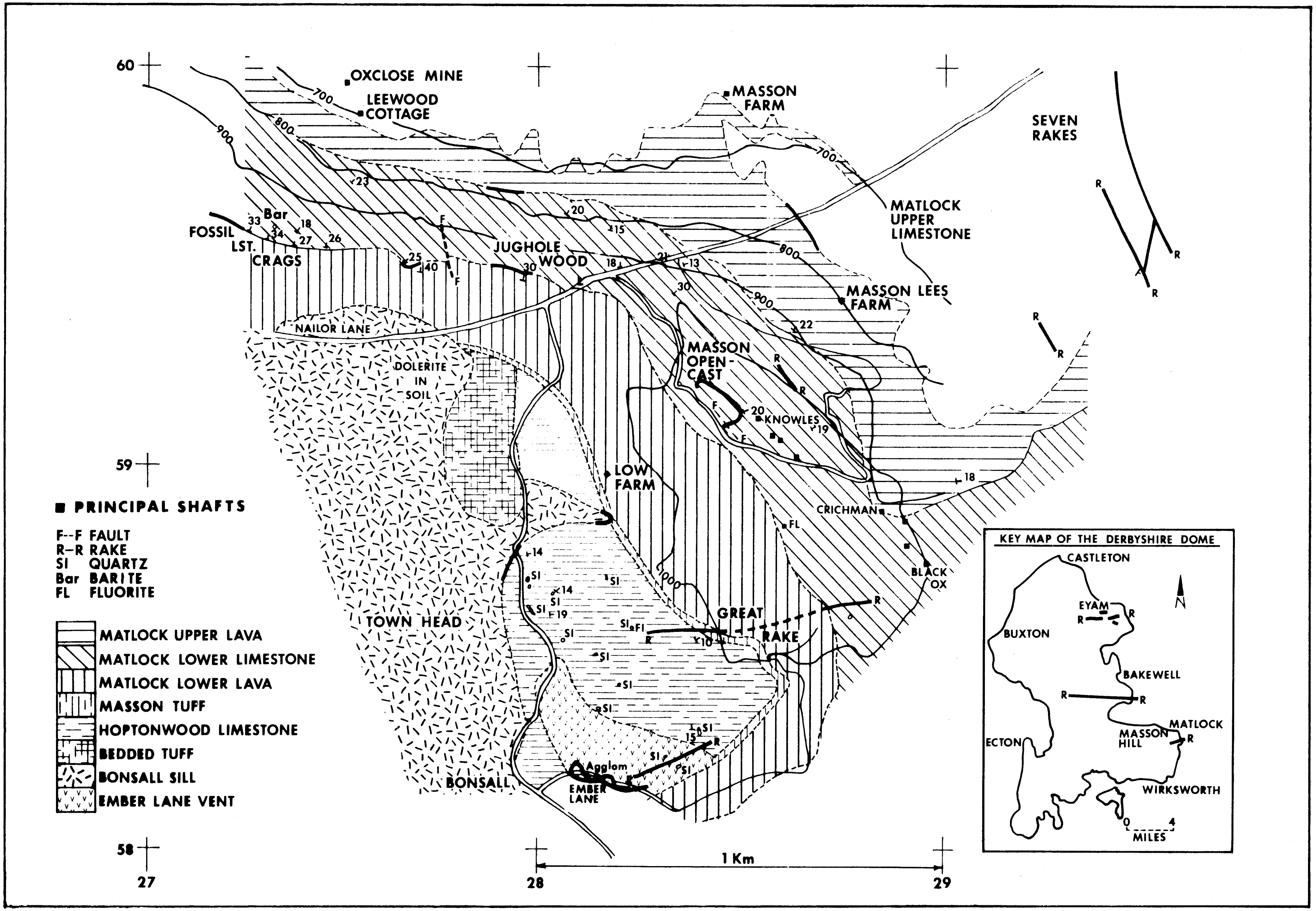
Introduction

Mining has been active around Matlock, Derbyshire, from medieval times to the present, firstly for lead and more recently for fluorspar. Amongst the more important areas has been the summit of Masson Hill (SK 28505920) which has been intensely mined for fluorspar throughout this century, most recently (1973) by La Porte Chemicals Ltd. Although there is no extensive mining at present, future exploitation is intended. More detailed discussions of the workings have been given by Dunham (1952) and Ford and Ineson (1971).

The mineralization consists of a series of intermittent smaller flats and/or pipes over a distance of 1.5 km. The largest single flat (or more strictly a pipe since the strike length is greater than its width along the dip) is that at the site of Masson Opencast Quarry and has a strike length of greater than 500 m and width of 240 m, (Dunham, 1952). The main ore horizon is restricted to the basal 6 m of the Matlock Lower Limestone (Lower Carboniferous, Brigantian age) although mineralization is found to occur above this within the overlying dolomites of the same formation.

Mineralogically the ore consists of approximately 60% fluorite, 20% quartz, 15% calcite and less than 5% barite, and traces of galena, sphalerite and other sulphides. It occurs as replacements of the limestone and as open space infilling, and is the direct result of the interaction of a number of geological processes. These influenced the availability of a suitable host rock or open void space; or controlled the direction and rate of flow of the mineralizing

Mercian Geol. Vol. 6, No. 4. 1978.
pp. 245-255, 4 text-figs. Plate 17.



Text-fig.1. Geology of Masson Hill, Derbyshire.

fluids. Amongst the more important, and the ones to be considered here were:-

(a) The regional and local structures - these effected the vertical pathways of the ore solutions and produced open spaces.

(b) The varying lithologies - these provided suitable or unsuitable host rocks and permeability/porosity interfaces that controlled horizontal fluid movements.

Detailed mapping and sampling along the Matlock Lower Limestone outcrop from (SK 27005970) to Matlock Bath (SK 29005800), and especially within Masson Opencast Quarry, supplemented by underground mapping at Jughole Mine (SK 27935971) and Knowles Mine (SK 28705918) allows a semiquantitative analysis of the importance of the two controls upon the emplacement of the ore bodies.

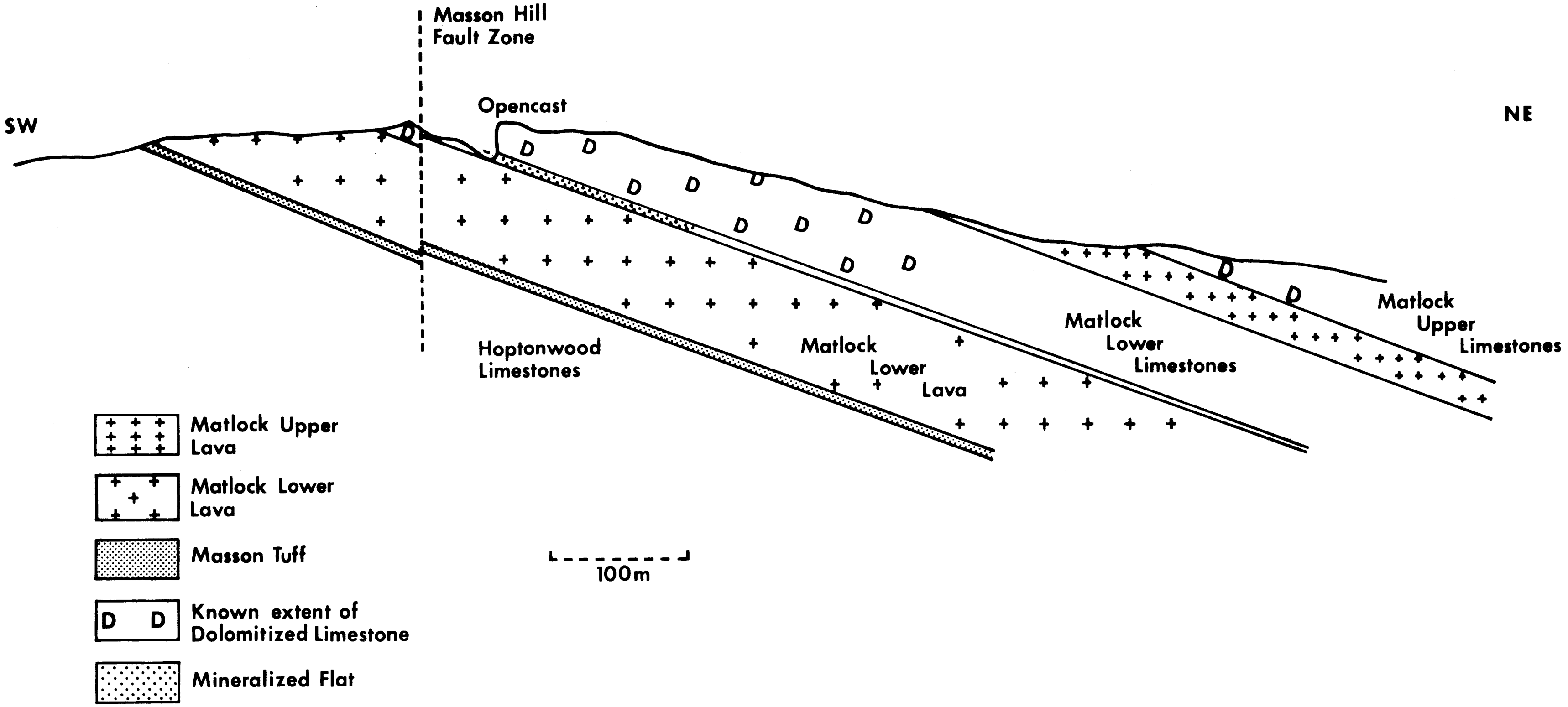
The first detailed description of the fluorspar deposits of the Masson Hill flat was given by Dunham (1952, pp. 97-100); more recent descriptions have been given by Smith *et al.*, (1967, pp. 43-44), Ford (1967, pp. 64-68; 1969, pp. 83-84), and Ixer (1972). Only Dunham was able to study the main economic ore-body at Masson Mine (the site of the present-day Masson Opencast Quarry) prior to its removal during the Second World War. The local structure has been discussed by Dunham (1952), Weaver (1974) and Firman and Bagshaw (1974) and the stratigraphy by Dunham (1952) and Ixer (1975). The mineralogy and paragenesis of the ore has been discussed by Dunham (1952) and Ixer (1974).

Structural Controls

Text-fig. 1 illustrates the geology of Masson Hill and shows the main areas of mining, which correspond to the more extensively mineralized portions of the Masson Hill flat. These are at Jughole Wood, Masson Opencast Site and a zone running south-eastwards from Knowles Mine to Black Ox Shaft. The mineralization occurs within the gently dipping (20-30°) Matlock Lower Limestone and this, together with the enclosing Matlock Upper and Lower Lavas, occurs on the northern limb of the eastward plunging Matlock Anticline. The axis of the anticline lies to the north of Great Rake and is subparallel to it. Superimposed upon the anticline are a series of approximately north-west trending faults, exemplified by Seven Rakes and by the fault zone along the topographic crest of Masson Hill. Within this zone faults occur at Jughole Mine (SK 27935971), west of Jughole Wood (SK 28795946) and within the Masson Opencast Mine (SK 2848591), the last is shown in plate 17, fig. 1). They all have small downthrows to the south-west of 10 m. or less and are filled with clay-gouge and hence unmineralized. None of them can be traced far but all are up-dip of the main mineralization. An extension of the fault found within the opencast excavation projected south-eastwards to some faulting, seen to be cut by Great Rake at (SK 28725865), would continue to be up-dip, parallel and close to the zone of greatest mineral workings. Although the evidence for this continuation is slight, such a fault would explain the distribution of mineralization in this part of the flat.

Text-fig. 2 shows a schematic section through the Matlock Group at Masson Opencast Quarry, together with the Masson Hill Fault and its associated flat. It can be seen that any mineralizing fluids travelling from the north-east up-dip towards the crest of the anticline would be stopped by the impermeable barrier of the clay filled fault, so producing a concentration of fluids on the down-dip side of the fault. This situation of vertical ponding by infilled faults is fairly common in Derbyshire (Firman and Bagshaw 1974, p. 153).

In addition to the major structures, jointing is well developed, especially within the dolomites, although the limestones beneath them are only poorly jointed. Structural measurements were taken from the Matlock Lower Limestone Group within the Masson Opencast Quarry. Both the mineralized and barren joints occur as a conjugate set, trending northwest-southeast and northeast-southwest. The master set has a mean orientation of 314° (317 readings) which is parallel to the Masson Hill fault zone, whilst the subordinate set has a mean orientation of 049° (233 readings). This compares with Dunham's (1952) suggestion for the mineralized master set having an orientation of 300°, with a conjugate pair at approximately 030°. The apparent difference may be due to



Text-fig. 2. A section through the fluorspar flat at Masson Opencast Quarry showing the proximity of the mineralisation to the Masson Hill Fault.

Dunham having taken his structural measurements within the main economic ore-body which has since been mined out to give the Masson Opencast Quarry. For the Matlock areas as a whole, north of the Bonsall Fault, the main mineralized joint set has an orientation of 305° and the minor set 045° (Weaver, 1974).

Weaver (1974) has suggested that this jointing is Variscan (Upper Carboniferous-Permian) in age, but if this is so, the difference in joint density between the limestones and dolomites must indicate that both lithologies were present prior to the imposition of the jointing. Thus the dolomitization could not be related to the overlying Zechstein Sea as suggested by Ford (1969) and must be of Carboniferous age. This is consistent with studies of the dolomitization of the Carboniferous Limestone in other areas, notably in South Wales (Bhatt, 1976).

Text-fig. 3 shows the distribution of poles to joints when plotted with regard to the dominant mineralization that they carry. No major differences for the distribution of minerals between the two sets is noticeable, although there is a slight tendency for the master set to carry the fluorite and fluorite-calcite mineralization and the minor set to carry the barite, gelena and calcite. From textural and paragenetic evidence it can be shown that the fluorite is early, whilst the barite, galena and calcite mineralization is later (Ixer, 1974).

The results suggest that both joint sets were open throughout the mineralization providing open spaces for deposition and allowing the fluids free access to the host rocks. The difference in mineralization between the joint sets may indicate some differential movement between them, or, if the mineralization is polyphase as suggested by Firman and Bagshaw (1974), that the later fluids did travel along slightly different pathways.

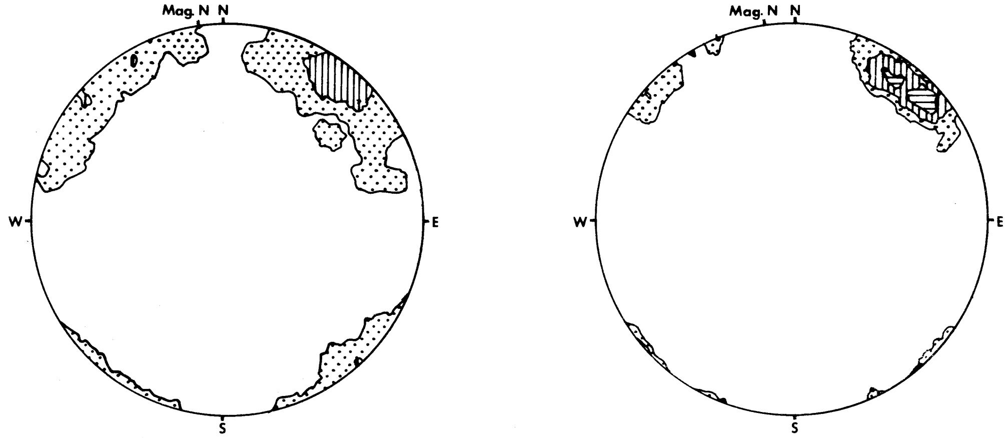
Litholgical Controls

A detailed stratigraphical and lithological description for much of the Matlock Group is given by Ixer (1975) based on measured sections within Masson Opencast Quarry and on borehole data. With the addition of the section given by Dunham (1952), a generalized stratigraphy for the southern half of the Masson Hill Flat can be derived (Table 1). Included within this stratigraphy is the important volcanic clay horizon known as the 'Little Toadstone'. This horizon is not seen in Masson Opencast Quarry although its stratigraphical position coincides with the main dolomite - limestone junction.

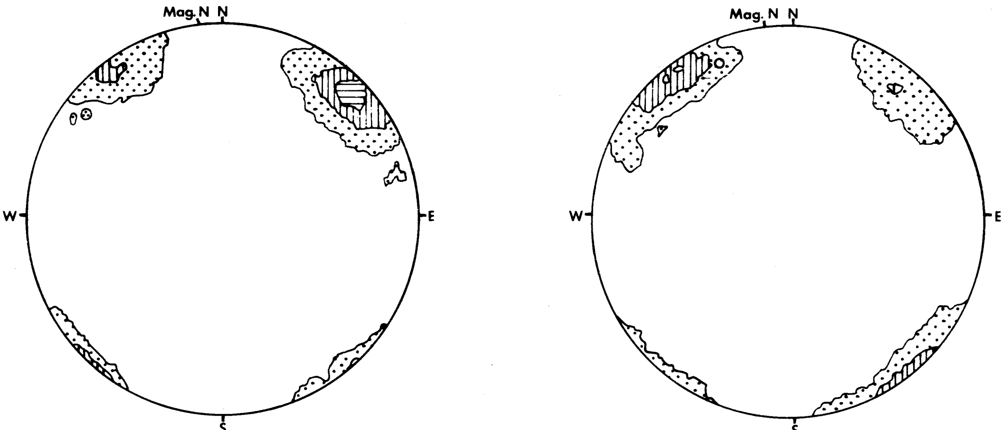
Table 1

	metres
Matlock Upper Lava	21.50
Dolomite and fine-grained limestone rafts	13.50
Clay bentonite (Wayboard 4)	0.30
Dolomite	2.65
Clay bentonite (Wayboard 3)	0.10
Dolomite	10.40
Clay bentonite (Wayboard 2)	0.02
Dolomite, silicified at the base	3.00
Clay bentonite (Little Toadstone)	0.80
Coarse crinoidal limestone	2.45
Clay bentonite (Wayboard 1)	0.05
Coarse crinoidal limestone	3.05
Matlock Lower Lava	78.00

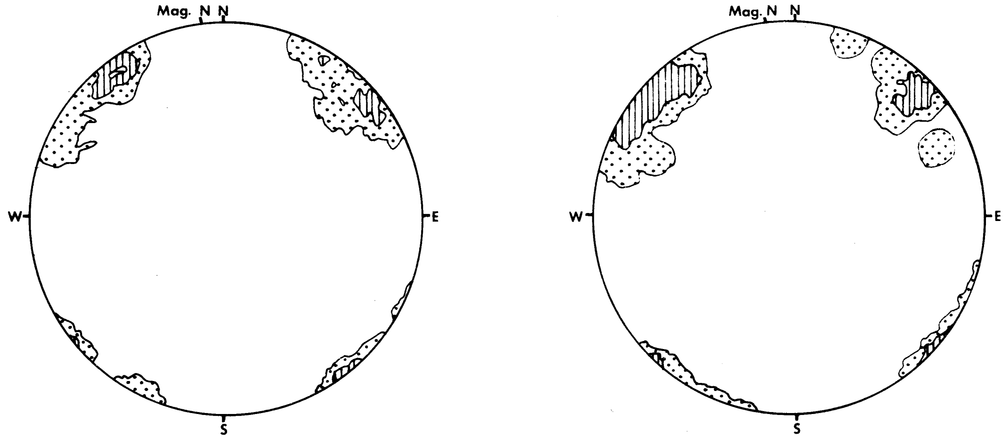
The major lithologies found at Masson Hill are coarse and fine-grained limestones, dolomites and their silicified equivalents, together with altered volcanic rocks, namely olivine basalts and bentonite clays. It is generally accepted on textural evidence that all these rock types were present prior to the main mineralization (Ford 1969, Smith *et al.* 1967) and that it was upon these rocks that the ore fluids interacted. It should be remembered that this assumes that the carbonate diagenesis of the limestones and alteration of the volcanics was completed prior to mineralization. An examination of each of the lithologies and their associated styles of mineralization should, therefore, help explain the small scale distribution of the ore. Additionally, text-fig. 4 which shows the results of chemical analyses for lime (CaO), magnesia (MgO) and silica (SiO_2) for a measured section within Masson Opencast Quarry, semi-



POLES TO BARREN JOINTS IN DOLOMITE 155 **POLES TO JOINTS with FLUORITE 75**



POLES TO JOINTS with FLUORITE & CALCITE 115 **POLES TO JOINTS with CALCITE 125**



POLES TO JOINTS with BARITE 58 **POLES TO JOINTS with GALENA 40**

☐ <3% per 1% Area
░ <10% per 1% Area
▥ <20% per 1% Area
▤ >20% per 1% Area

Text-fig.3. Equal area projections of poles to joint planes, plotted according to their dominant mineralisation.

quantitatively demonstrates the distribution of the various lithologies with respect to each other and illustrates some of the fluid pathways. The magnesia and its equivalent lime is assumed to be found as dolomite and any excess lime as calcite. Neither the Little Toadstone nor Wayboard 1 are shown in text-fig. 4 as neither occurred within the section sampled.

Lithologically the limestones vary from fine-grained and porcellanous to coarse-grained and bioclastic, comprising crinoidal and shell debris. Text-fig. 4 shows that the unaltered limestones (containing less than one per cent by weight magnesia) are at the base of the sequence, whilst incompletely dolomitized limestones lie above and below clay wayboards 2, 3 and 4. The isolated porcellanous limestone rafts can be seen to lie above Wayboard 4 in plate fig. 2 but were not included in the sampled section and are, therefore, not represented in text-fig. 4.

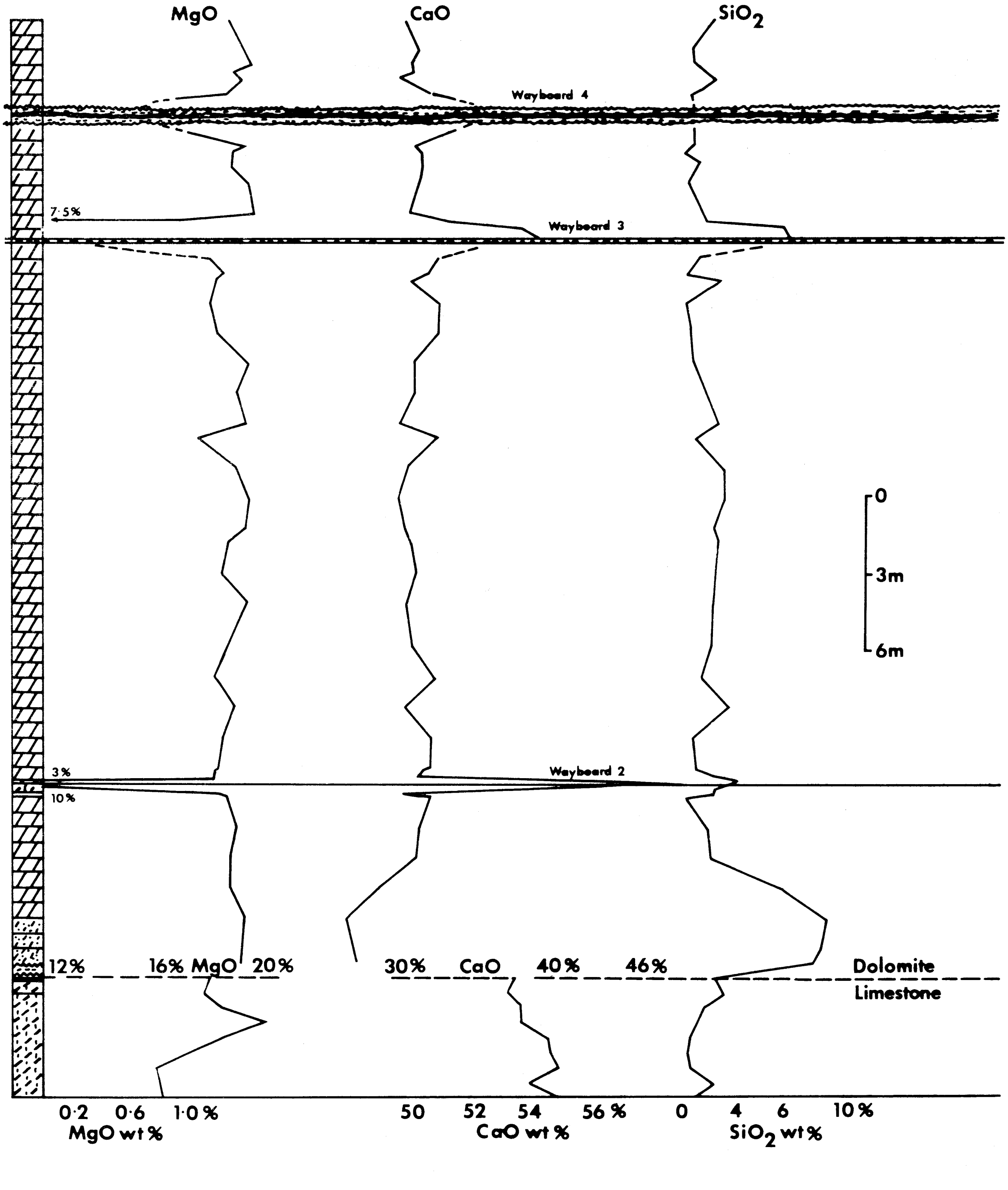
Open space infilling is associated with the poorly developed jointing and within the large (up to several metres across) solution cavities; in both cases as 5 - 10 mm thick skins of mineralization. Replacement occurs wherever the ore solutions contacted the limestones and hence is found at all the limestone-dolomite junctions, usually penetrating up to 0.20 m into the limestone. Complete metasomatic replacement is limited to the limestones beneath the Little Toadstone and above the Lower Lava. Macroscopically and microscopically the replacement can be seen to have been initiated within the coarsely-grained recrystallized fossil fragments (particularly corals and brachiopods) and then to have continued into the fine-grained matrix.

Dolomitization is sporadic throughout the Matlock Lower Limestones, decreasing in importance towards the north-west of Masson Hill until it becomes absent. Within Masson Opencast Quarry the dolomitization is extensive, and text-fig. 4 shows its remarkable compositional uniformity away from the clay horizons and also the very sharp junction with the basal limestone; the change from pure limestone to pure dolomite occurring within 15 mm. This abruptness is also characteristic of the porcellanous limestone-dolomite boundaries. As most of these junctions are parallel to subparallel to the bedding, the intensity of dolomitization would appear to reflect a primary lithological (grain size variation or porosity difference) or chemical variance between differing limestone posts.

Visible mineralization shows on joints, some open bedding planes, and in solution cavities which are normally rimmed by 0.01 - 0.05 m. of fluorite and completely filled with calcite scalenohedra. Microscopically, mineralization is restricted to small veinlets or within coarse calcite spar representing undolomitized fossil fragments.

The average silica content of the limestones and dolomites is less than 2% by weight and is found as small (2 - 10 mm) nodules. Greater silicification shows as 5 mm thick skins of intensely silicified dolomite/limestone along joint planes. Extensive development of this has produced 3 - 4 m high vertical pipes, an example of which is shown in plate 17, fig. 2. Equally important is the silicification that followed the previously established permeability interfaces. Text-fig. 4 shows that the major silification (up to 10% by weight) lies directly above the main dolomite-limestone junction, whilst slightly enhanced silicification occurs within the dolomitized limestones above and below wayboards 2 and 3. If within the dolomites the silica and lime contents are compared, a strongly antipathetic relationship is found confirming the petrographic evidence that only calcite is replaced by the quartz and that dolomite is unaffected. Hence the slight increase in silicification next to the wayboards may be related more to the increase in calcite content of the adjacent carbonates than to the thickness and ponding ability of the clay horizons themselves.

Total silicification is rare and associated with the mineralization forming two rock-types, cherts and 'silica-rock'. The cherts are found parallel to the bedding within the upper dolomites as discontinuous black bands. In thin section the rock comprises a quartz mosaic with embayed and isolated fluorite, barite and calcite, suggesting that the main silicification is later than some of the mineralization. By contrast the silica-rock, which is randomly distributed in the limestones, but more extensively developed away from the flat, towards Bonsall Village



Text-fig. 4. Stratigraphical variations of magnesia, lime, and silica within the Matlock Lower Limestone at Masson Opencast Quarry.

(Bemrose 1898, Smith *et al.*, 1967, pp. 39 and 265), is light coloured and has an open-box structure of quartz stringers upon which euhedral fluorite and quartz have grown. The rock appears to be the result of the complete dissolution of the calcite from a fractured and partially silicified limestone, followed by open space mineralization.

The thickness of the Matlock Upper Lava (21 m) and Lower Lava (78 m), together with their poorly developed jointing and high clay content, has made the basalts highly impermeable. Therefore they have exerted a constant control upon any fluids passing through the sequence. The presence of large solution cavities and extensive mineralization found in the basal Lower Limestone shows that early groundwaters and subsequently the mineralizing fluids were floored by the underlying basalt. A small pond within the base of the open pit (which is excavated down to the Lower Lava) suggests that the basalt is still an effective impermeable horizon. The basalts are themselves largely unmineralized.

The wayboards vary in thickness from 0.80 m to less than 0.05 m and are composed of clays. The presence of premineralization solution cavities above and below the wayboards (examples are shown in plate 17, fig. 2) and the inhibition of the dolomitization indicate that the clay horizons influenced the movement of the fluids within the limestones. However, within the dolomites the degree of silicification and of later mineralization within the carbonates adjacent to the wayboards is only slightly greater than the average for the rock. This suggests that the wayboards were insufficiently thick (all are less than 0.30 m) to form an effective barrier to the vertical movements of the later fluids through the now established jointing. Only within the basal, undolomitized and hence poorly jointed limestones, did the wayboards influence the movement of the mineralizing fluids producing the 6 m thick metasomatic replacement flat beneath the 0.80 m thick Little Toadstone.

Sequence of Events

The following were probably the major events leading to the production of the Masson Hill flat:

1. The deposition within shallow waters of mainly coarse-grained limestones and intermittent volcanic ash bands, between the extrusion of two basaltic lava flows. A variety of early diagenetic changes within the limestones (namely the aragonite to calcite transition, pressure solution and compaction) would result in volume changes. The establishment of the limestone-lava and limestone-ash band horizons is important in controlling horizontal fluid movement.
2. Groundwaters produced solution cavities by dissolution of adjacent limestones above and below the limestone-volcanic junctions.
3. Dolomitization of the coarse-grained limestones by magnesian fluids again following the established bedding and lithological horizons. The intensity of dolomitization was controlled by grain size and chemistry of the limestones and inhibited by proximity to the volcanics. The volume change resulting from the dolomitization increased the permeability of the dolomites and led to the establishment of the major dolomite - coarse-grained limestone junction (at the same stratigraphic level as the Little Toadstone) plus many minor dolomite - fine-grained limestone horizons as important pathways.
4. The Matlock Anticline and Masson Hill Fault zone were formed by the Variscan earth-movements, establishing an approximately north-eastward dip on the limestone/lava sequence. The establishment of good vertical pathways within the well-jointed dolomites and the loss of the dolomite-clay wayboard junctions as effective horizontal pathways/barriers.
5. Silica-rich fluids, following all the vertical and horizontal pathways, locally silicified limestones and dolomites.

6. Hot dense acidic mineralizing fluids moved up the Masson Anticline until they encountered the clay filled Masson Hill fault. The fluids followed the established pathways. Metasomatic mineralization occurred when calcite encountered large volumes of moving mineralizing fluids (i.e. at the limestone-dolomite junctions) or where the fluids were physically ponded (as in the case of the basal limestones beneath the Little Toadstone). Void emplacement also took place and was related to the volume of fluids passing through, as witnessed by the completely filled solution cavities in the dolomites but their only partially filled equivalents in the limestones.

Acknowledgements

This paper is based on the major part of a Ph.D. thesis submitted to the University of Manchester. Thanks are due to Dr. A. C. Dunham who suggested the topic and supervised the work. Financial assistance and help were obtained from La Porte Chemicals Ltd. and are gratefully acknowledged, as is help from their Divisional Geologist, Dr. J.E. Mason. Dr. P. Turner too is thanked for critically reading the manuscript.

References

ARNOLD-BEMROSE, H.H. 1898. On a quartz-rock in the Carboniferous Limestone of Derbyshire. *Q. Jl. geol. Soc. Lond.*, vol. 54, pp. 169-183.

BHATT, J.J. 1976. Geochemistry and petrology of the Main Limestone Series (Lower Carboniferous), South Wales, U.K. *Sed. Geol.*, vol. 15, pp. 55-86.

DUNHAM, K.C. 1952. Fluorspar 4th Edit. *Mem. Geol. Surv., Min. Resources*, 4.

FIRMAN, R.J. and BAGSHAW, C. 1974. A re-appraisal of the controls on non-metallic gangue mineral distribution in Derbyshire. *Mercian Geol.*, vol. 5, pp. 145-161.

FORD, T.D. 1967. *Some mineral deposits in the Carboniferous Limestone of Derbyshire.* pp. 53-75 (in Neves and Downie, 1967, see below).

FORD, T.D. 1969. The stratiform ore-deposits of Derbyshire. In "Sedimentary ores: Ancient and Modern" (Revised). *Proc. 15th Inter-University Geological Congress.* Leicester, 1967.

FORD, T.D. and INESON, P.R. 1971. The fluorspar mining potential of the Derbyshire oilfield. *Trans. Inst. Mining. Metall.*, vol. B80, pp. 186-210.

IXER, R.A. 1972. *Controls of Mineralization in Derbyshire.* Ph.D. thesis, University of Manchester.

IXER, R.A. 1974. The mineralogy and paragenesis of a fluorspar flat at Masson Hill, Matlock, Derbyshire. *Miner. Mag.*, vol. 39, pp. 811-815.

IXER, R.A. 1975. A revision of part of the Matlock Group at Masson Hill, Matlock, Derbyshire. *Mercian Geol.*, vol. 5, pp. 181-188.

NEVES, R, and DOWNIE, C. 1967. *Geological Excursions in the Sheffield Region and Peak District National Park.* 163 pp. Sheffield.

SMITH, E.G., RHYS, G.H., and EDEN, R.A. 1967. Geology of the country around Chesterfield, Matlock and Mansfield. *Mem. Geol. Surv. G.B.*, 430 pp.

WEAVER, D.J. 1974. Systematic jointing in South Derbyshire. *Mercian Geol.*, vol.5, pp. 115-132.

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Fig. 1. View of Masson Opencast Quarry looking south-eastwards. The clay filled Masson Hill fault (F) can be seen cutting the Matlock Lower Limestones, with the dolomites on either side having slightly different dips.

Fig. 2. View of Masson Opencast Quarry looking north-east. Three clay wayboards (black lines) are present (2, 3 and 4) with their associated solution cavities (below wayboards 2 and 3). An isolated porcellenous limestone raft can be seen (just above wayboard 4). A prominent silicified limestone-dolomite rib can be seen on the left of the photograph (labelled Si).

A REVIEW OF THE MINERALOGY OF THE TURKISH BORATE DEPOSITS

by

Cahit Helvaci

Summary

The known borate deposits of Turkey were deposited in lacustrine sediments of Tertiary age during periods of volcanic activity which commenced in the early Tertiary period and continued at least to the beginning of the Quaternary. All Turkish borate deposits appear to be associated with volcanic activity and they have been classified as deposits related to volcanic activity.

Although colemanite, a very common calcium borate, is the predominant mineral in all borate districts apart from Kirka, the detailed mineralogy of the Turkish borate deposits varies considerably. Other principal borate minerals are ulexite (sodium calcium borate) and borax (sodium borate). Borax occurs only at Kirka. Tertschite occurs in the Bigadiç deposits and pandermite is also restricted appearing only in the Bigadiç and Sultançayiri deposits.

Turkey has made recent rapid strides towards rivalling the U.S.A. as the world's leading producer of borates. Boron and borate minerals find extensive uses in today's modern industries.

Introduction

This paper adds further to the knowledge of borate minerals in Turkish deposits reported by a few previous workers, namely Murdock (1958), Wendel (1962), Özpeker (1969) and finally Brown and Jones (1971). Since then, Inan (1973) and Helvaci (1977) have carried out detailed research work on the Kirka and the Emet deposits respectively, which has resulted in new mineralogical discoveries and contributed considerably to the understanding of the borate minerals and deposits in Turkey.

Although boron is one of the rarer and more unevenly distributed elements in the Earth's crust, there are extraordinary concentrations of boron on an industrial scale in some localized areas. Borate minerals are formed in various environments and in very different conditions. The most important economic deposits are very closely related to the Tertiary volcanic activity in orogenic belts. They are situated close to converging plate margins; characterized by andesitic-rhyolitic magmas; arid or semi-arid climates; and non-marine evaporite environments. All Turkish, United States, South American and many other commercial borate deposits are non-marine evaporites associated with volcanic activity.

The known borate deposits of Turkey occur in Western Anatolia, south of the Marmana Sea, within an area roughly 300 km east-west by 150 km north-south. They are located mainly in the following districts:- M.K. Pasha, Bursa province; Susurluk and Bigadiç, Balikesir province; Emet, Kutahya province; and Kirka, Eskisehir province (text-fig.1). Today, however, borate mining in Turkey is confined to the Emet, Kirka and Bigadiç districts.

The known borate deposits of Turkey were formed in the lacustrine sediments of Tertiary age during periods of volcanic activity which commenced in the early Tertiary period and continued at least to the beginning of the Quaternary. Although the lithology of the borate deposits shows some differences from one deposit to another, they are, generally, interbedded

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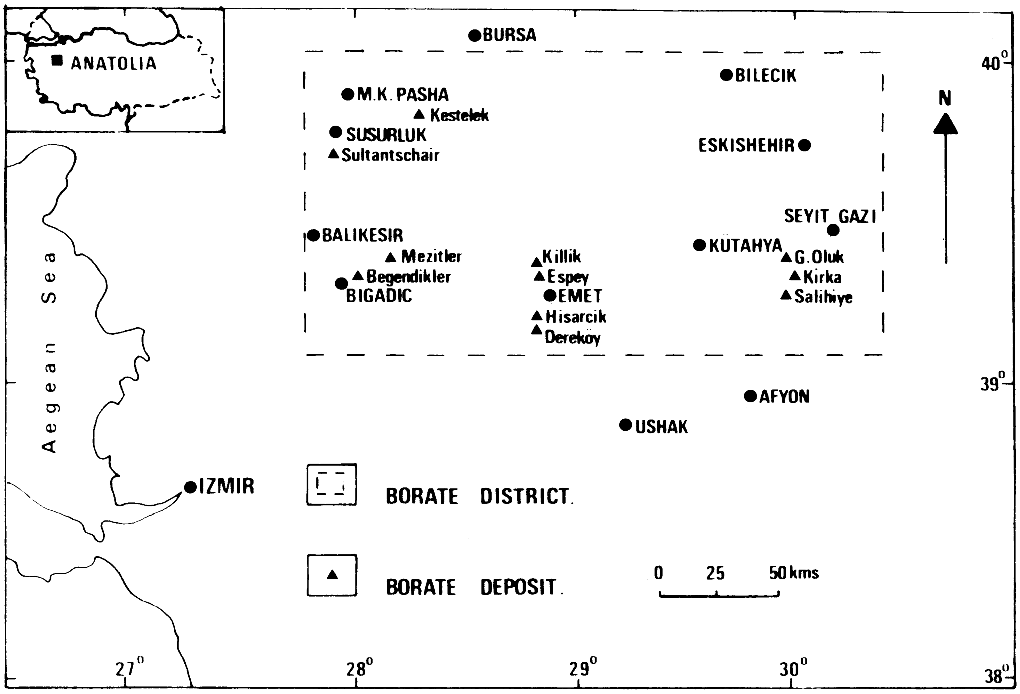
pp.257-270, 1 text-fig. Plates 18,
19, 20.



Text-fig.1. Borate districts in Anatolia W. Turkey (reproduced with permission of the Institution of Mining and Metallurgy)

with conglomerate, sandstone, tuff, clay, marl and limestone. Sediments in the borate lakes often show clear evidence of cyclicity. Borate minerals were deposited in separate or possibly interconnected lake basins under arid or semi-arid climatic conditions.

Pyroclastic and volcanic rocks of rhyolitic, dacitic, trachytic, andesitic and basaltic composition are intercalated with these lacustrine sediments. The existence of volcanic rocks in every borate district suggests that volcanic activity may have been necessary for the formation of borates. Much of the sediment in the borate basins seems to have been derived from volcanic terrain.

In general, the dip of the Tertiary sediments, interbedded with borates, vary from nearly horizontal to over 30°, but they are intensively dislocated by NE-SW and NW-SE-trending gravity faults. This structure is strikingly reflected in a stepwise topography. The predominant faults are normal, with dips that range from 30° to vertical. Thermal springs, which at present deposits travertine; are widespread in some of the deposits. The total Tertiary sedimentary thickness varies from one deposit to another, probably because of deposition in a chain of interconnected lakes, and exceeds maximum 750 m in the Emet deposits. The extreme thickness of the borate zones at Emet and Kirka indicates that there have been somewhat different conditions existing at the time of the formation of these deposits. The depositional basins of borate deposits, according to present knowledge, are all elongated, the long axis usually being north-south.

The borate deposits differ in detail from each other but have the following features in common:-

(a) They are restricted to Tertiary lacustrine sediments deposited in a non-marine environment under arid or semi-arid climatic conditions.

(b) They were apparently deposited in sedimentary intermontane basins of limited extent in regions where fresh-water limestone deposition was widespread both before and after borate formation.

(a) In addition to borates these basins were the repositories for clastic sediments, i.e. conglomerate, sandstone, clay, marl and tuff, much of which are of volcanic origin.

(b) Although the lithology of the borate deposits shows some differences from one to another, sediments in the borate lakes often show clear evidence of cyclicity.

(c) All Turkish borate deposits appear to be associated with volcanic activity and they were classified by Aristarain and Hulbut, 1972 as deposits related to volcanic activity.

(f) Borate occurrences are associated with volcanic rocks; both intrusive and extrusive volcanic rocks are common in the neighbourhood of the borate basins.

(g) More typical evaporite minerals, such as halite and trona, are not found in Turkish borate deposits.

(h) The palaeogeographic scenario seems to have consisted of shallow lakes fed partly by hot springs and partly by streams which carried sediments from the surrounding volcanic, limestone and basement terrain. The rocks which may have been exposed in the catchment areas appear to be in restricted and closed basins.

Minerology

The unique character of the borate deposits in Turkey indicates that the conditions of formations of these deposits are different from those that lead to the formation of the more typical non-marine evaporite deposits. Although colemanite, a very common calcium borate, is the predominent mineral in all borate districts apart from Kirka, the detailed mineralogy of the Turkish borate deposits varies considerably, but they may be roughly classified as follows:

1. Ca borate deposits (Emet, Bigadiç, Kestelek, Sultançayiri).
2. Na borate deposit (Kirka).

Borate minerals hitherto recorded from Turkish deposits are mainly Ca; Ca-Mg; Na and Mg borates. A rare Sr borate has been found at Kirka (Baysal, 1972) and Ca-As and Sr borates have been reported from the Emet district (Helvaci and Firman, 1976 and Helvaci, 1977). Table 1 gives the complete list of borate minerals from the Turkish deposits and shows that each deposit has its characteristic assemblage of minerals.

Generally, borate minerals are associated with calcite, dolomite, gypsum, celestite, realgar, orpiment and sulphur. The mineralogy of the Emet borate deposits is unique among the other Turkish borate deposits, because of unusual occurrences of Ca-As and Sr borates and the high content of sulphur, realgar, orpiment and celestite.

Borate and non-borate minerals, according to their chemical composition and their mineralogical relationships with each other in the Turkish deposits, may be divided into ten groups namely the calcium borates, the sodium-calcium borates, the sodium borates, the magnesium-calcium borates, the magnesium borates, the strontium borates, the silicon-calcium borates, the complex borates, the compound borates and the non-borates.

Borate minerals within each group have nearly the same chemical composition, differing from one to another principally the amount of water of hydration in the structure.

Mineral descriptions

Calcium borates

Inyoite ($2CaO.3B_2O_3.13H_2O$)

Inyoite occurs locally at some of the mines in the Kirka and Bigadiç deposits. It is found as intergrown crystal masses, discrete tabular crystals and crystal groups, colourless to white (Plate 18, fig.1). A few of the crystals are 2.5 cm or larger, but most are microscopic in scale and have been altered. Some of the inyoite in the deposits had altered to meyerhofferite and/or colemanite. Sometimes it occurs as clear, coarse-grained, euhedral aggregates. It is clearly associated with meyerhofferite, colemanite and ulexite.

Table 1 Borate minerals found in the Turkish borate deposits

Mineral Name	Oxide Formula	B_2O_3 Content wt%	Deposit	References
Inyoite	$2CaO.3B_2O_3.13H_2O$	37.62	Kirka, Bigadiç	Meixner (1953b)
Meyerhofferite	$2CaO.3B_2O_3.7H_2O$	46.72	Emet, Kirka, Bigadiç	Meixner (1953b); Helvaci *et al.*, (1976)
Colemanite	$2CaO.2B_2O_3.5H_2O$	50.81	Emet, Kirka, Bigadiç Kestelek	Meixner (1952)
Tertschite	$4CaO.5B_2O_3.20H_2O$	37.32	Bigadiç	Meixner (1952)
Pandermite (= priceite)	$4CaO.5B_2O_3.7H_2O$	54.59(49.84)	Bigadiç, Sultançayiri	Schlüter (1928)
Ulexite	$Na_2O.2CaO.5B_2O_3.16H_2O$	42.95	Emet, Kirka, Bigadiç	Meixner (1953b); Helvaci *et al.* (1976)
Borax	$Na_2O.2B_2O_3.10H_2O$	36.51	Kirka	Inan (1972); Baysal (1972)
Tincalconite	$Na_2O.2B_2O_3.5H_2O$	47.80	Kirka	Helvaci (1977)
Kernite	$Na_2O.2B_2O_3.4H_2O$	51.02	Kirka	Helvaci (1977)
Hydroboracite	$CaO.MgO.3B_2O_3.6H_2O$	50.53	Emet, Kirka, Bigadiç	Özpeker (1969); Helvaci (1974)
Inderborite	$CaO.MgO.3B_2O_3.11H_2O$	41.49	Kirka	Baysal (1973)
Inderite	$2MgO.3B_2O_3.15H_2O$	37.32	Kirka	Inan (1972); Baysal (1973)
Kurnakovite	$2MgO.3B_2O_3.15H_2O$	39.89	Kirka	Inan (1973); Baysal (1973)
Tunellite	$SrO.3B_2O_3.4H_2O$	54.32	Emet, Kirka	Baysal (1972); Helvaci *et al.*, (1976)
Veatchite (*senso lato*)	$4SrO.11B_2O_3.7H_2O$	58.16	Emet	Helvaci (1974); Helvaci *et al.*, (1976)
Howlite	$4CaO.5B_2O_3.2SiO_2.5H_2O$	44.49	Bigadiç	Özpeker (1969)
Terruggite	$4CaO.MgO.6B_2O_3.As_2O_5$ $20H_2O$	32.76	Emet	Negro *et al.*, (1973) Helvaci *et al.*, (1976)
Cahnite	$4CaO.B_2O_3.As_2O_5.4H_2O$	11.69	Emet	Helvaci *et al.*, (1976)

Meyerhofferite ($2CaO.3B_2O_3.7H_2O$)

Meyerhofferite is found as small grey-bluish coloured nodules up to 8 cm in diameter associated with colemanite and inyoite and sometimes with ulexite. It occurs as nodules of coarsely crystalline radiating crystals intergrown with clay at the margins. Small vughs in the centre of the nodule contain delicate acicular crystals (Plate 18, fig. 2), which are also meyerhofferite. It either forms by direct precipitation from calcium borate solutions or by the dehydration of inyoite, in the Turkish deposits.

Colemanite ($2CaO.2B_2O_3.5H_2O$)

Colemanite is by far the commonest mineral deposits and for this reason some occurrences are usually referred to commercially as colemanite deposits. It occurs in many different forms ranging from minute stellate clusters of crystals in clay to ovoid nodules up to 50 cm in diameter and as continuous layers. The individual crystals which make up the nodules are colourless, grey, pink and dark blue. Among the commoner habits are nodular forms with radiating structures (Plate 18, fig. 3); massive granular colemanite (fig. 6); disseminiated crystals, often stellate, in a clay matrix (fig. 5); fibrous layers surrounding nodules (fig. 6); thin layers interbedded with clay, sometimes brecciated; and vugh fillings (fig. 7); bladed euhedral crystals (fig. 4).

Nodules are by far the commonest form of colemanite, but these nodules exhibit a large variety of shapes and sizes. There is a tendency for the smaller nodules to be spherical and the larger ones to be ovoid. Some, irrespective of size, contain vughs; which sometimes contain a liquid; others have a core of granular colemanite which is coarsely crystalline and second-generation in origin. Closer inspection reveals that these nodules grew in successive stages, each layer being separated by a thin discontinuous veneer of clay. Later generations of colemanite crystals radiate from separate centres of nucleation on the original nodule.

Often it is difficult to identify all stages of nodule growth, but judging from the presence of included clay, it is clear that these nodules formed within the clays and tuffs below the sediment/water interface and probably continued to grow as the sediments were compacted in the Emet deposits (Helvaci and Firman, 1976 and Helvaci, 1977). Colemanite also results from the breakdown of ulexite or the dehydration of inyoite in the Kirka, Bigadiç and Kestelek deposits (Inan *et al.*, 1973; and Özpeker, 1969).

Tertschite ($4CaO.5B_2O_3.20H_2O$)

Terschite is found only in one locality in the Bigadiç deposits (Meixner, 1952). It is white, contains very fine fibres, shines like silk and has a similar appearance to ulexite. Sometimes it shows an earthly structure and its rare occurrence makes this mineral unique among the other borate minerals.

Pandermite (= priceite) ($4CaO.5B_2O_3.7H_2O$)

Pandermite occurs at the Sultançayiri and Bigadiç deposits. It was named after the place where it was found; then it was discovered that pandermite was identical to priceite described from Oregon, U.S.. The identity of pandermite with priceite has been established by chemical and optical studies. Pandermite is found as nodules and masses up to a ton in weight underlying beds of gypsum and clay. It appears white in colour, compact and sometimes resembles limestone.

It alters to colemanite and calcite and is associated with colemanite, gypsum and calcite.

Sodium-calcium borates

Ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$)

Ulexite is the only mineral of the Na-Ca borate series found in the deposits. It occurs at three levels and always as massive and cauliflower-like nodules in the Emet deposits (Plate 18, fig. 8); fibrous, cone, rosette, 'cotton ball' and columnar textures are observed in the Kirka deposit (Plate 19, fig.1). Sometimes, very thin fibrous ulexite crystals growing on top of the massive and cauliflower-like ulexite nodules have been observed and cauliflower-like nodules composed of randomly orientated crystals, 1 - 5 cm long, form independent layers up to a few metres in thickness.

Ulexite is commonly associated with colemanite and hydroboracite in the Emet deposits, but no alteration to colemanite or from any other mineral has been observed. It is usually very soft. The purest forms of ulexite are white, but many are grey due to the nodule growing in the clay. Thus, like colemanite and meyerhofferite, ulexite nodules appear to have developed within and not on the sediments (Helvaci, *et al.*, 1976; Helvaci, 1977).

Ulexite is commonly associated with borax, colemanite and inyoite in borate layers, and with kurnakovite and tunellite in clay layers in the Kirka deposit. Cone and rosette-shaped aggregates of ulexite are found as pseudomorphs after borax on the borax layers at borax-clay interfaces in the Kirka deposit (Inan *et al.*, 1973). Ulexite showing fibre-optical properties has not been recorded from the Turkish deposits, because ulexite commonly appear to be impure due to the clay contents.

Sodium borates

Borax ($Na_2O. 2B_2O_3. 10H_2O$)

Borax is by far the most abundant borate mineral found in the Kirka deposit (Inan, 1972 and Inan *et al.*, 1973), and for this reason it is usually called a borax deposit. It is restricted to the Kirka deposit. The highest concentrations of borax are in the central part of the deposit. Fresh, pure borax is colourless and transparent (Plate 19, fig.2), but in places, where it is fine-grained and interbedded with clay, it is light pink, yellowish-orange or grey due to fine inclusions of foreign material. Borax occurs mainly as subhedral and anhedral crystals usually 1 mm - 10 mm in size. Large masses of subhedral borax crystals are often found in the cavities created after burial. Sometimes it is also observed as disseminated individual crystals in the clay matrix and as borax-clay breccia. Some very large crystals, up to 10 m in length and 2 m broad, cutting across the bedding, have been observed (Inan *et al.*, 1973).

Borax occurs chiefly (Plate 19, fig.3) in almost monomineralic zones interbedded with clay and associated with tincalconite and fibrous or "cotton ball" ulexite. In many places tincalconite forms a thin film on the exposed part of borax crystals and borax shows a transformation into ulexite at borax-clay interfaces.

Tincalconite ($Na_2O. 2B_2O_3. 5H_2O$)

Tincalconite is also restricted to the Kirka deposit and does not form independent crystals in this deposit but occurs only as an alteration product of borax (Plate 19, fig.4) and kernite (Plate 19, fig.5). The fine microscopic crystals of tincalconite develop very rapidly on borax or kernite crystals in contact with atmosphere, in a matter of days depending on the humidity and temperature (Inan *et al.*, 1973).

Kernite ($Na_2O. 2B_2O_3. 4H_2O$)

Kernite has a restricted distribution and is found only at one locality in the underground workings of the Kirka deposit. New kernite crystals may be found when the underground workings advance. It is developed in the deeper part of the sodium borate body at Kirka. (Helvaci, 1977).

It occurs as colourless, transparent but sometimes white elongated needle-shaped, or group of needle-shaped, crystals which are surrounded by a zone or borax. Individual crystals vary in their length, which is up to 10 cm. Kernite alters by dehydration to white tincalconite which occurs as fine-grained coatings on kernite crystals that have been exposed to the atmosphere (Plate 19, fig.5).

Magnesium-calcite borates

Hydroboracite ($CaO.MgO.3B_2O_3.6H_2O$)

Hydroboracite is found throughout all the major deposits and occurs sporadically at different horizons and in clay layers. It forms small clusters (nodules) in which radiating needle-shaped crystals, 0.5-5 cm, are randomly orientated (Plate 19, fig. 6). Radiating needle-shaped crystals of hydroboracite intersect with each other and groups of them show a conical appearance (Plate 19, fig. 7).

Sometimes, it forms thin layers within the interbedded clay. In the thin section, the needle-shaped crystals of hydroboracite have a fibrous texture. This mineral is usually white, but sometimes it appears yellowish in colour due to the presence of realgar and orpiment in the Emet deposits (Helvaci, 1977). It is associated with colemanite and ulexite and sometimes with tunellite.

Inderborite ($CaO.MgO.3B_2O_3.11H_2O$).

Inderborite occurs very rarely and is restricted to the Kirka deposits. It is found intergrown with kurnakovite and ulexite, especially with the former in the deposit (Baysal, 1973). It occurs in the form of thick prismatic crystals which can reach a few centimeters in length. The inderborite crystals are often in white colour, semitransparent and they show glassy or weak pearly luster on the cleavage faces. Colourless and transparent crystals are also found. It is clearly associated with kirnakovite, ulexite and calcite.

Magnestium borates

Inderite ($2MgO.3B_2O_3.15H_2O$)

Inderite is described from the Kirka deposit and has a restricted distribution (Baysal, 1973). It has been found with kurnakovite only in the upper part of the borate zone in the deposit. Inderite commonly occurs either as thin rods and needles or as radial and spherulitic aggregates which are usually associated with clay and kurnakovite crystals. The inderite crystals are 1-2 cm long and 1-2 mm wide. The crystals are colourless, transparent and have a glassy luster which is vitreous to pearly on cleavage planes, dull and greasy on irregular surfaces. Sometimes inderite appears grey in colour, because it often contains small amounts of clay. It is commonly found in close association with kurnakovite.

Kurnakovite ($2MgO.3B_2O_3.15H_2O$)

Kurnakovite is found in the upper part of the Kirka deposit and forms a non-continuous layer in the clay just above the main borate body. The kurnakovite layer consists largely of 1-20 cm long individual, colourless grey or sometimes pink, elongated, euhedral crystals (Plate 19, fig. 8) and crystal aggregates. Its distribution is similar to that of inderite but it is much more common. It coexists frequently with ulexite, inderite and tunellite and less frequently with borax. (Inan *et al.*, 1973).

Strontium borates

Tunellite ($SrO.3B_2O_3.4H_2O$)

Tunellite has a restricted distribution and has been found only in the lower part of the borate zone in the Emet deposits and in the clay layers in the Kirka deposit. It occurs in very small amounts.

Tunellite commonly occurs either as individual flattened crystals (Plate 20, fig. 1), 1-5 cm in length, or as thin tabular-shaped crystals which have nucleated on (but not replaced) ulexite. Pure flattened tunellite crystals are colourless, transparent and have perfectly developed cleavages parallel to flattened surfaces, which resemble muscovite flakes (Plate 20, fig. 1). Alternatively tunellite occurs as small white nodules with radiating structures, which have apparently grown in the interbedded clays (Plate 20, fig. 2). In the Emet deposits, it is associated with ulexite and colemanite whereas in the Kirka deposit, it coexists with hydroboracite and ulexite. This mineral was described from the Kirka deposit by Baysal (1972) and from the Emet deposits by Helvaci *et al.*, (1976), but has not been identified in any other Turkish borate deposits.

Veatchite (*sensu lato*) ($4SrO.11B_2O_3.7H_2O$)

Veatchite is very rare, occurring sporadically at one horizon in the northern basin of the Emet deposits. It appears as a very pure white mineral often with clay inclusions, with small (up to 2 cm in diameter) and large (up to 6 cm in diameter) nodules made up of little needle-shaped crystals. Sometimes very small nodules are associated together and show mammilary appearance (Plate 20, fig. 3).

Veachite (*sensu lato*) occurs as felted masses of very small crystals which are sufficiently curved to preclude a positive distinction between veatchite and p-veatchite (Braitsch, 1959) by single crystals X-ray examination. Due to the absence of suitable crystals, the single crystal study has failed to distinguish between veatchite and p-veatchite (Helvaci, 1977).

This mineral is usually associated with colemanite. Field and textural evidence shows that this mineral replaces colemanite and is not associated with the other Sr borate, tunellite. It was first recorded from the Turkish borate deposits by Helvaci (1974). (Helvaci and Firman (1976)).

Silicon-calcium borates

Howlite ($4CaO.5B_2O_3.2SiO_2.5H_2O$)

Howlite has a very restricted distribution and has been found only in the Domaz mine of the Bigadiç deposits (Özpeker, 1969). It occurs as compact nodular masses, internally dense and structureless and resembles unglazed porcelain; sometimes chalk-like, earthy, scaly, or with a slaty structure. It is white in colour and translucent in thin splinters, and is associated with colemanite.

Complex borates

Teruggite ($4CaO.MgO.6B_2O_3.As_2O_5.20H_2O$)

Teruggite is rare, occurring sporadically at one horizon in the southern basin of the Emet deposits, as very pure white, powdery potato-shaped nodules containing countless minute white euhedral crystals. The nodules of teruggite range from 2 to 10 cm in diameter (Plate 20, fig. 4).

Occasionally these powdery potato-shaped teruggite nodules contain very small spherulites of cahnite (Plate 20, fig. 5). This is the first record of this type of teruggite and cahnite occurrence from borate deposits. The crystal structure of teruggite from the Emet deposits was described by Negro, Kumbasar and Ungaretti (1973).

The sporadic occurrence of teruggite and cahnite, compared with the almost universal distribution of arsenic sulphides in the Emet deposits, suggests that borates developed in areas in which the brines were difficient in sulphides (probably H_2S) which would have otherwise precipitated the arsenic as realgar instead of arsenic bearing borates. Teruggite is associated with cahnite and colemanite.

In the thin section, the crystals of teruggite are colourless, prismatic-shaped and are greatly elongated along the C axis. These crystals usually appear very small and needle-shaped. Occasionally spherulites of cahnite occur in the teruggite masses and fibrous crystals of cahnite show a radial texture (Plate 19, fig. 6).

Compound borates

Cahnite ($4CaO.B_2O_3.AS_2O_5.4H_2O$)

Cahnite, a very rare borate mineral, was first recorded from Franklin, New Jersey by Palache, *et al.*, (1927), appearing in the cavities of axinite veinlets associated with pegmatites cutting the main ore-body. Later discoveries of this mineral are associated with scarn zones as reported from the Klodeborg mine, Arendal, Norway, by Bugge (1951) and from Eastern Siberia, U.S.S.R. by Malinko (1966), Cahnite was also recorded by Embrey (1960), from a cavity in dark grey leucitic lava at Capo di Bove, Rome, Italy, where it is found on calcite associated with phillipsite and chabazite.

Cahnite was first recorded from the Emet borate deposits by Helvaci and Firman (1976). It had not hitherto been identified from borate deposits. In the Emet borate deposits, cahnite occurs as very small spherulites in powdery potato-shaped teruggite nodules in the southern area (Plate 20, fig. 6), and as a coating on euhedral colemanite crystals in vughs in colemanite nodules in the northern area (Plate 20, fig. 7). Cahnite is rare; occurring sporadically only at one horizon. It is associated with colemanite and calcite in the northern basin, whereas it is associated with teruggite and colemanite in the southern basin.

The spherulites of cahnite are generally very small, rarely exceeding 2 mm in diameter and occurring usually singly, but occasionally two or three coalesce together (Plate 20, fig. 8). Cahnite is white and light brown in colour with a notably glassy lustre. In the thin section, the cahnite spherulites contain needle-shaped and fibrous crystals which often show a radial texture (Plate 20, fig. 6).

Non-borates:

A number of non-borate minerals associated with borates occur in the borate zone of the deposits. Generally borate minerals are associated with calcite, dolomite, gypsum, celestite, realgar and orpiment. The last two minerals along with celestite, native sulphur and gypsum do not occur in the Kirka deposit whereas these minerals are abundant throughout the Emet deposits. Dolomite does not occur in the Emet deposits. Calcite, quartz and chert are common in all the deposits. Gypsum and calcite are the common non-borate minerals occuring in the other Turkish borate deposits.

The occurrence of the clay minerals (such as montmorillonite and illite) in all deposits, and sulphide and sulphate minerals in the Emet deposits is ubiquitous.

The economic importance of borate minerals:

Turkey is currently the second largest producer of borate minerals and has the world's largest reserves. The level of output is rapidly rising towards that of the USA. and has been continuously expanded to meet increasing demands of world consumers. Already Turkey is the major world producer of colemanite much of which comes from the Emet Valley and further increases, particularly of borax from Kirka, are likely to lead to Turkey dominating the world markets. Proved and probable reserves of all boron minerals are vast in relation to output and are measured in hundreds of years supply, even by the most conservative estimates.

The possible large use of boron and borates minerals in different types of industrial products will rapidly increase the demand of borates in crude and manufactured forms such as boric acid and borax salts. Production of crude borates in Turkey will relatively expand enlarging demand and supply relationships in the whole world. Production and consumption of crude and refined boron products has grown impressively in recent years and because of borates' diversity of use, even stronger growth is anticipated in the 1970's. The growth of consumption, reflecting the fact that the largest markets are in household and industrial cleaners and the glass and ceramic industries, is closely related to the growth of population and the use of durables, and can fluctuate.

Boron products are used in a surprisingly wide variety of industries; literally hundreds of products, from fibre-glass and pharmaceuticals to fertilizers and photographic chemicals contain the same basic ingredient - borax. The requirements of the glass, enamel and other traditional user industries has tended to rise steadily with increased population, with a rising standard of living and with industrial development in general, but the recent quite rapid expansion of the boron products industry owes much to the growth shown by sodium perborate, glass fibre and nylon.

Boron is a versatile and useful element used mainly in the form of its many compounds, of which borax and boric acid are most well known. Boron compounds are used extensively in the glass and ceramics industries, where their low melting points and excellent fluxing properties are utilized. Their properties are also advantageous in brazing, welding, soldering and refining.

Borax and boric acid are used in soaps, cleaners, and detergents because of their bactericidal properties, easy solubility in water, and excellent water-softening properties. Their mild alkalinity in water and germicidal properties make them useful in toothpaste, mouthwash, and eyewash preparations. Water solutions of borax are used in dyeing leather and textiles, in cleansing hides and skins, in plasters and paints, to prevent mildew and give high gloss to starches, and to prevent mold on leather, textiles, and citrus fruits. In agriculture, borax is added to fertilizers to supply boron as an essential plant nutrient. Boron compounds are also used to control weeds.

Boron compounds, being excellent fluxing materials, are especially useful in welding, soldering, brazing metals and in metal refining and are also added to alloy steels to increase hardness. Some elemental boron is used as a deoxidizer in nonferrous metallurgical reactions, as a grain refiner in aluminium, as a thermal neutron absorber in atomic reactors, in delayed action fuses, as an ignitor in radio tubes, and as a coating material in solar batteries.

Compounds of boron such as boron carbide, titanium boride, tungsten boride and boron nitride are among the hardest substances known. The cubic boron nitride known by the trade name Borazon is harder than diamond and has a greater thermal stability. Boron nitride is also useful as a thermal insulator and as a mould lubricant in glass manufacture. Boron carbide is used in the manufacture of abrasion-resistant parts of spray nozzles, bearing liners, and furnace parts; in the atomic energy field as nuclear reactor control elements and radiation shields; and as an abrasive for ultrasonic grinding and drilling. Boron trichloride is used as a catalyst, synthesis intermediate and extinguishing agent whereas boron trifuloride is used as a catalyst for many organic reactions.

Organic boron compounds such as borate esters are finding greater use as dehydrating agents, synthesis intermediates, special solvents, sources of boron for catalysts, plasticizers, and adhesion additives for latex paint, and fire retardants in plastics and protective coatings. Boron compounds such as diborane (B_2H_6), pentaborane (B_5H_8), decaborane ($B_{10}H_{14}$), and alkyl boranes are potential jet and rocket fuels.

New discoveries and the rapid increase in the living standard of huge sectors of society the world over will create greater demands for wonderful boron compounds. Interest in borate minerals and deposits will grow accordingly.

The above account on the use of borate minerals is based on Miller (1965) and Aristrain and Hurlbut (1972).

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References

ARISTARAIN, L. F. and HURLBUT, C.S. Jnr. 1972. Boron minerals and deposits. Part I - Uses, distribution and economic minerals of boron. Part II - Geological environments and classification of boron deposits. *Min. Record.* Vol.3, pp.165-220.

BAYSAL, O. 1972. Tunellite, a new hydrous strontium borate from the Salikaya borate deposits in Turkey. *Bull. Min. Res. Expl. Inst. Turkey.* No.79, pp.22-29, Ankara.

BAYSAL, O. 1973. New hydrous magnesium-borate minerals in Turkey: kurnakovite, inderite, inderborite. *Bull. Min. Res. Expl. Inst. Turkey.* No.80, pp.93-103, Ankara.

BRAITSCH, O. 1959. Über p-veatchit, eine neue veatchite-varietat aus den Zechsteinsalz. *Beitrage zue Mineralogie und Petrographie*, Vol.6, pp.352-356.

BROWN, W.W. and JONES, K.D. 1971. Borate deposits of Turkey in *Geology and History of Turkey.* The Petroleum Exploration Society of Libya, Tripoli. Campbell, A.S. (ed.)

BUGGE, Jens A.W. 1951. Minerals from the skarn iron ore deposits at Arendal, Norway. Cahnite from Klodeberg mine. *K. Norske Vidensk. Selskab. Forh.* Vol.24, pp.79-81.

EMBREY, P. G. 1960. Cahnite from Capo di Bove, Rome. *Min. Mag.*, Vol.32, pp.666-668.

HELVACI, C. 1974. Contribution to discussion of a paper by Inan, K., Dunham, A.C. and Esson, *Trans. Inst. Min. Metall.* (Section B.), Vol.83, pp.B.36.

HELVACI, C. 1977. *Geology, mineralogy and geochemistry of the borate deposits and associated rocks at the Emet Valley, Turkey.* Ph.D. Thesis, University of Nottingham.

HELVACI, C. and FIRMAN, R.J. 1976. Geological setting and mineralogy of Emet borate deposits, Turkey. *Trans. Inst. Mining Metall.* (Section B), Vol.85, pp. B.142-152.

INAN, K. 1972. New borate district, Eskisehir-Kirka province, Turkey, *Trans. Inst. Mining and Metall.*, Vol. 81, pp.B163-165.

INAN, K. 1973. *The mineralogy and geochemistry of the Kirka borate deposit, Turkey.* Ph.D. Thesis, University of Manchester.

INAN, K., DUNHAM, A.C. and ESSON, J. 1973. The mineralogy, geochemistry and Origin of the Kirka borate deposit, Eskisehir province, Turkey. *Trans. Inst. Min. Metall.* (Sect.B). Vol.82, pp.B.114-123.

MALINKO, S.V. 1966. First find of cahnite in the U.S.S.R. *Dokl. Acad. Sci. U.S.S.R.*, Earth Sci. Sect., Vol.166, pp.116-120. Transl. pp. 695-697.

MEIXNER, H. 1952. Einige Boratminerale (colemanit und Tertschit, ein neues Mineral) aus der Turkei. *Fortschr. Mineralogie*, Vol. 31, pp. 39-42.

MILLER, W. C. 1965. Boron in Mineral facts and problems. *Bureau of Mines, Bull.* Vol. 630, pp. 1-9.

MURDOCK, T. G. 1958. The boron industry in Turkey. *Mineral Trade Notes*, Special supplement, No. 53, Vol. 46, No. 5.

NEGRO, A. D., KUMBARSAR, I. and UNGARETTI, L. 1973. The crystal structure of teruggite. *Amer. Mineral.* 58, pp. 1034-1043.

OZPEKER, I. 1969. *Western Anatolian borate deposits and their genetic studies.* Ph.D. dissertation (Turkish text). Technical University of Istanbul.

PALACHE, C. and BAUER, L. H. 1972. Cahnite, a new boroarsenate of calcium from Franklin, New Jersey. *Amer. Mineral.* Vol. 12, pp. 149-153.

WENDEL, C. A. 1962. Boron in Turkey. *Mineral Trade Notes*, Vol. 54, No. 6.

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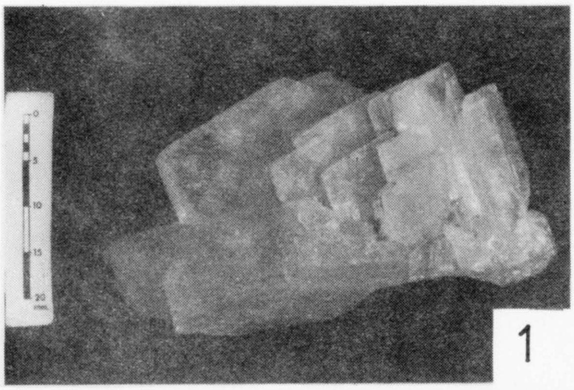
EXPLANATION FOR PLATES 18 and 19

Plate 18,	fig. 1.	Large inyoite aggregate showing tabular crystals.
"	fig. 2.	Meyerhofferite nodule showing coarsely crystalline radiating crystals and vugh in the centre, containing acicular crystals, Espey underground mine, Emet.
"	fig. 3.	Section of colemanite nodule showing radiating structure with clay injection inbetween colemanite crystals, vugh in the centre filled with euhedral colemanite crystals and clay covering the outer edge of the nodule. Killik underground mine, Emet.
"	fig. 4	Cluster of bladed euhedral colemanite crystals from Espey underground mine, Emet.
"	fig. 5.	Semi-developed stellate colemanite crystals in a clay matrix showing radiating groups of colemanite crystals, Killik underground mine, Emet.
"	fig. 6.	Massive colemanite surrounded by the layer of fibrous colemanite. Clay associated with colemanite is montmorillonite, Espey underground mine. Emet.
"	fig. 7.	Euhedral colemanite crystals filling vughs and cavities, Espey underground mine, Emet.
"	fig. 8.	Occurrence of massive cauliflower-like ulexite nodule with silky appearance at the Killik mine, Emet.
Plate 19,	fig. 1.	Occurrence of columnar ulexite at the Kirka deposit.
"	fig. 2.	Colourless and transparent borax body interbedded with clay, Sarikaya underground mine, Kirka.
"	fig. 3.	Borax (grey) interbedded with very thin clay bands (light), Sarikaya underground mine, Kirka.
"	fig. 4.	Borax crystals with tincalconite occurring as a thin film coat on surface, Sarikaya opencast mine, Kirka.
"	fig. 5.	Kernite crystals with tincalconite occurring as a thin fine-grained coat on upper surface, Kirka.
"	fig. 6.	A small cluster of hydroboracite showing radiating needle-shaped crystals which are randomly orientated, Sarikaya locality, Emet.
"	fig. 7.	Radiating crystals of hydroboracite intersecting with each other and groups of them showing a conical appearance, Killik locality, Emet.
"	fig. 8.	Well developed kurnakovite crystal from Kirka deposit.

EXPLANATION FOR PLATE 20

Plate 20, fig. 1.	Individual flattened tunellite crystals showing perfectly developed cleavages and resembling muscovite flakes, Espey mine, Emet.
" fig. 2.	Small white tunellite nodules with radiating structures growing in the interbedded clays, Killik mine, Emet.
" fig. 3.	Very small nodules of a veatchite mineral associated together showing mammillary appearance, Killik mine, Emet.
" fig. 4.	A very pure white and powdery potato-shaped teruggite nodule, with rare clay inclusions, Kapikaya locality, Emet.
" fig. 5.	A powdery potato-shaped teruggite nodule containing very small spherulites of cahnite. Note also countless minute white euhedral crystals of teruggite, Kapikaya locality, Emet.
" fig. 6.	A spherulite of cahnite occurring in the teruggite masses, Emet. Plane polarized light, X10.
" fig. 7.	Cahnite occurring as a coating on euhedral colemanite crystals, Espey locality, Emet.
" fig. 8.	Spherulites of cahnite which rarely exceed 2 mm in diameter, Kapikaya locality, Emet.

Plate 18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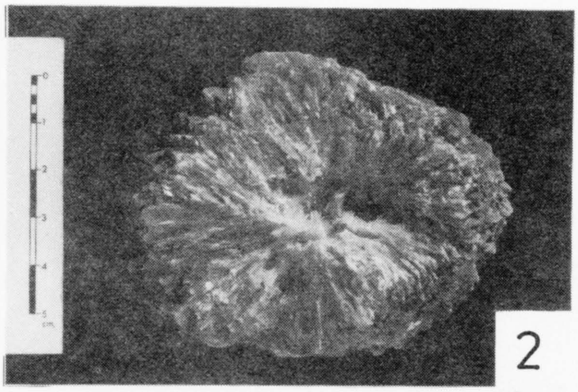
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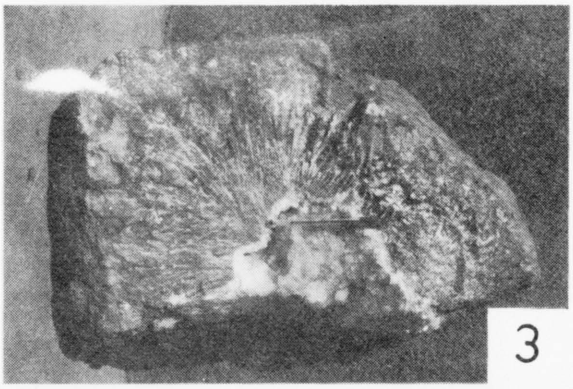
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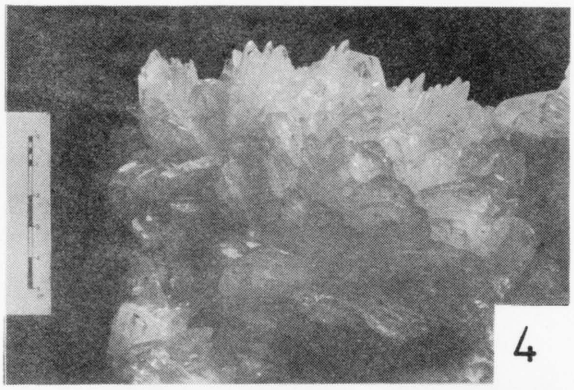
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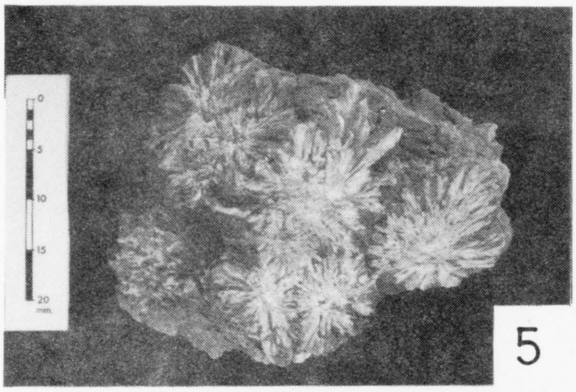
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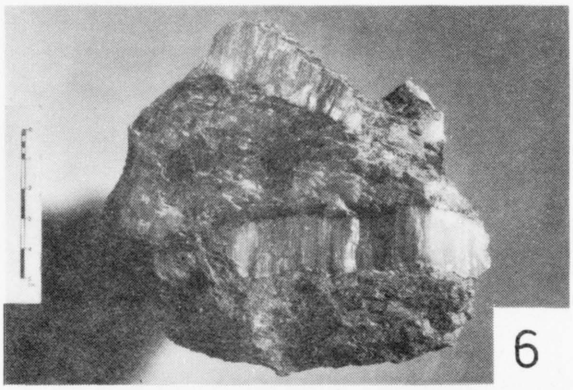
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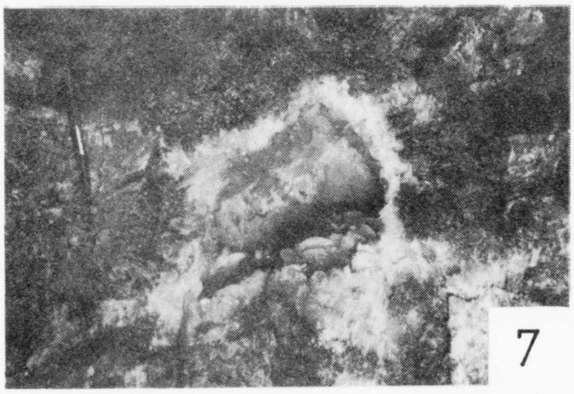
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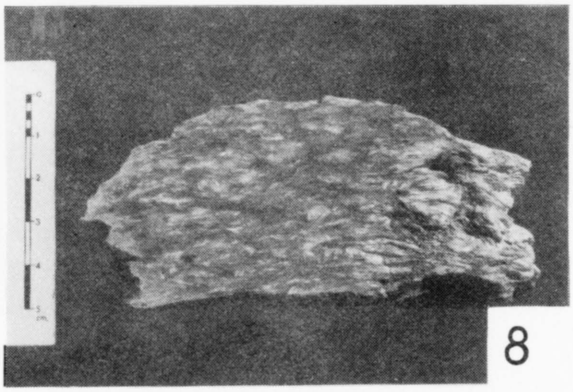
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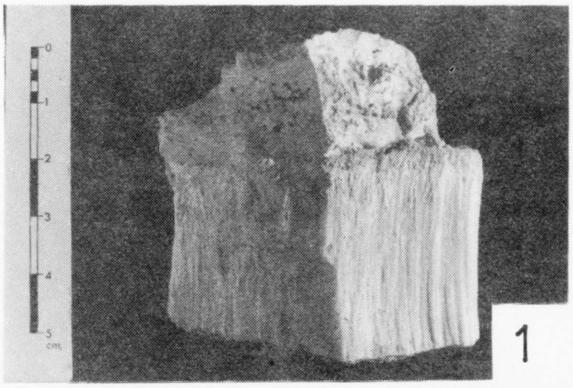
Helvaci - Turkish borates (explanation p. 269).

Plate 19



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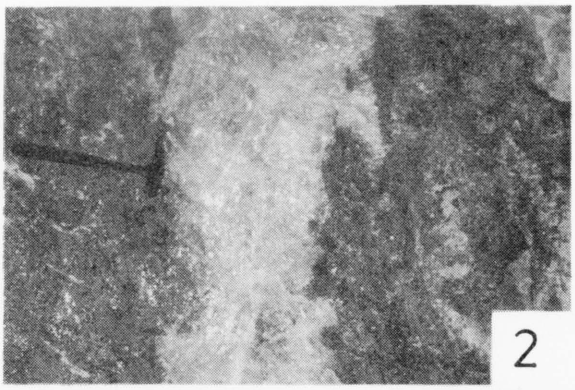

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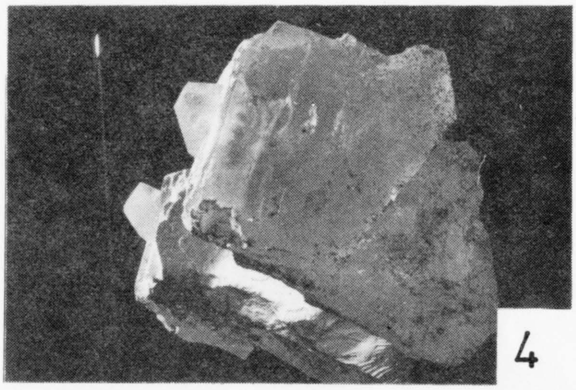

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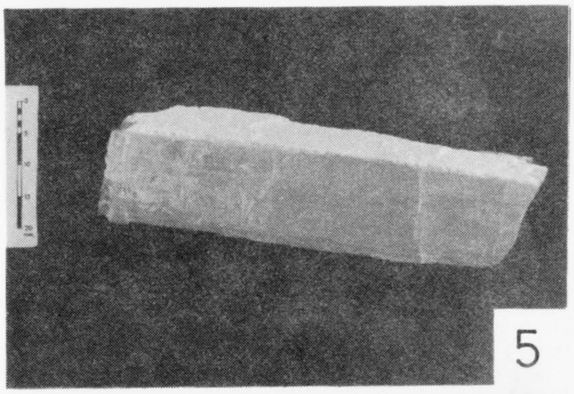

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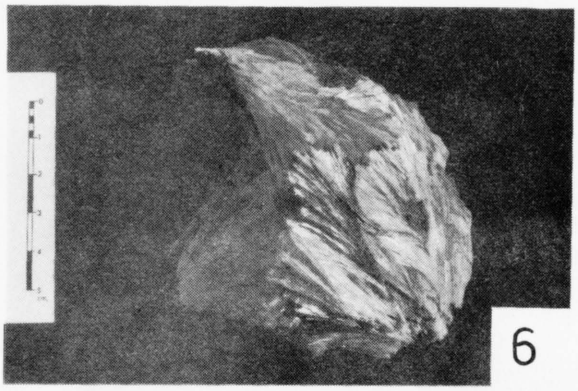

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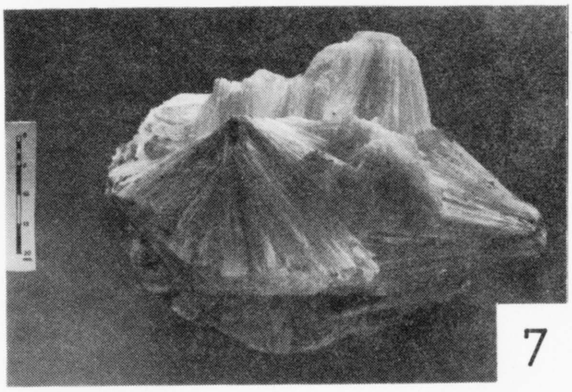

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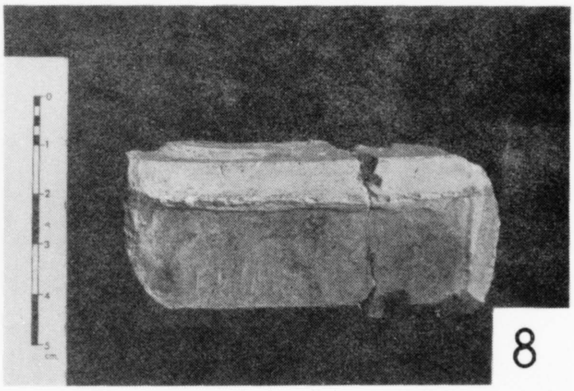

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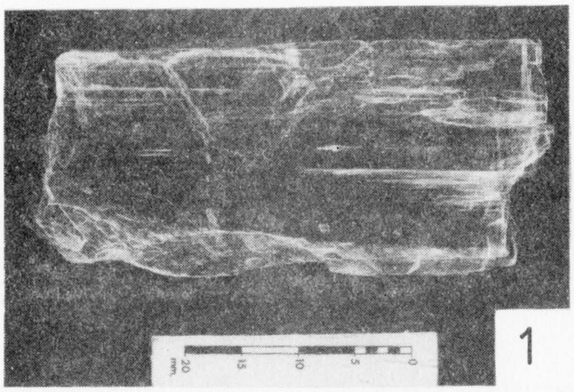
Helvaci - Turkish borates (explanation p. 269).



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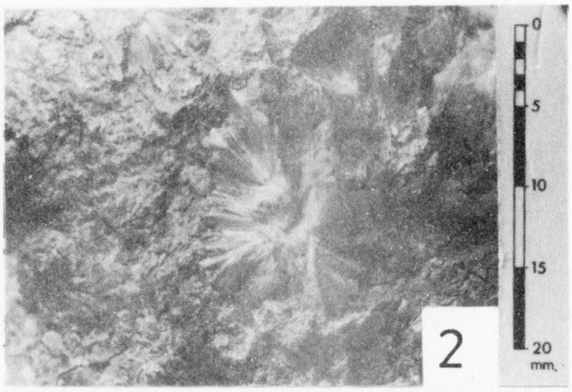

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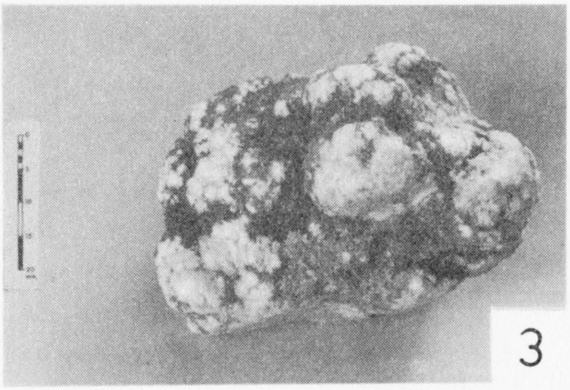

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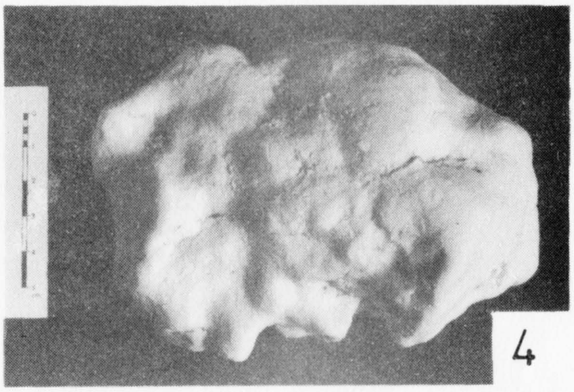

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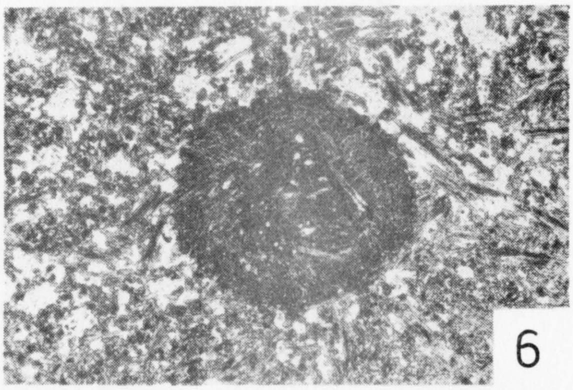

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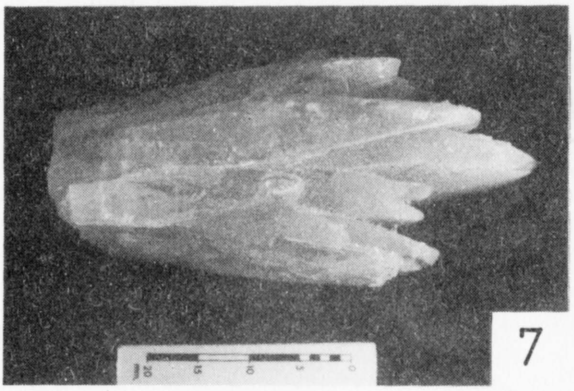

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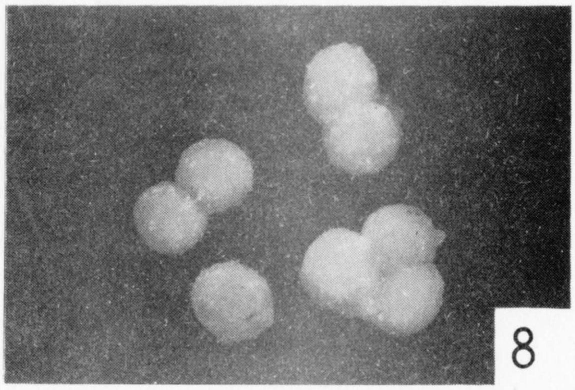

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Helvaci - Turkish borates (explanation p. 270).

A STUDY OF THE THERMOLUMINESCENCE OF FLUORITES FROM THE PENNINE OREFIELDS OF ENGLAND

by

P.J. Rogers and D.W. Sears

Summary

Four main types of thermoluminescence in fluorite samples from the Pennine orefields, have been determined. The glow-curve produced by calculation can be qualitatively related to the abundance of certain trace elements. The studies show that yttrium is an important factor in classifying the thermoluminescence of the fluorites.

Introduction

The Pennine orefields of England (text-fig.1) typified by deposits of galena, zinc blende, barite and fluorite are similar to others found in North America, Europe, Russia and North Africa, together they represent a remarkable concentration of lead, zinc, barium and fluorine in the Earth's crust. The deposits can be broadly described as stratabound, that is, they are confined to particular stratigraphical horizons on a regional scale but may be discordant on a local scale.

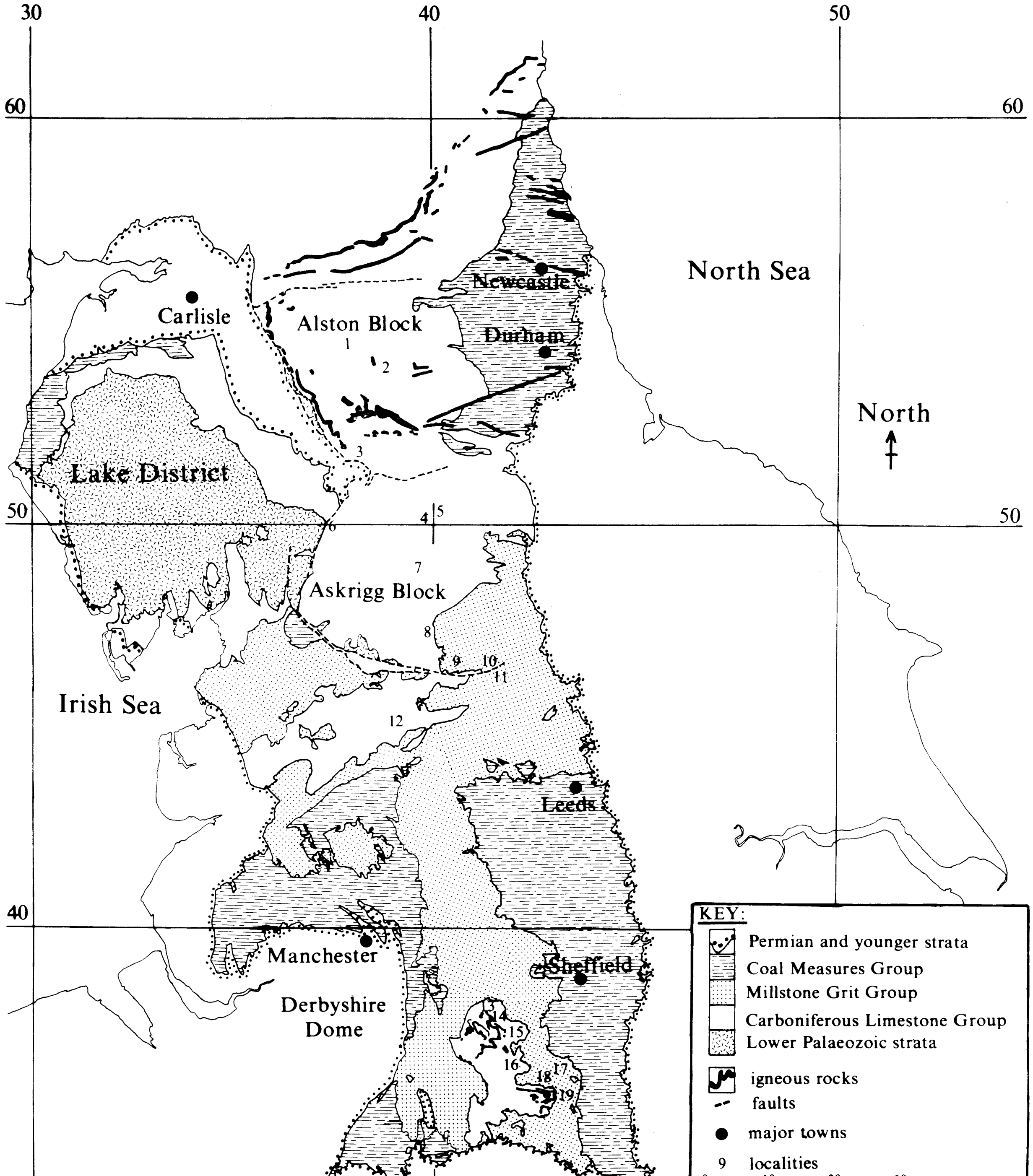
The Pennine orefields have had a long mining history dating from pre-Roman times. Roman pigs of lead have been found in Yorkshire and Derbyshire, together with some old workings thought to belong to this period. Mining, sporadically continued through the Middle Ages, but the main period of lead mining occurred between the late 18th and early 19th centuries. The industry evolved from largely hand-won methods of ore extraction to some degree of mechanisation during the period of the Industrial Revolution.

Lead mining in the Pennines generally ceased in the 1880's with the sharp worldwide fall in the price of lead. Exceptionally, individual mines such as the Millclose Mine (Trail 1939) continued production. An excellent historical review of lead mining history in the Pennines is given by Raistrick and Jennings (1965). More detailed historical accounts of the Alston and Askrigg orefields are given by Dunham (1948: 1974) and by Ford and Rieuwerts (1968) for Derbyshire. Most of the present day mining industry is restricted to the gangue minerals, fluorite and barite, which has grown steadily in importance since about 1900 (Dunham 1944; Notholt and Highley 1971; Collins 1972).

The mineral deposits are associated with Carboniferous limestones and sandstones and shales of Viséan and Namurian age. Igneous activity during the Carboniferous produced the basalt lavas (or toadstones) and intrusives in Derbyshire (Shirley 1949; 1959) and the quartz-dolerite Whin Sill in the Alston orefield (Dunham 1948). Stratigraphy played an important role in localizing the mineralization in a number of preferred rock formations or 'bearing beds'. Each bed is formed into a trap for the mineralizing fluid with an impermeable shale or igneous rock member acting as a cap or floor.

The Pennine orefields are located in tectonically stable upland areas within the Peak District and Yorkshire Dales National Parks. The Northern Pennine orefields rest on Lower Palaezoic strata, which were initially thought to form a single rigid block (Marr 1921), the latter was subsequently divided into a northern, Alston Block (Trotter and Hollingworth 1928) and a southern, Askrigg Block (Hudson 1933). Geographically, the two blocks are separated by a shallow, broad structural depression including Stainmore and Cotherstone Moor (Versey

Mercian Geol. Vol.6, No.4, 1978.
pp.271-280, 4 text-figs.



Text-fig. 1. Outline geology of the Pennine Orefields. (Locality numbers 1 - 19 given at the foot of the opposite page).

1927; Reading 1957). Unlike the Derbyshire 'Dome' (Shirley and Horsfield 1940) these blocks are underlain by Caledonian granitic batholiths (Bott 1967) not necessarily concerned with the mineralisation upon which Carboniferous strata lie unconformably (Dunham *et al.* 1965; Dunham 1975). Sedimentation on the blocks during the Lower Carboniferous was generally slow with shallow water deposits accumulating. The intervening gulfs (or basins) of deeper water sediments have up to three times the sedimentary thicknesses of the blocks (Kent 1966, 1974; Dunham 1973).

The main veins occupy mineralized faults usually with a small throw. In the more competent 'bearing beds', these fissure deposits (or rakes) usually form steep ribbon bodies with their length many times their height. Flats (of flots) take the form of bedding-controlled replacement deposits. Pipe deposits normally consist of irregular mineral bodies usually found at the intersection of a fissure or joint and the bedding (Ford 1969). The veins are often found with a banded mineral fill and, despite the generally simple major mineral assemblage, a large number of minor mineral species are found (Dunham 1948, 1959; Ford and Sarjeant 1964). The mineralization is generally polyphase in character often with a complex paragenetic sequence (Ineson and AlKufaishi 1970). Zoning of the gangue minerals is conspicuous in the Alston and Askrigg Blocks (Dunham 1934 and 1952). The zoning of the Derbyshire orefield is discussed by Firman and Bagshaw (1974).

Estimates of the age of the Pennine mineralization vary from Variscan (Moorbath 1962), although this age is disputed (Mitchell and Krouse 1971), to Mesozoic (Dunham *et al.* 1968). Isotopic dating of clay minerals from Derbyshire (Ineson and Mitchell, 1973) indicates a series of mineralizing episodes spread over a 100 million years from Permo-Triassic to Jurassic times.

Previous Analytical Work

Pennine fluorites have been studied using XRF and other methods and analytical results are given by Dunham (1952), Palache *et al.* (1951), Haber Schausberger and Schroll (1967), Derré (1972) and Jeffrey (1967). Smith (1974a) in a very detailed study gives a large number of analyses and demonstrates their application to economic geology (Smith, 1974b). Derbyshire Blue John has been studied in great analytical detail by Mackenzie and Green (1971) and Braithwaite *et al.* (1973).

Thermoluminescence Studies

Thermoluminescence (TL) is the luminescence produced on heating a mineral specimen. The thermal energy dislodges electrons which have been excited and trapped in the crystal lattice by ionising radiation. The electrons drop to the ground state via a luminescent centre and in doing so emit light, which can be measured to produce the glow-curve. TL is therefore a function of the ionising radiation received and the thermal history of the specimen (Randall and Wilkins, 1945).

List of Localities for Text-fig. 1

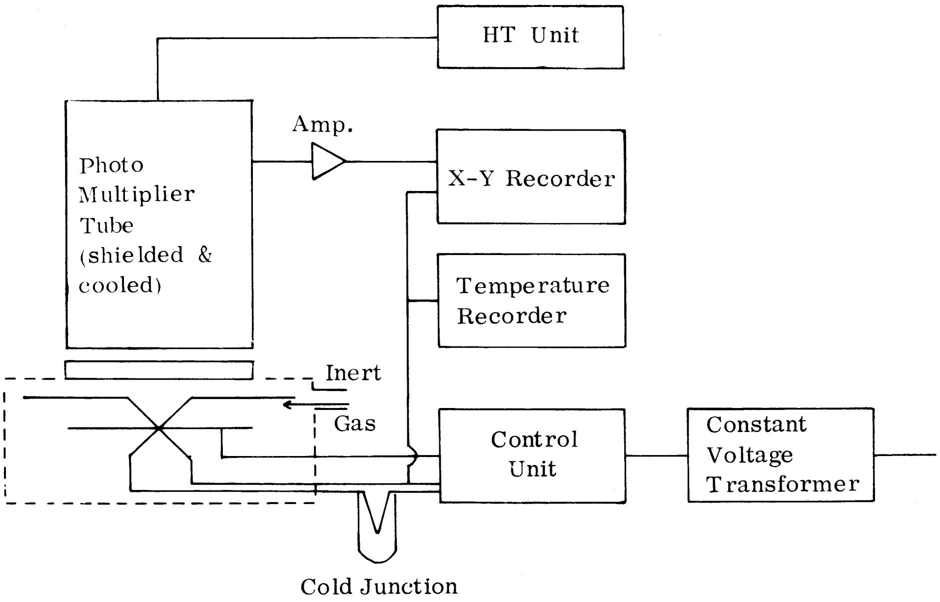
1. Nenthead, Alston Block
2. Weardale, Alston Block
3. Hilton Mine, Scordale, Cumbria
4. Gunnerside Gill, Askrigg Block
5. Arkengarthdale, Askrigg Block
6. Clouds End Fell, Askrigg Block
7. Wet Grooves/Seata Mines, Askrigg Block
8. Kettlewell, Askrigg Block
9. Grassington Moor, Askrigg Block
10. Ashfoldside Beck, Askrigg Block
11. Greenhow Hill, Askrigg Block
12. Raydale, Lothersdale
13. Castleton, Derbyshire
14. Bradwell/Hucklow Edge area, Derbyshire
15. Longstone Edge, Derbyshire
16. Alport mines, Derbyshire
17. Ashover, Derbyshire
18. Matlock area, Derbyshire
19. Crich, Derbyshire

The X-Ray Fluorescence (XRF) method produces secondary x-rays which result from disturbances in the electronic structure by bombarding the specimen with x-rays. The minerals produce unique spectral lines, which, when compared to those of a known standard, enable the chemical composition of the mineral being analysed to be elucidated (Adler 1966). The fluorite lines can then be eliminating leaving the lines of the impurities, particularly the trace elements.

The thermoluminescence (TL) and trace element content of 53 fluorites from the epigenetic mineral deposits of the Pennine orefields have been examined in an attempt to understand the causes of TL and to demonstrate differences in TL between the fluorite samples.

Apparatus and Technique

The apparatus consists (text-fig. 2) of a molybdenum strip heated electrically by an electronic control unit at 5.0 ± 0.05°C s^{-1}. The powdered fluorite is ground, sieved and placed on a defined area of the filament and heated in an inert atmosphere. The light is measured with an EMI 9635B photomultiplier tube and the amplified signal plotted on the y-axis of an x-y recorder. Temperature, as measured by a chromel-alumel thermocouple, is plotted on the x-axis. A glow-curve is thereby obtained directly, the reproductibility being better than 5%. Samples are "drained" of their natural TL by being heated to 500°C and given a standard dose of about 50 krad of γ-rays from a Co^{60} source. The XRF analyses were performed on a Phillips PW212 machine using synthetic spiked standards of pure calcium fluoride. The detection limits are strontium 2 ppm, barium 8 ppm, cerium 9 ppm, yttrium 3 ppm and lanthanum 5 ppm.



Text. fig. 2. Schematic diagram of the thermolumescence apparatus (from Sears and Mills 1974)

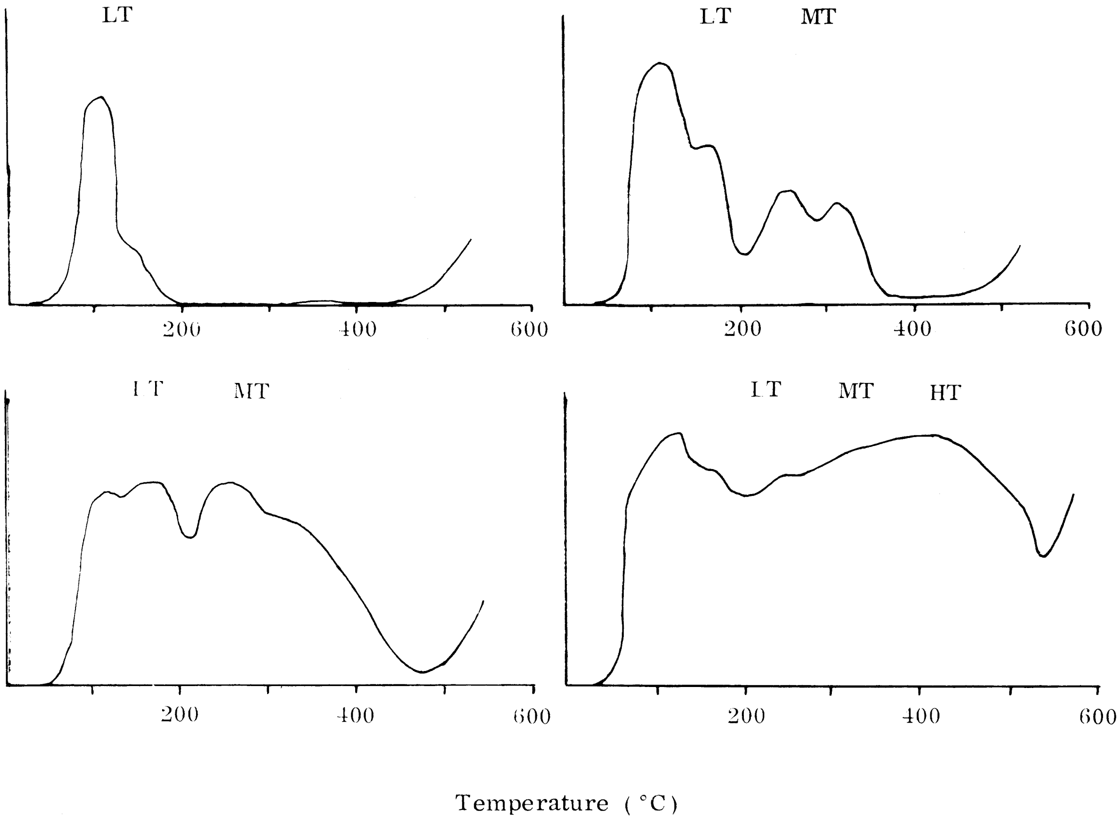
Results

The glow-curves (TL vs. temperature) of the 53 specimens show considerable variation in their structure and in total TL. It was found that distinctive features in the glow-curve can be related qualitatively to the abundance of certain trace elements.

The fluorites and their localities are listed in Table 1 (p. 275). On the basis of their glow curves, the specimens can be divided into four broad groups (text-fig. 3), but there is not always a sharp distinction and some groups grade into each other (for example 2 and 3);

Table 1 - Trace element contents and thermoluminescence of fluorites

Location Fluorite samples	Trace Element Content ppm					Thermoluminescence	
	Ba	Sr	Yr	Ce	La	Area under glow curve (arb units)	Glow curve type see fig. 1.
Escoe Hill, nr. Linton, Yorks.	37	40	19	18	1	386	1
Rimington Mine, Ings Beck, Lancs.	5586	134	23	0	0	978	2
Main Vein, Raygill Quarry, Yorks.	241	39	13	5	9	2317	4
Cloud End Fell, Cumberland.	2845	52	27	0	0	799	3
Birkett Hill, Cumberland.	20	36	24	24	0	381	1
Beevor Mine, Yarnbury, Grassington, Yorks.	13455	143	31	0	0	1690	3
Middle Vein, Grassington Moor, Yorks.	648	53	26	6	14	378	1
Bycliffe Vein, " " "	48	31	27	15	0	494	1
Bycliffe Vein, Ashfoldsidebeck, Yorks.	0	50	81	0	0	881	2
Starbotton Fell, Kettlewell, Yorks.	22	34	21	33	9	424	1
Middlesmoor Pasture "	14506	132	26	0	0	242	1
Galloway Vein, Greenhow Hill, Yorks.	81	44	21	17	5	829	2
Greenhow Rake, " " "	17	47	27	21	0	484	1
Waterhole Veins, Gillfields Adit, Greenhow, Yorks.	24	45	29	26	15	750	2
Lolly Mine, Ramsgill, Nidderdale, Yorks.	269	48	50	21	2	770	2
Inman Vein, Appletreewick, Yorks.	29	38	16	20	3	392	1
Gill Heads Vein, " "	46	48	22	29	3	601	1
Seata Mine, Aysgarth, Yorks.	0	33	28	25	0	1565	3
Wet Grooves Mine, Askrigg, Yorks.	23	46	37	34	0	587	2
Keld Heads Vein, Wensley, Yorks.	2592	58	34	0	0	1842	3
Worton Mine, Nr. Bainbridge, Yorks.	25	46	82	41	5	1609	3
Sir Francis Mine, Nr. Gunnerside Gill, Yorks.	21168	320	47	0	19	1645	3
Bunton Level " " " "	3795	66	60	0	0	1162	3
North Rake Hush, " " " "	14186	160	71	0	0	1993	3
Merryfield Mine, Old Rake, Nr. Gunnerside Gill, Yorks.	5087	75	53	0	4	2415	3
Blakeside Vein, Surrender Moss, Nr. Reeth, Yorks.	5452	119	37	0	0	1163	3
Dam Rigg Vein, Arkengarthdale, " " Yorks.	168	51	49	26	0	583	2
Copperthwaite Vein, " " " "	31688	119	53	0	4	1518	3
Black Hills Hush, " " " "	45	52	45	0	0	1593	3
Moulds Top Mine " " " "	3608	79	47	0	0	1235	3
Blue John, One Vein, Winnats Pass, nr. Castleton, Derbyshire.	29	100	56	28	7	3054	4
Forest Shaft, Odin Vein, Nr. Castleton, Derbys.	13818	214	13	0	0	325	2
Earl Rake, Bradwell, Derbyshire.	13	57	16	31	0	72	2
Dirtlow Rake, Castleton, Derbyshire.	33	39	10	24	0	430	2
Ladywash Mine, Hucklow Edge Vein, Eyam, Derbys	50	48	12	4	1	393	2
Blyth Mine, Alport, Derbyshire.	19	41	16	6	0	130	2
Hazlebadge Hall, Bradwell, Derbyshire.	5071	87	19	0	0	169	2
Gregory Mine, Ashover, "	27	50	11	22	12	275	2
Starr's Wood, " "	3065	126	14	0	3	331	2
Long Rake, Raper Lodge, Alport, Derbyshire.	20778	423	16	0	0	174	2
Old End Mine, Crich, Derbyshire.	88	58	13	26	0	155	2
Clayton adit, Ecton Hill, Staffordshire.	204	37	23	0	2	212	2
Sallet Hole adit, Longstone Edge, Derbyshire.	2818	371	18	0	0	295	2
Low Mine, Great Rake, Matlock, Derbyshire.	20	102	19	43	4	2155	3
Heights Veins, Heights Quarry, Co. Durham.	15	50	293	155	101	3211	4
Knopley Level, Diana Vein, Allenheads Mine, Co. Durham.	95	19	213	63	12	3140	4
Smallcleugh Mine, Nenthead, Northumberland.	0	42	344	108	57	3068	4
Blackdene Mine, Blackdene, Co. Durham.	337	45	31	20	8	2935	4
Redburn Mine, Red Vein, Weardale, Co. Durham.	14	22	316	58	19	3011	4
Whitecheaps Mine, Poor Vein, Blanchland "	20	25	333	77	21	3230	4
Burtree Pasture Mine, Red Vein, Weardale,	17	18	261	52	12	2952	4
Sedling Mine, Sedling Vein, Weardale "	31	27	285	55	26	2885	4
Hilton Mine, Hilton, Cumberland.	47	47	200	49	30	1953	3

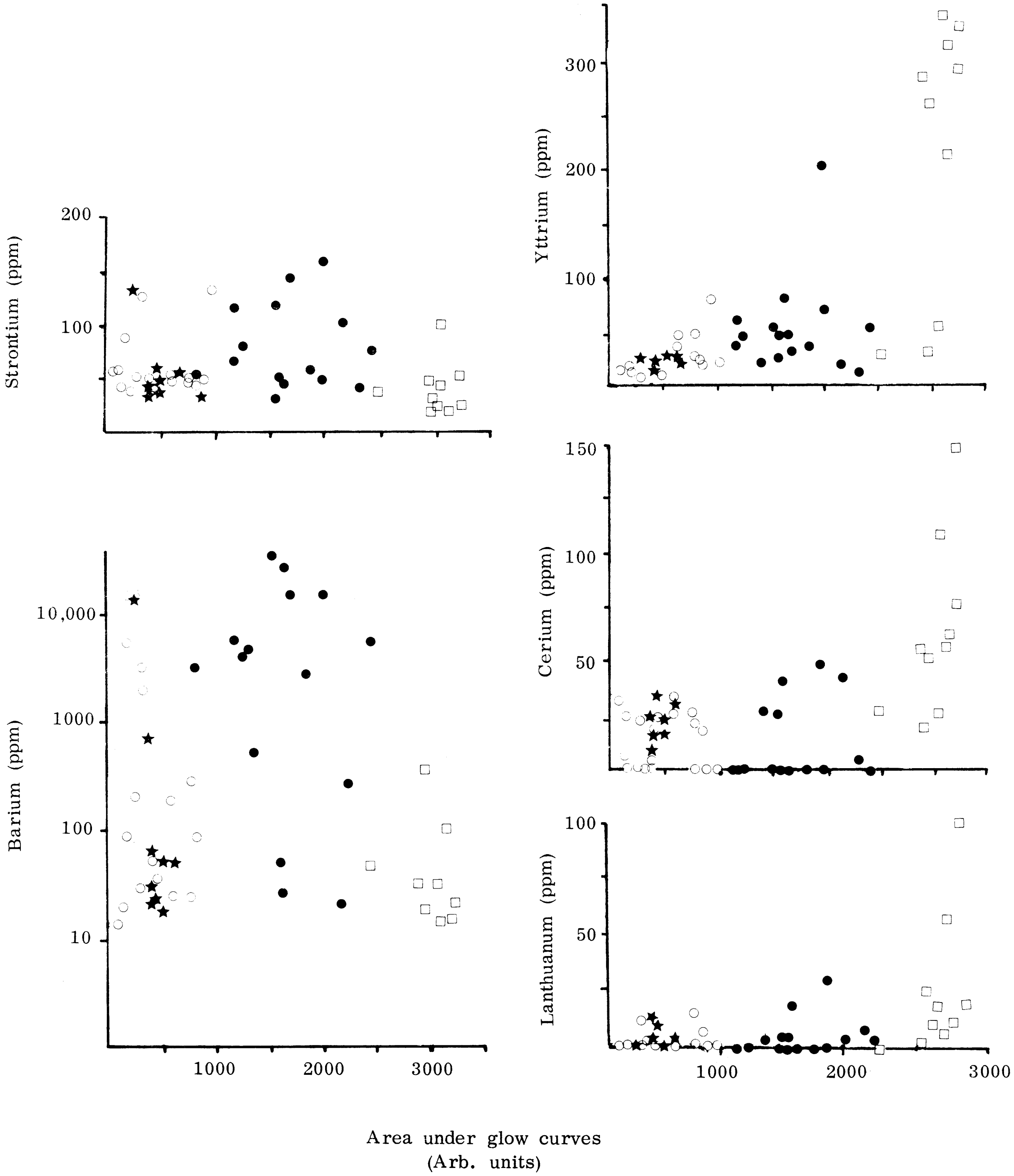


Text-fig. 3. Examples of the four types of glow-curve observed in the Pennine fluorites examined here where the light emitted is measured in the same arbitrary units for each curve. The temperature ranges LT, MT and HT indicate regions in which peaks were observed to appear in the 53 fluorites examined.

some subjectivity is therefore involved in the assignment. Single isolated peaks are rare in the glow-curves obtained but from an examination of all the 53 specimens, peaks appear to occur at 105 ± 10° (this group referred to as LT) 130 ± 15, 165 ± 10 °C (referred to as MT), 375 ± 15 and 380 - 450 °C (referred to as HT). Some caution must be taken in using peak position values as many factors (especially overlap) change them and the use of the less precise terms LT, MT and HT is preferred. With this nomenclature, glow-curves of type 1 consist only of LT, type 2 of intense LT and some MT, type 3 of intense LT and MT and type 4 of intense LT and HT.

It was possible to measure the content of barium, strontium, yttrium, cerium and lanthanum in all 53 specimens by x-ray fluorescence (XRF). The variation of the TL with trace element abundance is presented in text-fig. 4 in which the various glow-curve types are presented by different symbols. Strontium and barium are assumed to be present in samples of types 1, 2 and 4 in about equal amounts. The remaining glow-curve group, with intense MT, however, contains considerably more of these elements. The barium plot is logarithmic and certain samples with type 3 glow-curves contain more than 1000 times the quantity of barium found in the other types; this is probably due to barite contamination as intergrowths with fluorite.

A few points indicate that some specimens producing type 2 glow-curves contain high barium, but these are clearly separate from the main group of points for this type and are border-line specimens in their glow-curve group assignment. Although some type 1 and some type 3 specimens have barium and strontium, undoubtedly *most* of type 3 have high barium and strontium. Thus an enrichment in elements in calcium-substitutional sites may be responsible



Text-fig. 4. Variation in the content of five trace elements and TL content. The symbols represent the type of glow-curve displayed by the specimens; open circles - type 1, stars - type 2, dots - type 3 and squares - type 4.

for the thermoluminescence in the MT region of the glow-curves of fluorites. The enrichment is analogous to the mechanism for the production of TL in limestones and the feldspars of lunar rocks where manganese substitution for calcium is thought to be responsible (Medlin 1966). The process is contrary to the view (Semec and McDougall, 1969) that TL in this region is associated with Frenkel defects, i.e. interstitial ion-vacancy pairs.

Yttrium and other rare earths, cerium and lanthanum show a quite different trend. These elements, particularly yttrium, are present in greater quantities in samples giving type 4 glow-curves. An association between yttrium, the rare earths and thermoluminescence was mentioned by Menon (1971), and this work supports the conclusion that HT is associated with an enrichment of these elements.

The results do not indicate a relationship between LT glow-curves and trace elements; this supports McDougall (1970) who has suggested that lattice dislocations are responsible for thermoluminescence in this region.

Conclusions

Diagnostic qualitative features of the thermoluminescence (TL) glow-curve of Pennine fluorites can be related to the abundance of certain trace elements. It is possible to distinguish 4 types of TL in the fluorites, although the distinction is not always clear because some types grade from one class into another.

The studies show that the yttrium content is especially important with regard to the HT of Pennine fluorites. HT is a good indicator for the presence of ytrrium and rare earths. The TL also reflects the differences in yttrium and rare earth content between the Pennine orefields, the Alston Block having largely type 4, HT fluorites. The other orefields have a mixture of types 2 and 3 with subordinate type 1. This could well have some significance with regard to the genesis of the Pennine mineralization.

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References

ADLER, I. 1966. *X-Ray emission spectrography in geology*, Amsterdam, 270 pp.

BOTT, M.H.P. 1967. Geophysical investigations of the northern Pennine basement rocks. *Proc. Yorks. Geol. Soc.*, vol.36, pp. 139-150.

BRAITHWAITE, R.S.W., FLOWERS, W.T. HASZELDINE, R.N. and RUSSELL, M. 1973. The cause of the colour of Blue John and other purple fluorites. *Min. Mag.*, vol. 39, pp. 401-411.

COLLINS, R.S. 1972. Barium Minerals: *Mineral Dossier* No. 2, Min. Res. Consultative Committee, HMSO, 44p.

DERRÉ, C. 1972. *Histoire des dilons de fluourine et du bassin Houiller de langeac, annexe - analyse de terres rares danz la fluorine par activation dans les neutrons dermiques.* Unpub. Ph.D. thesis, University of Paris.

DUNHAM, K.C. 1934. Genesis of the north Pennine ore deposits *Q. Jl. geol. Soc. Lond.*, vol. 90, pp. 689-720.

DUNHAM, K.C. 1944. The production of galena and associated minerals, in the northern Pennines, with comparative statistics for Great Britain. *Trans. Instn. Min. Met.*, vol. 53, pp. 181-252.

DUNHAM, K.C. 1948. Geology of the northern Pennine orefield, vol. 1. *Mem. Geol. Surv.*, 357p.

DUNHAM, K.C. 1952. Fluorspar. 4th Edit. *Mem. Geol. Surv.*, Min. Resources, 4.

DUNHAM, K.C. 1959. Epigenetic mineralization in Yorkshire *Proc. Yorks. Geol. Soc.*, vol. 32, pp. 1-30.

DUNHAM, K.C. *et al.* 1973. A recent deep borehole, near Eyam, Derbyshire. Nature (Physical Sciences), vol. 241, pp. 84-85.

DUNHAM, K.C. 1974. The epigenetic mineral deposits: Rayner, D.H. and Hemingway, J.E. (eds.), *The geology and mineral resources of Yorkshire.* Leeds,'Yorks, Geol. Soc., 405p.

DUNHAM, K.C. 1975. Granite beneath the Pennines in north Yorkshire. *Proc. Yorks. Geol. Soc.*, vol. 40, pp. 191-194.

DUNHAM, K.C., DUNHAM, A.C., HODGE, B.L., and JOHNSON, G.A.L. 1965. Granite beneath Viséan sediments with mineralization at Rookhope, northern Pennines. *Q. Jl. geol. Soc. Lond.*, vol. 121, pp. 383-417.

DUNHAM, K.C., FITCH, F.J., INESON, P.R., MILLER, J.A. and MITCHELL, J.G. 1968. The geochronological significance of argon-40/argon-39 age determinations on the White Whin from the northern Pennines. *Proc. R. Soc.* A, vol. 307, pp. 251-266.

FIRMAN, R.J. and BAGSHAW, C. 1974. A re-appraisal of the controls of non-metallic gangue mineral distribution in Derbyshire. *Mercial Geol.*, vol. 5, pp. 145-161.

FORD, T.D. 1969. The stratiform ore-deposits of Derbyshire. In "*Sedimentary ores: Ancient and Modern*" (Revised). Proc. 15th Inter-University Congress, Leicester, 1967.

FORD, T.D. and RIEUWERTS, J.H. 1968. *Lead mining in the Peak District,* Bakewell: Peak Park Planning Board, 127p.

FORD, T.D. and SARJEANT, W.A.S. 1964. The Peak District minerals index. *Bull. Peak Distr. Mines Hist. Soc.*, vol. 2, pp. 122-150.

HUBER-SCHAUSBERGER, I., and SCHROLL, E. 1967. Uv-Lumineszenz und seltenerdgehalte in flusspaten. *Geochem. Cosmochim. Acta*, vol. 31, pp. 1333-1341.

HUDSON, R.G.S. 1933. The scenery and geology of north-west Yorkshire. *Proc. Geol. Assoc.*, vol.44, pp. 228-255.

INESON, P.R. and AL-KUFAISHI, F.A.M. 1970. The mineralogy and paragenetic sequence of Long Rake Vein at Raper Mine, Derbyshire. *Mercian Geol.*, vol.3, pp. 337-351.

INESON, P.R. and MITCHELL, J.C. 1973. Isotopic age determinations on clay minerals from lavas and tuffs of the Derbyshire ore field. *Geol. Mag.*, vol.109, pp. 501-512.

JEFFREY, P.G. 1967. Rare earth content of green fluorite - a new source of europium. *Nature* (Physical Sciences), vol.215, pp. 496-497.

KENT, P.E. 1966, The structure of the concealed Carboniferous rocks of north-eastern England. *Proc. Yorks. Geol. Soc.*, vol. 35, pp. 323-352.

KENT, P.E. 1974. Structural History *in* Rayner, D.H. and Hemingway, J.E. (eds.) *The Geology and Mineral Resources of Yorkshire*, pp. 13-28.

MACKENZIE, K.J.D. and GREEN, J.M. 1971. The cause of colouration in Derbyshire Blue John banded fluorite and other blue banded fluorites. *Min. Mag.*, vol.38, pp. 459-470.

MARR, J.E. 1921. The rigidity of north-west Yorkshire. *Naturalist*, pp. 63-72.

McDOUGALL, D.J. 1970. Relative concentrations of lattice defects as an index of the temperature of formation of fluorite. *Econ. Geol.*, vol.65, pp. 856-861.

MEDLIN, W.L. 1966. *Thermoluminescence of Geological Materials* ed. D.J. McDougall, Oxford, Academic Press.

MENON, A.K. 1971. A study of the growth of thermoluminescence in fluorites. *Modern Geol.*, vol.2, pp. 289-292.

MITCHELL, R.H. and KROUSE, H.R. 1971. Isotopic composition of sulfur and lead in galena from the Greenhow - Skyreholme area, Yorkshire, England. *Econ. Geol.*, vol.66, pp. 243-251.

MOORBATH, S. 1962. Lead isotope abundance studies on mineral occurrences in the British Isles and their geological significance *Phil. Trans. R. Soc.*, A, vol.254, pp. 295-360.

NOTHOLT, A.J.G. and HIGHLEY, D.E. 1971. Fluorspar: *Mineral Dossier* no.1., Min. Res. Consultative Committee, HMSO, 31 p.

PALACHE, C., BERMAN, H. and FRONDEL, C. 1951. *Dana's The system of mineralogy*, vol.2, 7th edition, New York, Wiley and sons, 1124pp.

RAISTRICK, A. and JENNINGS, B. 1965. *A history of lead mining in the Pennines*. Longmans, London, 347pp.

RANDALL, J.T. and WILKINS, M.F.H. 1945. Phosphorescence and electron traps. *Proc. R. Soc.* A, vol.184, pp. 366-407.

READING, H. G. 1957. The stratigraphy and structure of the Cotherstone syncline. *Q. Jl. geol. Soc. Lond.*, vol.113, pp.27-56.

SEARS, D.W. and MILLS, A.A. 1974. Thermoluminescence and the terrestrial age of meteoritics. *Meteorites*, vol.9, No.1, pp. 47-67.

SEMEC, B. and McDOUGALL, D.J. 1969. *Geol. Soc. Am. Prog. with Abstracts* of the 1969 Annual Meetings, 204pp.

SHIRLEY, J. 1949. The stratigraphical distribution of the lead-zinc ores of Mill Close Mine and the future prospects of the area. *XVIII Int. Geol. Congress.* London, Pt.7, pp. 353-351.

SHIRLEY, J. 1959. The Carboniferous Limestone of the Monyash-Wirksworth area, Derbyshire. Q.Jl. *Q. Jl. geol. Soc. Lond.*, vol.114, pp. 411-351.

SHIRLEY, J. and HORSEFIELD, E.J. 1940. The Carboniferous Limestone of the Castleton-Bradwell area, north Derbyshire. *Q. Jl. geol. Soc. Lond.*, vol.96, pp. 271-299 and vols.97, pp. 180-181.

SMITH, F.W. 1974a. *Factors governing the development of fluorspar orebodies in the Northern Pennine orefield.* Unpub. Ph.D. thesis, Univ. of Durham.

SMITH, F.W. 1974b. The Yttrium content of fluorite as a guide to vein intersections in partially developed fluorspar orebodies *Trans. Instn. Min. Eng.*, vol. 255, pp. 95-96.

TRAILL, J. G. 1939. The geology and development of Mill Close Mine, Derbyshire. *Econ. Geol.*, vol.34, pp.851-889.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1928. The Alston Block. *Geol. Mag.*, vol.65, pp. 433-448.

VERSEY, H. C. 1927. Post-Carboniferous movements in the Northumbrian fault block. *Proc. Yorks. Geol. Soc.*, vol.21, pp. 1-16.

A BRIEF REVIEW OF SOME ASPECTS OF GEOMORPHOLOGY IN ENGLAND AND WALES

by

J. Challinor

Introduction

Ever since the beginning of the present century, topographic relief in Britain and America has been largely explained on principles associated particularly with the name of the celebrated American geomorphologist W. M. Davis. The chief assumption made is that the character of the relief of a region depends primarily on the evolutionary stage reached in the course of a 'geographical cycle' (also called a 'cycle of erosion') initiated by a relatively rapid uplift, and that such cycles, in various stages of completion, may be repeated. The exponents of these ideas claim to find examples of their application in Britain in features which seem to me to be readily accounted for on more general and already well-established principles. The philosophical virtue of economy of hypothesis ('Ockham's razor') seems to be neglected. However, there are now signs that a new look is being taken at some of the aspects of geomorphology.

I have elsewhere (1974) tried to put very shortly something of the essentials of my own ideas, as opposed to those of Davis. From this (p. 464) I quote nearly verbatim as follows:-

'Geomorphology became, and has remained, so steeped in the Davisian ideas that it is very generally taken for granted that any feature that can possibly be explained in accordance with them is to be so explained. Thus such things as uplifted peneplains (entire or as remnant hill-tops) are claimed as being recognized, and certain irregularities in river profiles are made to give evidence of successive cycles induced by successive uplifts. There appears, however, to be an obvious and fundamental flaw in his premise. Uplift is assumed to be so rapid as to produce, all at once as it were, an elevated surface on which erosion begins and develops its work until, perhaps, another relatively sudden uplift superimposes another 'cycle'. But erosion would begin at the first emergence of the region from the sea and it would go on as the land more or less gradually rose. It is very unlikely that the land would ever approach, much less reach, the height to which the earth-movement would have carried it, and its form would at all stages be determined mainly by its geological structure, differential erosion of the less and more resistant rocks being the guiding principle. The land surface would be worn away and sculptured as it rose. At the same time, this subaerial erosion (of various kinds but normally chiefly fluvial) would everywhere tend to produce its characteristic curves and features, evolving in its own way according to particular circumstances. A river-system might well be initiated by an original up-warp or tilt.

Surely that is a more reasonable assumption as to the action and results of earth-processes than is the Davisian model? If so, observed land-forms conforming to what may be inferred as a deduction from it must, as a matter of logic and common sense, preferably be explained in that way.'

D.W. Johnson was one of Davis's students and disciples and in his well-known book (1919) he applied an evolutionary hypothesis to coastal geomorphology. In 1949 I published a paper in which I analysed an opposite view, a view analogous to the one I take regarding the entirely subaerial erosion and denudation of an inland area.

Throughout the geological history of any particular region there were, it seems, long periods during which the uplift of the land gained on the contemporaneous and continual down-cutting and removal processes of erosion and denudation. Between these periods were long intervals in which the lowering of the land gained, on the whole, on the effects of up-rising

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tendencies due to earth-movement. The higher the land, at any time, above base-level (sea-level) the greater the power of the combined erosion-denudation process, but all the time there would be a continual balance and adjustment between earth-movement on the one hand and erosion-denudation on the other.

A powerful impetus to view without prejudice the factors controlling relief was given in America by the publication in 1960 of a paper by T. Hack of the United States Geological Survey. In this he advocates a principle which he calls 'dynamic equilibrium'. If I understand him correctly this principle, which he applies in considerable detail, largely accords with the one I have outlined above. Hack's work has been further discussed in the course of Schumm and Lichty's paper (1965).

In the present article I propose to consider very briefly a few representative regions of England and Wales by way of illustrating my own ideas. We shall chiefly be concerned with the history of the 'hill-top surface', by which I mean an imaginary surface draping the hills and ridges of a region (more or less closely according to how it is envisaged). This surface may be imagined as extending from the higher onto the lower parts of a region.

Examples of the hill-top surface

North Cardiganshire

This is a region composed of Ordovician and Silurian rocks, chiefly the latter. The view that has for long been advocated is that the hill-top surface here comprises several 'platforms' representing plains formed originally either just above sea-level (subaerial peneplains) or just below sea-level (plains of marine denudation) which have been successively raised by earth-movement, the highest, forming a plateau, being the earliest. My own view, first detailed in 1930, is that there is one surface, continuously carved by subaerial erosion out of a region uplifted, perhaps, during Tertiary times.

If we take the extensive 'high plateau' of the region, how is it that erosion, which has admittedly deeply dissected the plateau, has proceeded just so far as to leave intact the tops of the hills? The hills must surely have been lowered while the valleys were being carved out. The surface on which this morphological development was initiated would have been hundreds, if not thousands, of feet above the present plateau; that is, taking the action of the earth-movement by itself and ignoring the effect of erosion while the uplift was going on. I would explain the existence of the plateau as being the natural result of erosion working on rocks which, over the greater part of the area, are of much the same resistance. The mountain of Plynlimon, being composed of the harder Ordovician rocks in the core of a structural dome, stands out above the plateau on the principle of differential erosion.

The consideration of the production of this surface in Cardiganshire and the neighbouring country begins with A. C. Ramsay's paper 'On the denudation of South Wales' in 1846. He views the whole surface of Central Wales, hills and valleys alike, as an uplifted surface which had been not only planed off, but deeply hollowed out, by marine erosion. In 1866, with his attention on northern and north-central Wales, Ramsay put forward the same general idea of an uplifted planed surface but he now (1866) accepts the fact that the valleys have since been carved out by subaerial erosion. He recognizes plateau-surfaces, each at a different height, over several areas respectively of different rock-resistance, but he does not attempt to reconcile this correspondence with his hypothesis which, indeed, it seems clearly to contradict. He places the age of the uplift as far back as pre-Triassic (Hercynian) times. These views were repeated unchanged in 1881 and they were re-stated, with special reference to Cardiganshire, in his book on Great Britain (e.g., the last edition, 1894).

Ramsay's hypothesis, with variations, persisted, becoming more and more firmly fixed in geological literature. For instance, we find W. G. Fearnsides remarking that the Central Uplands of Wales are 'indeed an ancient peneplain deeply dissected ... probably an early

Tertiary surface of subaerial denudation' (1910). O. T. Jones's more detailed and precise rendering of essentially the same story, in 1911 and 1924, served to fix it still further.

In addition to the postulated uplifted plain forming the high plateau of northern Cardiganshire, several other 'platforms' have been forced on the relief, against all the evidence, including that adduced by the advocates themselves. Among the more recent publications in which this has continued to be done are those of E. H. Brown (1950, 1952, 1956, 1957, 1960) and O. T. Jones (1952, 1957, 1961). J. C. Rodda (1970) while claiming that his analysis supports a three-fold planation suggested by Brown (which it does not seem to do) nevertheless admits that 'it also indicates that Challinor's single surface is almost as appropriate'. I have reviewed this whole subject at some length (1951), reprinted with an additional paragraph (1969).

Snowdonia

The diversity of ideas about the origin and evolution of the present mountains of Snowdonia (formed out of Ordovician, with some Cambrian, rocks) was well shown at a meeting of the Geological Society of London on 3 November 1937, when a paper by Edward Greenly was read on 'The age of the mountains of Snowdonia' (published in 1938) and discussed by some of the most eminent geologists of the day.

When we view the Snowdon mountain-group from any point outside, for instance from Anglesey, we can imagine a line connecting the higher summits, and we see that this line is a fairly even one. Combining several such views we find that the summits reach a gently convex hill-top surface. This is also evident from a map showing the relief and the heights of the hills.

It may at first sight be tempting to suggest that this imaginary hill-top surface coincides with a once-real surface of a dome-shaped mass out of which the mountains have been carved by erosion.

Whatever the history of the height and relief of North Wales during Upper Palaeozoic and Mesozoic times may have been, it seems to be generally assumed (e.g. George, 1961, p. 77) that by early Tertiary times, at the latest, that region had become worn down to a low-lying, more or less level, surface. This surface may have been beneath the sea in late Cretaceous times (but there are no deposits of Cretaceous age) or a plain not far above sea-level. Again it seems to be generally assumed (e.g. George, 1961 p. 78) that this surface was later raised by stresses in the earth's crust, perhaps as a distant effect of the Alpine (Tertiary) orogenic movements. The supposed dome-shaped mass whose surface is envisaged as coinciding with the present hill-top surface might thus, as was suggested by Greenly (1938 pp. 119-120), have been formed by this uplift. There are, however, what appear to be fatal objections to this idea.

The same considerations apply here as in Cardiganshire and are even more obvious. I have called attention to them recently in writing about Snowdonia (1973). It seems particularly impossible here that the present hill-top surface could be, or could represent in any way, an original low-lying surface which had been uplifted into a gentle dome; any such surface would be completely lost, because while the valleys were being carved out, the whole surface could hardly escape being greatly lowered by the general erosion and denudation going on everywhere at the same time.

It is, however, highly improbable that any uplifted original unmodified surface ever existed. Erosion, both subaerial and marine, would start its work as soon as the plain began to rise. It would never reach the height or assume the form that would have been produced by the earth-movement alone.

The Lake District of Cumbria

The main features of the structural and morphological history of the Lake District appear to admit of little doubt, forming indeed a well-known 'model'.

The core of the region - that is, the Lake District proper - is, like Snowdonia, composed of Lower Palaeozoic rocks. Here, the highest mountains (the Scafells, Helvellyn, Skiddaw) all reach a little over 3000 ft so that there may be said to be a nearly horizontal hill-top surface at this level. Taking this mountainous core by itself there seems no reason why it should not have been suggested, as it was in the case of Snowdonia, that this imaginary hill-top surface, restored to reality, was a plain that had been uplifted to its present position. So far as I know, this suggestion has never been made; and with good reason, for it would have been difficult to maintain when the structure of the whole region was taken into account. As is very well known, the Lower Palaeozoic core is surrounded by Carboniferous rocks which presumably covered the whole area and which were uplifted in the form of a dome, subsequently being removed by erosion from the central part. This erosion has continued, cutting deeply into the resistant core which has remained all the time (particularly the part of it composed of the hard Ordovician rocks) to stand higher than its surroundings of later rocks. The radial drainage of rivers and lakes is assumed to have originated on this uplifted surface.

The geological history of the district is given diagrammatically in, for instance, Eastwood *et al.* (1971, p. 5); the uplift there being shown as renewed in post-Triassic times. Moseley (1972) places this second gentle doming as part of the Alpine (Tertiary) movements. We do not know the relative rates of uplift and contemporaneous erosion; a question which, in general, seems to be of the utmost importance in geomorphology.

S.E. Hollingworth, however, in two papers (1937, 1938), has claimed to recognize remnants of platforms at several levels corresponding approximately to nearly level surfaces formed originally just above or just below sea-level. He admits that these are 'deeply dissected and preserved in comparatively small residuals... However, owing to dissection, the varying resistance to erosion of the constituent rocks, and the masking effects of glacial erosion and deposition, the presence of platforms is not at first sight apparent. Nor are the residuals sufficiently continuous to indicate an obvious linking up on the basis of altitude' (1938, p. 56).

I have never myself seen anything in the landscape of the Lake District that would suggest the presence of any such 'platforms'. My contention throughout this review is to suggest that the logical procedure as regards interpretation is to show, first of all, that features such as so-called 'uplifted platforms' and 'rejuvenation effects' on river-profiles would not be produced by the normal action of erosion working on a stable land.

The Weald

A detailed review of the history of the development of the rivers and relief of the Weald of south-east England has recently (1973) been made by B.C. Worssam of the Institute of Geological Sciences (Geological Survey). To quote from parts of the preliminary matter of this paper:

'In 1895 W.M. Davis, in a paper dealing with a large part of eastern England, described the development of the rivers of the Weald in terms of his theory of the cycle of erosion. With this authoritative paper as their example most subsequent writers on the geomorphology of the Weald, up to and including Linton (1969), have tended to describe the Weald as providing straightforward illustrations of the working of the cycle of erosion theory. Wooldridge and Linton's *Surface and Drainage of South-East England*, published in 1939 and reissued with amendments in 1955, and which since its first publication has been regarded as the standard work on its subject (see Clayton, 1969), is certainly written from a Davisian standpoint' (p.1).

'The concept of dynamic equilibrium, put forward by J.T. Hack in 1960, provides a simpler explanation of the present topography of the Weald than does the cycle of erosion theory of W.M. Davis. Doubt is cast on the existence in the Weald of a '200-ft Platform' and of a '400-ft Platform'. The evidence for a '600-ft' or 'Pliocene Platform' is reviewed; remnants of a Pliocene plane of unconformity on the Chalk of the North Downs form a topographical platform at about 600 ft above O.D., but S.W. Wooldridge and D.L. Linton's ideas on the denudation history of the Weald, based as they are on the assumption that this topographical platform represents the offshore equivalent of a Davisian peneplane, appear to be structurally unsound' (Summary on p.v.).

Worssam, however, if I have understood him rightly, seems to have some difficulty in establishing any very clear fundamental difference between the 'offshore equivalent of a Davisian peneplane' and a 'plane of unconformity', and (what is the most important similarity between the two) in either case the plane is supposed to have been raised to form a present platform (hill-top surface) at about 600 ft. The difficulty is the presence of several patches of Pliocene deposits, of various ages, at places on the Chalk at or near this level.

The difficulty would be removed - there would be no need to have any platform at all raised from below sea-level to 600 ft - if it could be shown that these Pliocene deposits were not *in situ*. In a paper by E.R. Shephard-Thorn (1975), another senior officer of the Geological Survey, the suggestion is made that these high-level deposits on the Chalk 'have been glacially transported to their present locations from the southern bight of the North Sea' (p. 538). He says: 'Traditionally, south-east England has always been regarded as lying beyond the maximum southerly extent of the Pleistocene ice-sheets in Britain. If, however, the recent proposals of former glaciations of the English Channel and adjacent areas, by ice-sheets originating on the western margin of the European continental shelf (Kellaway and Others, 1975; Destombes *et al.*, 1975), gain acceptance, many aspects of the development of the Wealden landscape call for fresh consideration. For example, could Wooldridge's Pliocene surface be in reality an old glacial terrain of the earliest Pleistocene, with the clay-with-flints its relict till and the high-level deposits of the Chalk downs glacially rafted equivalents of the East Anglian Crags?' (p. 544).

It therefore seems reasonable to suppose that both accordances (including the so-called 'bevels') and variations in height along the Chalk escarpments, and along the Lower Greensand escarpments, and the high central area of the Weald, are all due to erosion working on the principle of dynamic equilibrium; with any oscillations of sea-level during the Glacial Period being taken in its stride.

The two papers here discussed go deeply into their subject matter and are fully documented. Of the works they refer to, I here list only those mentioned in the extracts I have quoted above, with one exception, a paper by D.K.C. Jones (1974) which contains a detailed discussion and criticism of Linton's ideas.

Southern Pennines

The present state of ideas concerning certain aspects of the geomorphology of this region is shown in the publication by Walsh *et al.*, (1972), to which may be added the lively excursion report by Ford (1972). This paper, which is copiously documented with historical references, is concerned primarily with the Neogene Brassington Formation. In the first place it describes these highly interesting deposits, one of which contains fossil plants considered to be of Lower Pliocene age, and discusses the manner of their present occurrence in 'pockets' in the Carboniferous Limestone, having evidently foundered therein through a process of solution subsidence. Secondly, there is consideration of the bearing of these observations and inferences 'on the evolution of Upland Britain'. Throughout the paper these two strands are interwoven. Whereas the first is everywhere strictly factual and logical, the second is almost entirely speculation. The authors admit the speculative element, but they are clearly ready to accept without argument the presumption of uplifted planes of erosion. The critical, and linked, questions here are: at what geographical level (relative to sea level) was the Brassington Formation of sands, gravels, and clays deposited and how did it come to be at a considerable height, a height well above even its present position in the pockets of the limestone upland? The authors state that they are 'of the opinion that there can be little doubt that the Brassington Formation... accumulated in a terrestrial environment on what is now, through uplift, a high-level planation surface above the Pennines' (p. 523). The other possibilities - though not seriously considered in the paper - are (1) that the deposits were formed *in situ* at the high level from which they seem to have foundered into the pockets or (2) that they had been transported, presumably by glacial action, to that high elevation from elsewhere.

There is no more fundamental and well-known fact-and-inference in geology than this - that it is a regular thing for deposits to be laid down in the sea and subsequently to be raised to form land (perhaps at a great height), the strata becoming more or less bent, broken, and deformed in the process. The Carboniferous rocks of the Pennines are an eloquent example of this; the uplift occurring at the end of Carboniferous times, as proved by the unconformable Permo-Trias. In contrast to this certainty is the extremely dubious evidence about the subsequent history of what is now the southern Pennines. For instance, what effect, if any, did the Alpine (Tertiary) movements have? As to the recognition, in the present relief, of uplifted planes of erosion; the criticisms that I have already made as regards the other regions considered (though so briefly) in the present article apply here as indeed throughout Britain and further afield. It is my native land on the western edge of the Peak District - the Namurian and Millstone Grit country of the Roaches, Morridge, Gun Hill, Shuttlingslowe - that I see so clearly in my mind as I write. It certainly appears to me that it would be very difficult to find any 'platforms' of uplifted erosion surfaces here, where there is such a beautiful expression of the intimate relationship between land-form and geological structure.

I leave it to the Mercian geologists to ponder, to reason, and to discuss.

Acknowledgement

I am grateful to Dr. Trevor Ford for drawing my attention to some references in the South Pennines section.

References

BROWN, E.H. 1950. Erosion surfaces in north Cardiganshire. *Trans. Inst. Brit. Geog.*, vol. 16, pp. 49-56.

BROWN, E.H. 1952. The river Ystwyth, Cardiganshire: a geomorphological analysis. *Proc. Geol. Assoc.*, vol. 63, pp. 244-269.

BROWN, E.H. 1956. The 600-foot platform in Wales. *Proc. Int. Geog. Cong.*, 17th Congress, pp. 304-312.

BROWN, E.H. 1957. The physique of Wales. *Geog. Jl.*, vol. 123, pp. 208-230.

BROWN, E.H. 1960. *The relief and drainage of Wales.* Cardiff.

CHALLINOR, J. 1930. The hill-top surface of north Cardiganshire. *Geography*, vol. 15, pp. 651-656.

CHALLINOR, J. 1949. A principle in coastal geomorphology. *Geography*, vol. 34, pp. 212-215.

CHALLINOR, J. 1951. Geological research in Cardiganshire, 1842-1949. *Ceredigion*, vol. 1, pp. 144-176.

CHALLINOR, J. 1969. Geological research in Cardiganshire, 1842-1967. *Welsh Geological Quarterly*, vol. 4, pp. 3-37.

CHALLINOR, J.	1974. [Review.] *Geol. Mag.*, vol.111, pp.463-464,
CHALLINOR, J., and BATES, D.E.B.	1973. *Geology explained in North Wales.* Newton Abbot.
CLAYTON, K.M.	1969. Post-war research on the geomorphology of south-east England. *Area* (*Inst. Brit. Geog.*), no.2, pp. 9-11.
DAVIS, W.M.	1895. The development of certain English rivers. *Geog. Jl.*, vol.5, pp. 127-146.
DESTOMBES, J.P. SHPHARD-THORN, E.R., and REDDING, J.H.	1975. A buried valley system in the Strait of Dover. *Phil. Trans. R. Soc. Lond.*, vol.A 279, pp. 243-256.
EASTWOOD, T and others.	1971. *British Regional Geology: Northern England.* Fourth edition. London.
FEARNSIDES, W.G.	1910. North and Central Wales. In *Geology in the field* (ed. H.W. Monckton and R.S. Herries), pp. 786-825. London.
FORD, T.D.	1972. Field meeting in the Peak District. *Proc. Geol. Assoc.*, vol.83, pp. 231-236.
GEORGE, T.N.	1961. *British Regional Geology: North Wales.* Third edition, completely revised. London.
GREENLY, E.	1938. The age of the mountains of Snowdonia. *Q. Jl. geol. Soc. Lond.*, vol.94, pp.117-124.
HACK, J.T.	1960. Interpretation of erosional topography in humid temperate regions. *Amer. Jl. Sci.*, vol.258A, pp.80-97.
HOLLINGWORTH, S.E.	1937. High level erosional platforms in Cumberland and Furness. *Proc. Yorks. Geol. Soc.*, vol.23, pp.159-177.
HOLLINGWORTH, S.E.	1938. The recognition and correlation of high-level erosion surfaces in Britain: a statistical study. *Q. Jl. geol. Soc. Lond.*, vol.94, pp.58-84.
JOHNSON, D.W.	1919. *Shore processes and shoreline development.* New York.
JONES, D.K.C.	1974. The influence of the Calabrian transgression on the drainage and evolution of south-east England. In Brown, E.H., and Waters, R.S. (eds.,) *Progress in Geomorphology, Inst. Brit. Geographers Special Publication*, no.7, pp.139-158.
JONES, O.T.	1911. The physical features and geology of Central Wales. In *National Union of Teachers: souvenir of Aberystwyth conference* (ed. J. Ballinger), pp.25-51. London.
JONES, O.T.	1924. The upper Towy drainage system. *Q. Jl. geol. Soc. Lond.*, vol.80, pp.568-609.
JONES, O.T.	1952. Anniversary address: The drainage system of Wales and the adjacent regions. *Q. Jl. geol. Soc. Lond.*, vol.107, pp.201-225.

JONES, O.T. 1957. Correspondence: The physique of Wales. *Geol. Mag.*, vol.94, pp.511-512.

JONES, O.T. 1961. Essay review: The relief and drainage of Wales. *Geol. Mag.*, vol.98, pp.436-438.

KELLAWAY, G.A., REDDING, J.H., SHEPHARD-THORN, E.R., and DESTOMBES, J.P. 1975. The Quaternary history of the English Channel. *Phil. Trans. Roy. Soc. Lond.*, vol. A 279, pp.189-218.

LINTON, D.L. 1969. The formative years in geomorphological research in south-east England. *Area* (*Inst. Brit. Geog.*), no.2, pp.1-8.

MOSELEY, F. 1972. A tectonic history of north-west England. *Q. Jl. geol. Soc. Lond.*, vol.128, pp.561-598.

RAMSAY, A.C. 1846. On the denudation of South Wales and the adjacent counties of England. *Mem. Geol. Surv. G.B.*, vol.1, pp.297-335.

RAMSAY, A.C. 1866. *The geology of North Wales. Mem. Geol. Surv. G.B.*, vol.3, (second edition, 1881).

RAMSAY, A.C. 1894. *The physical geology and geography of Great Britain* (Sixth edition, H.B. Woodward ed.) London.

RODDA, J.C. 1970. Planation surfaces in north Cardiganshire. *Trans. Inst. Brit. Geog.*, vol.34, pp.107-114.

SCHUMM, S.A. and LICHTY, R.W. 1965. Time, space and causality in geomorphology. *Amer. Jl. Sci.*, vol.263, pp.110-119.

SHEPHARD-THORN, E.R. 1975. The Quaternary of the Weald: a review. *Proc. Geol. Assoc.*, vol.86, pp.537-547.

WALSH, P.T., BOULTER, M.C., IJTABA, M., and URBANI, D.M. 1972. The preservation of the Neogene Brassington formation of the southern Pennines and its bearing on the evolution of upland Britain. *Q. Jl. geol. Soc. Lond.*, vol.128, pp.519-559.

WOOLDRIDGE, S.W. and LINTON, D.L. 1939. Structure, surface and drainage in south-east England. *Inst. Brit. Geog.*, no.10.

WOOLDRIDGE, S.W. and LINTON, D.L. 1955. *Structure, surface and drainage in south-east England.* London.

WORSSAM, B.C. 1973. A new look at river capture and at the denudation history of the Weald. *Rep. Inst. Geol. Sci.*, no. 73/17.

FOSSILS FROM THE PRE-CAMBRIAN OF CHARNWOOD FOREST, LEICESTERSHIRE

by

Helen E. Boynton

Summary

New records of fossils from the Pre-Cambrian rocks of Charnwood Forest have been made by a team of Adult Education students under the leadership of the author.

Fossils discovered, of the phylum Coelenterata, include *Cyclomedusa* cf. *davidi* Sprigg and *Cyclomedusa* sp., both of which were first recorded from Ediacara, South Australia. Certain other fossils are considered to be medusae or problematica. These are discussed and compared with forms from Newfoundland and Ediacara.

Further observations on *Charniodiscus concentricus* Ford suggest that his original ideas on their affinities to Himanthalian seaweeds may be correct.

Introduction

The latest search for fossils in Charnwood Forest started after a discussion on "Life in the Pre-Cambrian" at an Evening Class in 1976. Twelve students and their families spent many hours examining rock outcrops in the Forest. The results of this survey have yielded interesting specimens of Pre-Cambrian fossils not recorded previously in this country.

In past years the following papers concerned with the present study have been published. Hill & Bonney (1877) noted some "curious concretionary markings" in the "northern slate quarry at Hanging Rocks" but "disposed of their claim to be organic". Watts (1947) mapped the Geology of Charnwood Forest and divided the Pre-Cambrian rocks into the following groups which are still the basis of the stratigraphy today (Ford, 1968). They are as follows:-

Group C	Brand Series	3. Swithland Slates 2. Trachose Grit and Quartzite 1. Hanging Rocks and Conglomerate
Group B	Maplewell Series	4. Woodhouse and Bradgate Beds 3. Slate-Agglomerate 2. Beacon Hill Beds 1. Felsitic Agglomerate
Group A	Blackbrook Series	Blackbrook Beds

Watts postulated there was an increase in volcanic activity by the deposition of ashes which started in Blackbrook times, reached its maximum in the Maplewell Series and died away during the formation of the Brand beds. He also described the various intrusive members.

In 1957 a schoolboy, Roger Mason found the first fossils, from the Woodhouse Beds (Ford, 1958). They were named *Charnia masoni* Ford (featherlike structure attached to a disc) and *Charniodiscus concentricus* Ford (disc only). This author thought them to be algae of Himanthalian type (brown seaweed). In the later paper, Ford (1962), reported that Glaessner suggested a comparison of these Charnian fossils with modern Pennatulids (sea pens), based

Mercian Geol. Vol.6, No.4, 1978, pp.291-296, 2 text-figs. Plates 21, 22, 23.

on finds made in Australia and Africa (Glaessner, 1959). *C. concentricus* was later found at a second locality in Charnwood Forest (Ford, 1963). The various affinities of this fossil were reconsidered and it was concluded that an open mind be kept until further work had been undertaken. In (1968) he recorded a larger disc-like impression which he called *Cyclomedusa davidi* Sprigg (locality and horizon unspecified).

Ages of Charnian rocks, based on radio-active dating of the intrusive members, have appeared in three papers. Miller & Podmore (1961) dated the markfieldites (southern diorites) by the potassium-argon method at 690 million years old. They are intruded into the Woodhouse Beds in which fossils were found, thus making these sediments more than 700 m.y. in age and placing them in the younger Pre-Cambrian. Meneisy & Miller (1963) described the sedimentary rocks as ranging from 600 m.y. to 684 m.y. by the K-Ar. method, based on dating of some of the porphyroids, markfieldites and the Mountsorrel Granite. Cribb (1975) using the rubidium-strontium method, recorded the markfieldites as being 552 ± 58 m.y. and concluded that they were probably late Pre-Cambrian or early Cambrian in age. He said that they were younger than was originally thought, and considered that the slates into which they were intruded were Brandian in age; an idea which was originally postulated by Hill & Bonney (1878).

Pre-Cambrian fossils have been found from other localities in the world and two of these are used for comparison with the Charnian fossils. In the 1940's a fauna of jellyfish medusae and polychaete worms was discovered in the Pound Quartzite at Ediacara, South Australia. These were described in several papers of which Sprigg (1947), Sprigg (1949), Glaessner (1959), Glaessner & Daily (1959) and Glaessner & Wade (1966) are some. *Cyclomedusa* was first described and named by Sprigg (1947). In 1969, Misra described dendritic, leaf-like and circular impressions from Mistaken Point, Newfoundland, Canada. One medusa and one problematical impression from Charnwood Forest are compared with those from the Canadian locality.

Pre-Cambrian Fossils

Many exposures of Pre-Cambrian rocks in Charnwood Forest were examined for fossils. In addition to direct observation and photographs, 'brass-rubbing" techniques have been borrowed from the art world to aid interpretation of organic remains observed in the rock faces. This technique (a first, for The Mercian Geologist) consists of placing plain paper over the fossil and producing an image, by rubbing the surface of paper placed over the object, with Cobbler's heel wax. Text-fig. 2, p. 294 was produced in this way and then photographed and enlarged slightly. Organic remains have now been recorded from the Blackbrook Beds, the Woodhouse Beds (most specimens) and the Brand (?) Beds. The last correlation depends on Cribb's latest interpretation of the age of the slates into which the markfieldites are intruded.

In the interest of conservation details of localities have been withheld from this article, although they were given to the Editor and made available to the Referee. Details of the localities will be given by the author to *bona fide* research workers in this field.

Description of the fossils

New Charnian fossils were recorded from five localities. They have been allocated either to the genus *Cyclomedusa* or to the taxon, problematica.

Phylum Coelenterata

Class Hydrozoa (?) or Scyphozoa (?)

Genus *Cyclomedusa* Sprigg, 1947

Cyclomedusa cf. *davidi* Sprigg, 1947 (Plates 21, figs 3 & 4, and 22, fig. 1).

From a loose block of fine-grained ashes of possible Brand age, four specimens of *Cyclomedusa* cf. *davidi* Sprigg, 1947 were seen on a bedding plane. This was broken during quarrying and parts of three specimens retrieved. All four specimens were ovoid in shape with a slightly convex raised outer ring which was separated from an ovoid, central raised disc by a concave shallow depression. Specimens 1 (lost) and 2 measured 10×6 cm (Plate 21, fig. 4); specimen 3 17×10 cm (Plate 21, fig. 3) and specimen 4 had a flatter mineralized outer ring, extra inner ring and flatter central disc; this measured 17×8 cm (Plate 22, fig. 1). The three retrieved specimens showed some scalloping or frilling of their outer rings. All four were preserved as impressions. They have been placed in the species *Cyclomedusa* cf. *davidi* but tend to be larger than those originally described by Sprigg (1947) and do not show the pronounced radial lines of *C. gigantea* Sprigg.

Cyclomedusa sp. (cover photograph and Plate 21, figs. 1 & 2)

Four specimens of this genus were found on a bedding plane of the Woodhouse Beds. Two were well-defined, the third poor and the fourth broken. All four were ovoid in shape with their axes of greater length parallel with the cleavage direction which possibly indicated some deformation during metamorphism. The two well-preserved specimens showed prominent concentric, closely-spaced rings with a slightly raised small central disc from which issued one or two ill-defined bud-like structures. The largest specimen measured 22×16 cm, the second 7.5×2.2 cm and the remaining two were smaller and/or incomplete. The two larger specimens have also been likened by the author to *Madigania annulata* Sprigg 1949 which Glaessner & Wade (1966) placed in the genus *Cyclomedusa*.

Problematica

Six specimens of unknown affinity are regarded as problematica. They have been compared with forms from Newfoundland and Ediacara.

1. *Medusae* (?) Plate 22, figs. 2 & 3.

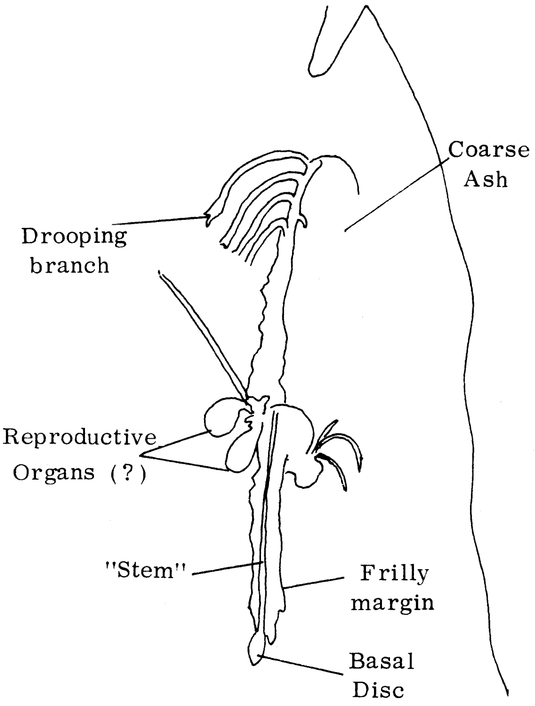
Three specimens of possible medusae were found on a bedding plane of the Blackbrook Beds, the oldest Charnian group of rocks. Each had slightly different morphology. One showed a three-fold form which may represent budding. Two circular medusae adjacent to each other showed pronounced internal structure and the third bud was only partially preserved. The whole organism measured 15×15 cm and the structures were represented by raised fairly thick ridges. The second specimen was more ovoid in form with a margin of wispy "curls" on it and again traces of internal structure. The long axis measured 12 cm. The third was circular in shape with an irregular margin and well-pronounced internal structure. It was poorly preserved but not unlike an unamed form pictured by Misra (1969 Plate 6B).

A fourth specimen (Plate 22, fig. 4) was found on a bedding plane at Markfield. This medusa (?) showed a single ovoid ring with raised ridge margin and two small knobs internally. It measured 15×9 cm and could be compared with a deformed shape of *Beltanella gilesi* Sprigg, 1947.

2. Two specimens of another problematical fossils were found in coarse-grained ash of the Woodhouse Beds. The larger one showed a well-defined basal knob-like disc from which arose a "stem" 13 cm long which was of fibrous nature and had frilly margins. After careful washing more structures appeared. The stem was offset to one side and from the apex there appeared to be a number of drooping branches. Halfway along the stem several sac-like structures could be seen which might have been reproductive organs. The smaller specimen was very poorly preserved and showed only drooping branches from a 'stem". It may have been a juvenile form. A sketch showing this morphology taken from Plate 23, fig. 1 is shown in text-fig. 1, p. 294.

3. "Water lily-like" fossil

From the *Charnia* crag (Ford, 1963) a "water lily-like" fossil was noted Plate 23, fig. 2) and is likened to a dendrite-like organism featured by Misra (1969 Plate 6A).

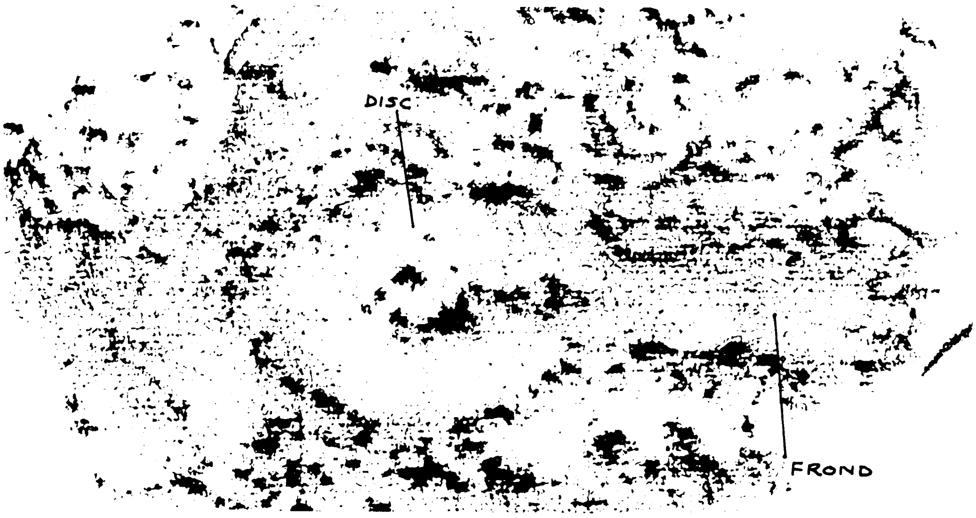


Text-fig. 1. Line drawing of "*Arborea*" taken from photograph. This fossil cannot be likened with any certainty to recorded fossils. A tentative suggestion is made here, that the specimens show some similarities to the species *Arborea arborea* Glaessner & Wade (1966). This genus was first called *Rangea* Glaessner & Daily (1959), *Rangea* being the name given to forms allied to *Charnia masoni* Ford, by Glaessner (1959).

Further notes on *Charniodiscus concentricus* Ford

Discs of *Charniodiscus concentricus* were studied in detail from Bradgate Park and Nanpantan. One part of the bedding plane of the *Charnia* crag was chosen for detailed wax rubbing. It measured two square feet and showed a cluster of discs with apparent long fronds attached and intertwining of the discs. Some of the fronds showed dichotomy at the tips. From a nearby crag of the Beacon Hill Beds possible associated fronds are shown in proximity to two discs (Plate 23, fig. 4).

Two discs, one on the *Charnia* crag and one from Nanpantan, appeared to show a stipe or frond arising from a disc (Plate 23, fig. 3).



Text-fig. 2. Wax rubbing of a disc from which arises a short branch; from a bedding plane at Nanpantan (x3).

The possible proximity and/or attachment of discs and fronds suggests that the original idea (Ford, 1958) of *C. concentricus* being the disc attachment of a Himanthalian seaweed may be correct and that these organisms lived and died in colonies.

Acknowledgements

I would like to thank the twelve students and their families for their hard work in the searching of the Charnian rocks. My special thanks go to Mrs. M.J. East and to my husband and daughter for their unfailing enthusiasm and careful observations. I gratefully acknowledge the help of a number of professional colleagues, especially Dr. T.D. Ford, and thank land owners who granted permission to visit their properties.

References

CRIBB, S.J. 1975. Rubidium-strontium ages and strontium isotope ratios from the igneous rocks of Leicestershire, *Q. Jl. geol. Soc.*, vol.131, pp.203-212.

FORD, T.D. 1958. Pre-Cambrian fossils from Charnwood Forest, *Proc. Yorks. Geol. Soc.*, vol.31, pp.211-217.

FORD, T.D. 1962. The oldest fossils, *New Scientist*, vol.15, pp.191-194.

FORD, T.D. 1963. The Pre-Cambrian fossils of Charnwood Forest, *Trans. Leic. Lit. and Phil. Soc.*, vol.57, pp.57-62.

FORD, T.D. 1968. *Geology of the East Midlands*, Leicester. 400 pp. Sylvester-Bradley, P.C., and Ford, T.D. (Eds.)

GLAESSNER, M.F. 1959. Pre-Cambrian Coelenterata from Australia, Africa and England, *Nature*, vol.183, pp.1472-1473.

GLAESSNER, M.F. 1959. The Geology and Late Pre-Cambrian fauna of the Ediacara Fossil Reserve, *Rec. S. Aust. Mus.*, vol.13, pp.369-401.

GLAESSNER, M.F., and WADE, M. 1966. The Late Pre-Cambrian fossils from Ediacara, South Australia, *Palaeontology*, vol.9, pp.599-628.

HILL, E., and BONNEY, T.G. 1877-8. The Precarboniferous rocks of Charnwood Forest, *Q. Jl. geol. Soc.*, Pt,1, vol.33, pp.754-789, pt.2, vol.34, pp.199-239.

MEINSY, M.J. and MILLER, J.A. 1963. A Geochronological study of the crystalline rocks of Charnwood Forest, England, *Geol. Mag.*, vol.100, pp. 507-523.

MILLER, J.A. and PODMORE, J.S. 1961. Age of Mountsorrel Granite, *Geol. Mag.* vol. 98, pp.86-88.

MISRA, S.B. 1969. Late Precambrian (?) fossils from South East Newfoundland, *Bull. geol. Soc. Am.*, vol.80, pp. 2133-2140.

SPRIGG, R.C. 1947. Early Cambrian (?) Jellyfishes from the Flinders Ranges, South Australia, *Trans. Roy. Soc. S.Aust.*, vol.71, pp.212-234.

SPRIGG, R.C. 1949. Early Cambrian "jellyfishes" of Ediacara, South Australia and Mount John, Kimberley District, Western Australia, *Trans. Roy. Soc. S. Aust.*, vol.73, pp.72-99.

WATTS, W.W. 1947. Geology of the Ancient rocks of Charnwood Forest, Leicester, 160 pp.

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Explanation for Plates 21 - 23, Cover (this issue)

Cover photograph		*Cyclomedusa* sp. Sprigg (×0.5). Woodhouse Beds. Direction of cleavage shown by five broken lines parallel with the long axis of the medusa. (Photograph by D. Boynton).
Plate 21.	fig. 1.	*Cyclomedusa* sp. Sprigg (×0.5) showing concentric rings, central disc and "bud" arising to north east side.
	fig. 2.	*Cyclomedusa* sp. Sprigg (×0.4). Cleavage direction clearly visible parallel with long axis of medusa.
	fig. 3.	*Cyclomedusa* cf. *davidi* Sprigg (×0.5)
	fig. 4.	*Cyclomedusa* cf. *davidi* Sprigg (×0.5) with frilling of outer ring.
Plate 22.	fig. 1.	*Cyclomedusa* cf. *davidi* Sprigg (×0.4). Broken specimen.
	fig. 2.	Medusae (?) showing three-fold budding (?) (×0.5). Blackbrook Beds.
	fig. 3.	Medusa showing irregular margin and some internal structure (×0.5).
	fig. 4.	Ovoid medusa with faint internal structure allied to *Beltanella gilesi* Sprigg (×0.75).
Plate 23,	fig. 1.	Specimen with long fibrous axis, small basal disc, sacs at halfway point and faint drooping branches, allied to *Arborea arborea* Glaessner & Wade, (×0.5). Woodhouse Beds.
	fig. 2.	"Water-lily" specimen (×0.5), *Charnia* crags, Woodhouse Beds.
	fig. 3.	*Charniodiscus concentricus* showing germination ? of a stipe by two buds ? (×1)
	fig. 4.	Two specimens of *C. concentricus* with possible associated fronds to the left of the discs (×0.5). Beacon Hill Beds.

ALL PLATES - VIEW FROM RIGHT HAND MARGIN

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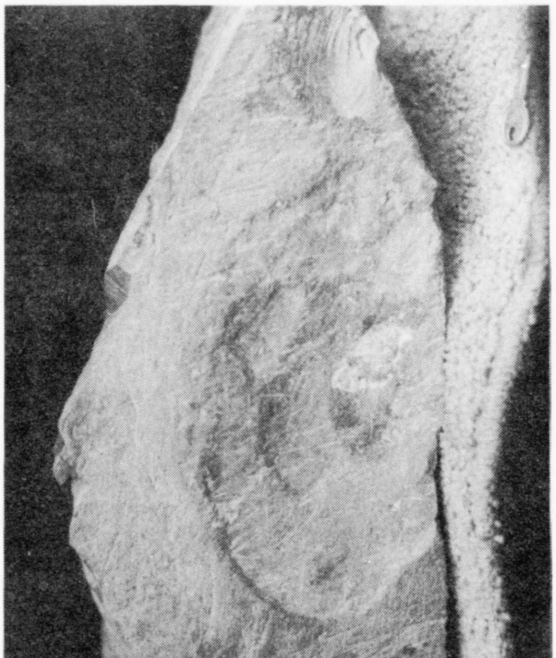

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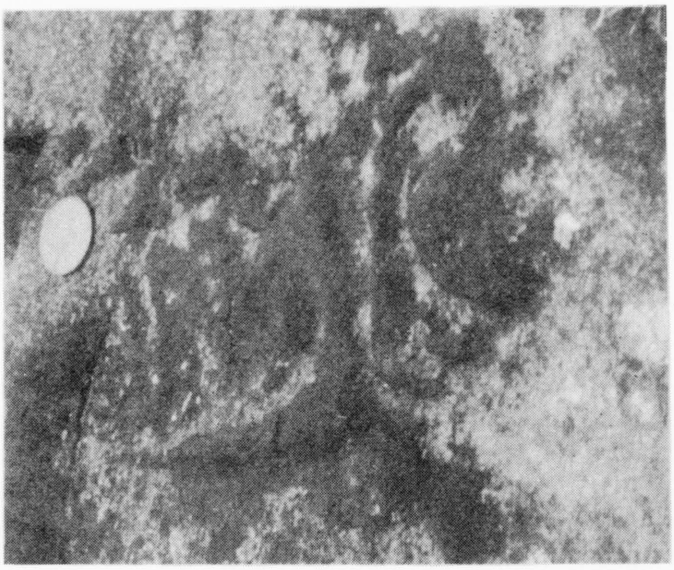

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Boynton, H. E. Charnwood Fossils.
(for explanation see p. 296)

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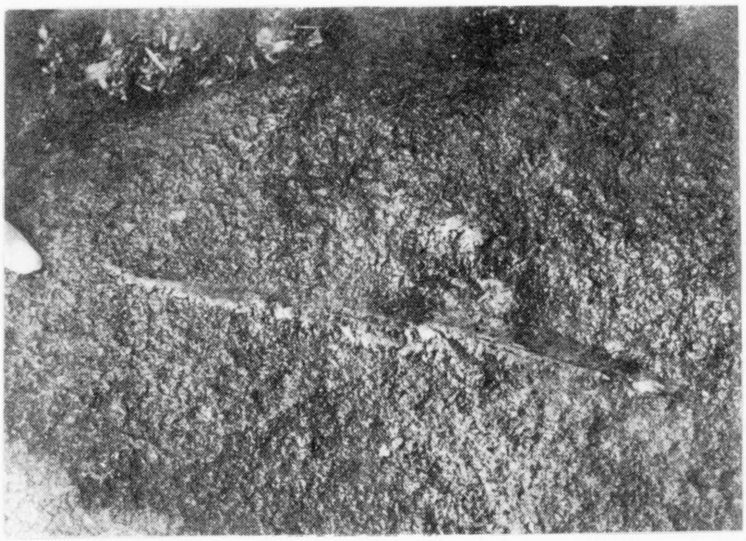

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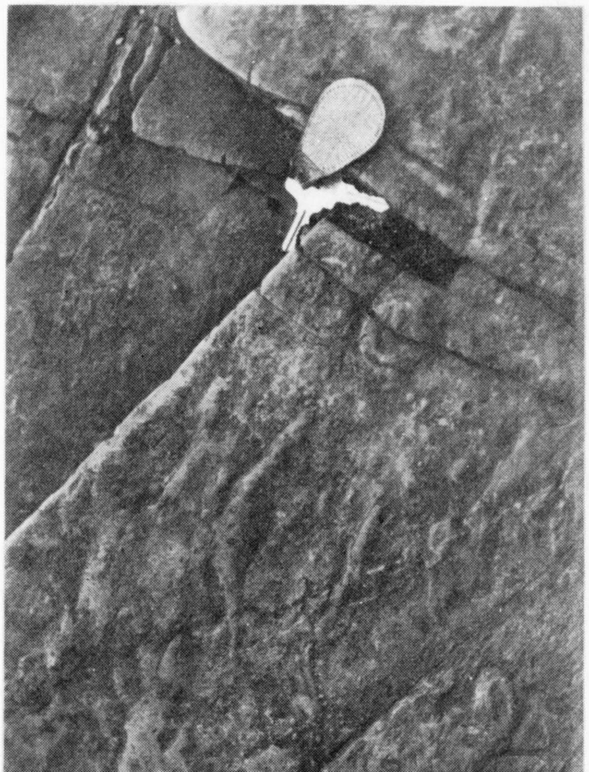

Boynton, H. E. Charnwood Fossils.
(for explanation see p. 296)

EXCURSION REPORT. IGNEOUS ROCKS OF CHARNWOOD FOREST

Leader - R.B. Elliott — Sunday, 4th July 1976

A large party left Nottingham about 9 a.m., and drove down the M1 to Exit 23 and the first stop at the Amey Roadstone quarry at Newhurst, Leicestershire (SK 487180). The quarry which was formerly the Charnwood Granite Quarry illustrates an elongated plug-like intrusion into volcanic tuffs with both faulted and intrusive margins, copper mineralisation and the unconformity of Triassic marls on Pre-Cambrian volcanics. The intrusion is an example of the Northern Diorites and members were able to see the altered mineralogy of two felspars, hornblende and epidote; the tuffs are lithified ash-fall deposits belonging to the Blackbrook Series; the main copper minerals found were malachite, bornite and chalcopyrite. Considerable interest was shown in the interpretation of the rough pre-Triassic surface, with its breccia covering, and deeply stained underlying rock as an old desert surface.

The excursion continued to High Sharply, which is owned by Squire de Lisle who had given us permission to visit on the condition that we left hammers in the bus. The rock here is a porphyroid of Peldar-type and is rhyolitic in composition. The western end of the crags has sheared nodular rocks, nevertheless with recognisable crystals of quartz and feldspar; the eastern end, reached by a delightful walk over short upland grass in brilliant sunshine, shows more clearly the primary porphyritic nature of the rock and gives long views over the Blackbrook Valley.

Whitwick Quarry (SK 444160) has unsheared Peldar-type porphyroid and illustrates some of the problems concerning the origin of 'porphyroids'. Many of the crystals are large and the aspect of the rock is coarse and intrusive. On the other hand, we were able to see on the many large fresh surface that parts of the rock are breccia-like with a structure akin to that of a flow-brecciated lava.

Lunches were eaten and/or drink at the Castle Rock (SK 453157) where thirsty geologists are always welcome.

After lunch with sun temperatures quite appropriate to a volcanic excursion the party welcomed the cool dappled shade of Cademan Wood (SK 446170. Here the members were able to see almost non-porphyritic porphyroids, the Grimley type porphyroid (SK436167) with its 'microphenocrysts' and some spectacular agglomerates with large porphyroid blocks in a fine-grained matrix. These coarse pyroclastic rocks are thought to indicate the near proximity of a volcanic vent.

The excursion then headed south to Cliffe Hill where there is a large quarry in Markfieldite (Monzonite) which is a distinctive decorative stone much used in past years for curbstones and setts. Its junctions with the enclosing volcanic tuffs are displayed at several places and members were able to see the Markfieldite in its normal coarse facies, fine-grained marginal facies, spotted contact rocks and epidote veining. After an hour in here, when several of us were beginning to look rosy, and rather flat tepid water from the garage tap was declared to be nectar, it was time to seek the shade of the bus and head back home.

The party returned to Nottingham about 5.30 p.m.

R.B. Elliott,
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The University,
Nottingham.

Mercian Geol. Vol.6, No.4.
1978, p.297.

WEEKEND EXCURSION: NORTH CROP OF THE SOUTH WALES COALFIELD

Leader: J.D. Weaver 6th - 8th May 1977

General Geological Setting

At the close of Silurian times the Lower Palaeozoic rocks were uplifted and folded by the Caledonian earth movements, which uplifted the Welsh area to form "St. George's Land". The sea retreated southwards and in Southern Britain was confined to the Devon and Cornwall area. South Wales appears to have been a low lying coastal plain with the sea to the south and mountains rising to the north, throughout Devonian times.

The sequence is divided into two parts by an unconformity which cuts out the middle Old Red Sandstone deposits. The Lower Old Red Sandstone starts with 45 m of shales and siltstones passing upwards into a thick sequence of shales, mudstones and siltstones (Red Marls 1,070 m) which are followed by 600 - 900 m of sandstones and conglomerates (Senni Beds and Brownstones Table 1). These deposits appear to be floodplain and river channel deposits with the sediment almost entirely derived from the north. Lying unconformably on top of the Lower, is the Upper Old Red Sandstone which, along the North Crop of the South Wales coalfield, grades upwards into the Dinantian limestones. The Upper Old Red Sandstone Group is composed of sandstones and conglomerates, which reach a maximum thickness of about 100 m in the Black Mountains of Carmarthenshire and Breconshire (Plateau Beds and Grey Grits). These deposits are interpreted as those of southward flowing rivers on a coastal plain.

At the close of Devonian times the sea invaded this flat lying coastal plain and the marine sequence of limestones of the Dinantian were deposited. The junction between the Upper Old Red Sandstone and the basal limestone shales shows a gentle advance of the sea and in places the junction appears to be conformable. The Dinantian sequences in the Tawe and Neath Valleys are incomplete, (Tables 1 and 2), the mid-Dinantian unconformity being strongly developed. At Abercraf the basal K zone limestones and shales are followed by the S_2 zone dark grey limestones and the D zone oolites and siliceous limestones, while at Penderyn the Z and C_2S_1 zones are thinly developed below the S_2 and D zones. The limestones were mostly deposited in a clear shallow sea with little influx of terrigenous sediment.

At the close of Dinantian times earth movements led to a radical change in the environment of deposition and the Namurian rocks were laid down unconformably on those of the Dinantian. It has been suggested (Jones 1974) that the Namurian sediments in South Wales resulted from the southward and southwestward spread of coastal flat and deltaic conditions. The Namurian is about 245 m thick composed of a sequence of sandstones and conglomerates (Basal Grit) followed by a sequence of shales with some thin sandstones (Namurian Shales). Marine horizons yielding goniatites allow correlation. The top of the Namurian is marked by the base of the *Gastrioceras subcrenatum* Marine Band.

The Wesphalian starts with a new phase of fluvial sedimentation reflected by the sands of the Farewell Rock. The Coal Measures are composed almost entirely of terrigenous detritus derived from nearby sources and carried into a shallow, subsiding trough of sedimentation by rivers from a landmass lying mainly to the north. Secondary sources of sediment are found in the east early in Westphalian times and in the south in late-Westphalian times. The lower Wesphalian is dominated by shales and the upper Westphalian by sandstones.

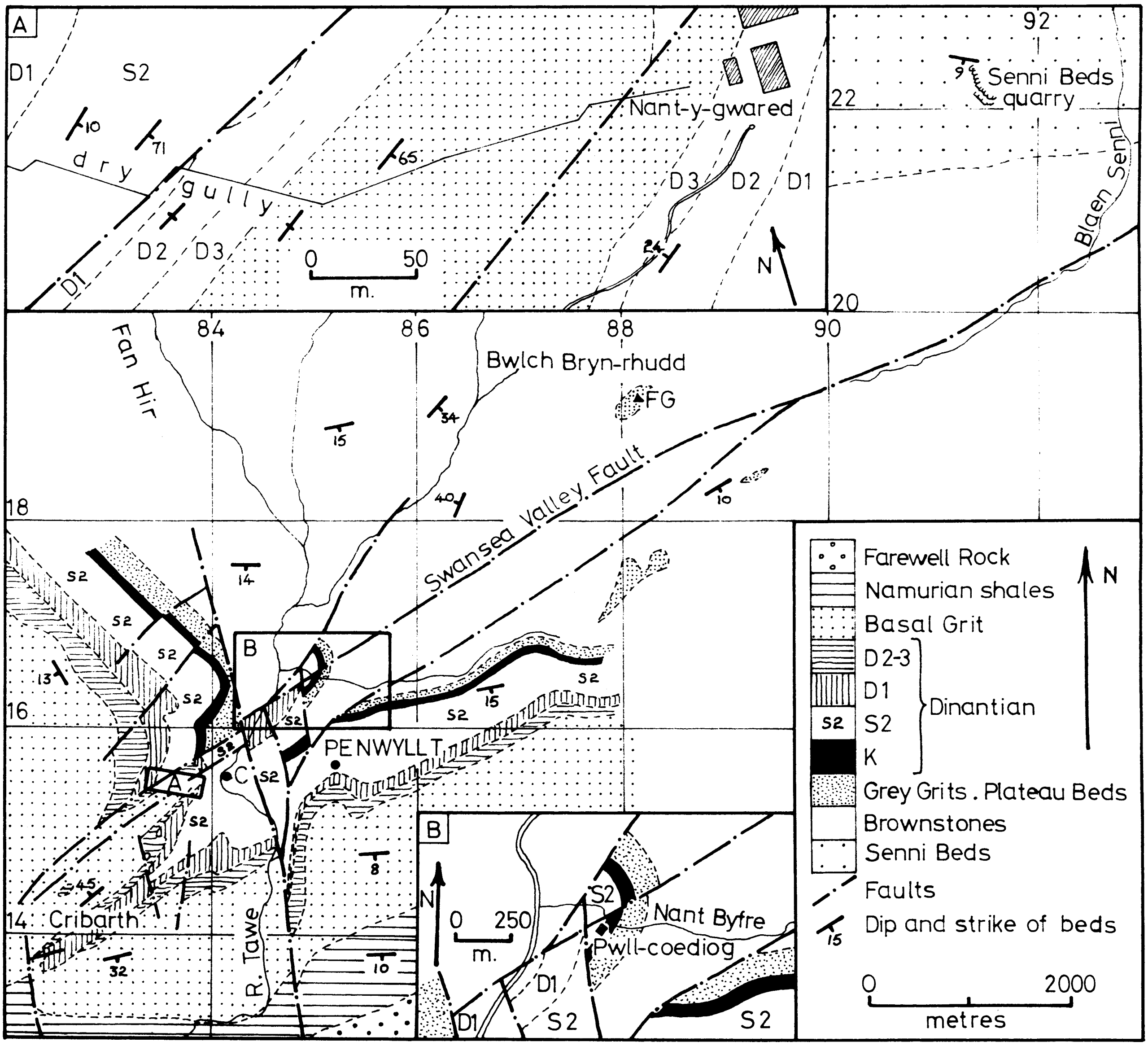
At the close of Westphalian times the whole of the South Wales area was affected by the Variscan orogeny which caused faulting, and folding of the Upper Palaeozoic rocks and no Stephanian, Permian or Lower Triassic rocks are thought to have been deposited. Sequences of Upper Triassic and Mesozoic rocks are now confined to the Vale of Glamorgan although they may once have covered much larger parts of the South Wales area.

Mercian Geol, Vol.6, No.4. 1978.
pp.299-306, text-figs. 1-4.

Quaternary till and peat deposits are scattered over the North Crop area and the Neath and Tawe Valleys were overdeepened by glacial action and have fairly thick layers of alluvium.

The main structural elements of South Wales are the E-W folds of the main coalfield, and Gower and southwest Dyfed; the NW-SE faults of the coalfield; and the NE-SW fault zones, which cut across the north-western edge of the coalfield. The North Crop of the coalfield forms the northern limb of the main synform, the dips are gentle, ranging from 5° to 30° southwards but generally about 15° to 20°. This limb is cut by a number of NNW-SSE and NW-SE dextral wrench faults and normal faults, usually with westerly downthrows and two powerful NE-SW shear zones, the Vale of Neath and Swansea Valley Disturbances.

The Neath Disturbance crosses the coalfield from Bryniau Gleision (7 km NNE of Merthyr Tydfil) to Glynneath and may extend from the Woolhope area in the north-east to Swansea Bay in the south-west (Owen 1954). The main structural elements of the Neath Disturbance are: impersistent NE-SW folds, which plunge south-westwards; the Dinas Fault, which is a NE-SW sinistral wrench fault with a displacement of 1,200 m; the Coed-Hir Fault, which is a NE-SW normal fault with a consistent southerly downthrow; and a large number of NW-SE faults, some of which have acted as dextral wrench faults, some as normal faults and some showing both wrench and normal movements.



Text-fig. 1. The geology of the area around Craig-y-nos, at the head of the Tawe Valley.
C. Craig-y-nos FG. Fan Gihirych

TABLE 1 Succession at the upper end of the Tawe Valley

			Thickness in metres
CARBONIFEROUS	WESTPHALIAN	Part of Upper Coal Measures, Pennant Sandstone - Rhondda and Llynfi Beds	400
		Middle Coal Measures	420
		Lower Coal Measures ("Farewell Rock" 40 m at base)	400
		Gastrioceras subcrenatum Marine Band	
	NAMURIAN	Shale Group	90
		Basal Grit	75
		Unconformity	
	DINANTIAN	D_3 zone shales and limestones	0-3
		D_2 zone cherty limestones	2-24
		D_1 zone oolites	12-18
		S_2 zone dark-grey limestones	60-150
		Unconformity	
		K zone shales and limestones	20-30
DEVONIAN	UPPER O.R.S.	Grey Grits	0-60
		Plateau Beds	6-25
		Unconformity	
	LOWER O.R.S.	Brownstones	425
		Senni Beds	300

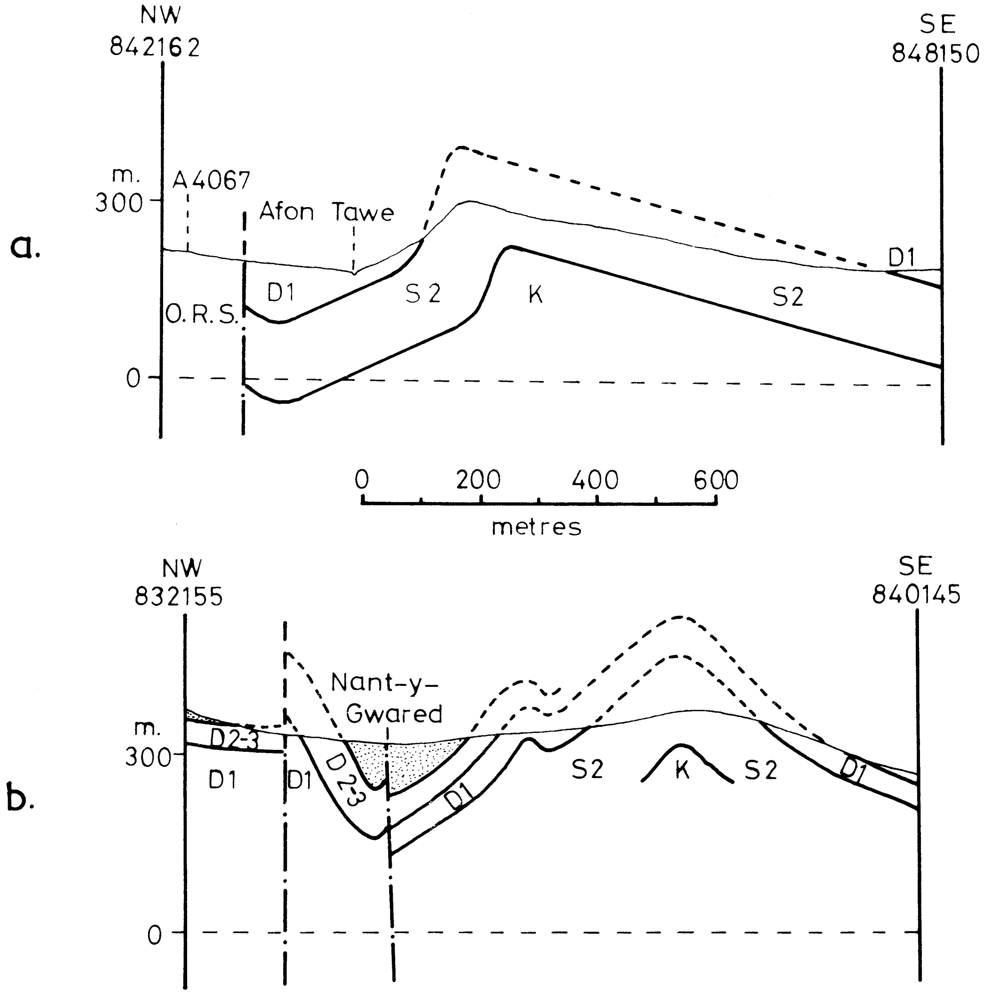
The Swansea Valley Disturbance is a similar line of faulting lying some 8 to 10 km north-west of the Neath Disturbance. This fault zone extends from Blaen Senni to Clydach and may extend north-eastwards to the Clee Hills and south-westwards to Swansea Bay (Weaver 1975). The main structural elements of the Swansea Valley belt are: NE-SW folds; a number of NE-SW faults, the main one of which, the Swansea Valley Fault, has a sinistral wrench component varying between 200 and 530 m; and a number of important NNW-SSE and NW-SE faults, some of which show wrench movements, some vertical movements and some both wrench and vertical movements.

Saturday A study was made of the Devonian (Old Red Sandstone) and Lower Carboniferous successions exposed in the upper part of the Tawe Valley. The party assembled at Bwlch Bryn-rhudd (SN 869196) at the head of the Tawe Valley. From this point the general features of the area are seen, in particular, the folding of the Carboniferous rocks on Cribarth (SN 830142) and the line of the main fault zone of the Swansea Valley Disturbance (text-fig.1). In the road cutting at Bwlch Bryn-rhudd the Brownstones (table 1 above) of the Lower Old Red Sandstone were examined. They consist of red-brown sandstones, siltstones, mudstones and a well developed mud flake conglomerate. Cross-bedding and ripple marks were considered to indicate river deposition, a muddy horizon having been ripped up by a river carrying sand to produce the mud flake conglomerate.

Proceeding north-eastwards towards Heol Senni the party visited a large disused quarry excavated in the Senni Beds (SN 914222). These were seen to be composed of grey and greenish-grey micaceous sandstones and siltstones with some thin shaly and some conglomeritic horizons. Some of the conglomerates contained numerous rounded fragments of a light grey, micritic limestone. The possible provenance of these fragments was discussed and it was noted that the nearest, present day, surface outcrops of limestones older than the Old Red Sandstone were in the Welsh Borderland, Silurian sequences. The possibility of other limestone outcrops, since eroded, was also discussed. Abundant mica in the sandstones gave them a mirror finish on fresh surfaces. Within the more silty horizons prolific, fairly well preserved, psilopsid plants were found.

The party then travelled south-westwards along the A4067 towards Abercraf. A brief stop was made at Pont Gihirych (SN 887211) to observe the mid-Devonian unconformity between the Plateau Beds and the Brownstones on the Fan Hir (SN 832200) and Fan Gihirych (SN 886190) escarpments. Continuing south-westwards the party assembled at Pwll-coediog farm (SN 849164) and walked to Nant Byfre (SN 851164). In this stream section the Upper Old Red Sandstone Plateau Beds and Grey Grits succession was studied. The Plateau Beds were seen to be composed of red-brown sandstones and siltstones and were overlain by grey, quartz conglomerates and coarse, grey sandstones of the Grey Grits. In the Plateau Beds about 1 - 2 m below the base of the Grey Grits a thin horizon of friable sandstone, 40 mm thick, yielded plates of the armoured placoderm *Bothriolepis* and also specimens of the brachiopod *Cyrtospirifer verneuili*. About 4 m below this horizon another thin friable sandstone yielded additional fish plates. Some trace fossil burrows were also noted in the sandstones above this second fish bed.

After lunch the party assembled at Craig-y-nos Castle (SN 840154) and proceeded up the track on the north side of the A4067 to Nant-y-gwared farm. From the track the folding associated with the Swansea Valley Disturbance was observed on Craig-y-Rhiwarth (SN 844157 text-fig. 2a) and at the north-east end of Cribarth (SN 839151 text-fig. 2b). In a dry gully



Text-fig. 2. a. Section across Craig-y-Rhiwarth
b. Section across the north-eastern end of Cribarth

TABLE 2 Succession at the upper end of the Neath Valley

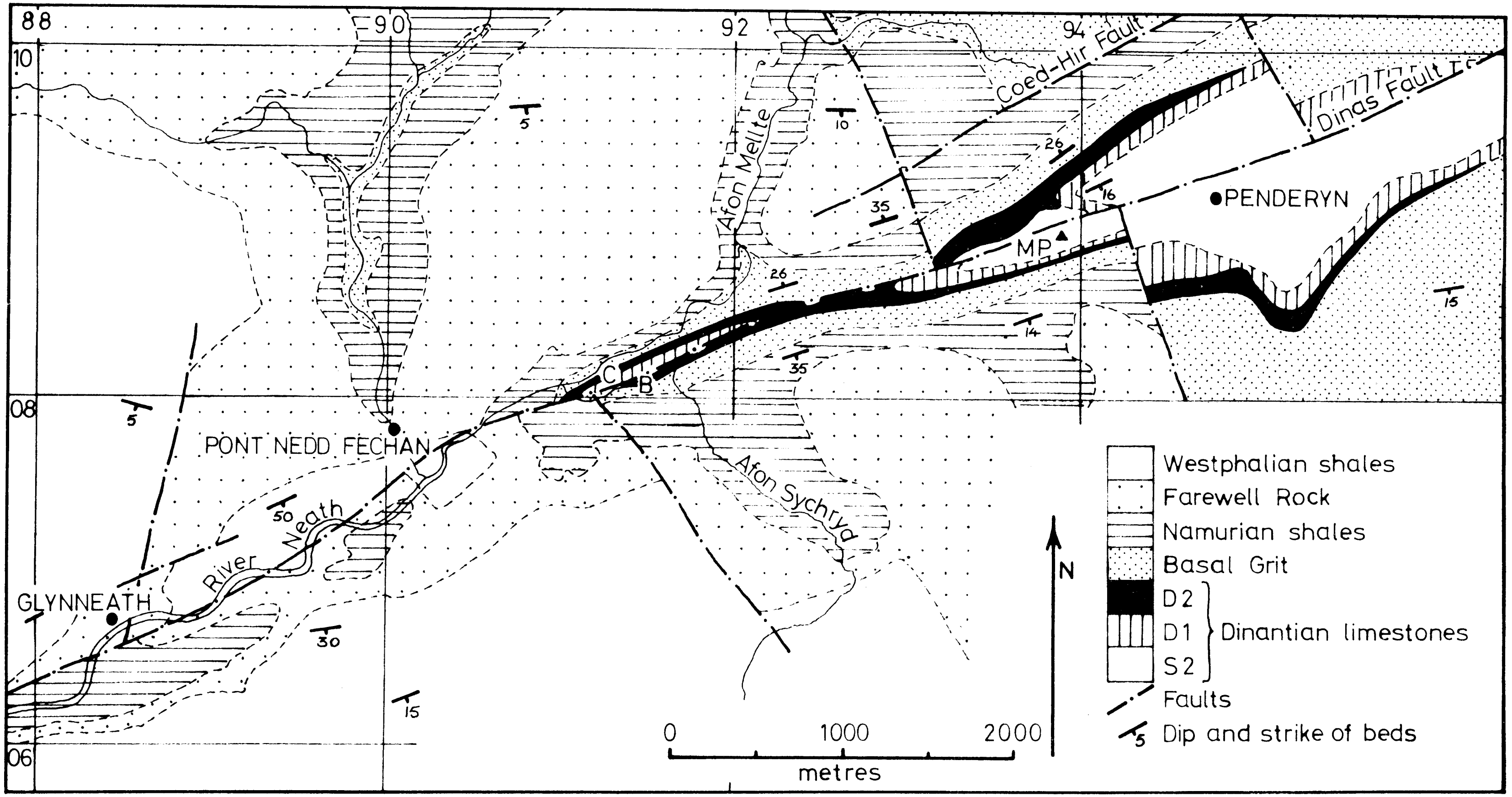
			Thickness in metres
CARBONIFEROUS	WESTPHALIAN	"Farewell Rock"	40 - 60
		Gastrioceras subcrenatum Marine Band	
	NAMURIAN	Shale Group	45 - 60
		Basal Grit	35 - 45
		Unconformity	
	DINANTIAN	D_2 Dark limestones	0 - 18
		D_1 Light oolite (Honeycomb Sandstone at base)	6 - 18
		S_2 Dark-grey limestones	90 - 120
		Z & C_2S_1 Rubbly limestones, oolite and dolomite	16 - 26
		K shales and limestones	24 - 30
DEVONIAN	UPPER O.R.S.	Grey Grits and Plateau Beds	45 - 60
		Unconformity	
	LOWER O.R.S.	Brownstones	at least 450

(SN 836155) running north-westwards from the farm a near vertical sequence of Carboniferous Basal Grit and D and S_2 zone limestones is seen. The inclination of the beds at this locality has been produced by the faulting. The Basal Grit is seen to be composed of coarse siliceous sandstones and quartz conglomerates. They are underlain by black calcareous shales and thin limestones of the D_3 zone, which are poorly exposed. Better exposure of these beds is found in the stream section, about 125 m south-west of the farm, where they yielded various brachiopods including *Eomarginifera longispina*, zaphrentid corals and crinoidal debris. Specimens of the trilobite *Griffithides* cf. *barkei* have also been found at this locality. In the dry gully the D_2 zone limestones are well exposed and consist of black siliceous limestones with nodules of chert. These are underlain by the D_1 light grey oolitic limestone, which is faulted against S_2 zone grey, crystalline limestones, yielding *Composita sp.* and some solitary corals.

The party travelled to Penwyllt (SN 854158) on the eastern side of the Tawe Valley and examined the limestone sequence and overlying Basal Grit in a line of quarries extending from SN 856160 to SN 855151. The most northerly of these quarries displayed the uppermost part of the K zone limestones and thin shales and the basal part of the S_2 zone limestones. Although the Z, C_1 and C_2S_1 zones are absent the junction between the S_2 and K zones appears to be conformable. About 2 m above the base of the S_2 zone a band of corals, about 0.3 m thick, showed good examples of *Lithostrotion martini* in life position. Other corals were collected from these limestones including *L. junceum* and *Syringopora*. Many brachiopods were also found including the zone fossil *Composita ficoides*. Walking southwards the party passed the main working quarry, which is in the middle part of the S_2 zone, and visited two small quarries, the first in the D_2 cherty limestones and the second in the Basal Grit. Heavy rain did not encourage a lengthy stay at these last exposures, but a well developed channel running N-S was observed in the Basal Grit. It was noted that the Basal Grit sequence here exhibited carbonaceous shales interbedded with sandstones and conglomerates.

On the return journey to Neath the party stopped briefly on the A4067 at Ystalyfera (SN 762078). From this vantage point the Upper Coal Measure, Pennant Sandstone Group, was observed to have slumped over the Middle Coal Measures on both sides of the valley. The most spectacular slump scars are seen on the south-east side of Mynydd Allt-y-grug, above the village of Godre'r-graig (SN 750070). Time did not permit a closer examination of the effects of this slumping in Godre'r-graig itself.

NOTE Permission must be sought from the farmers and quarry owners before visits are made to the localities listed above.

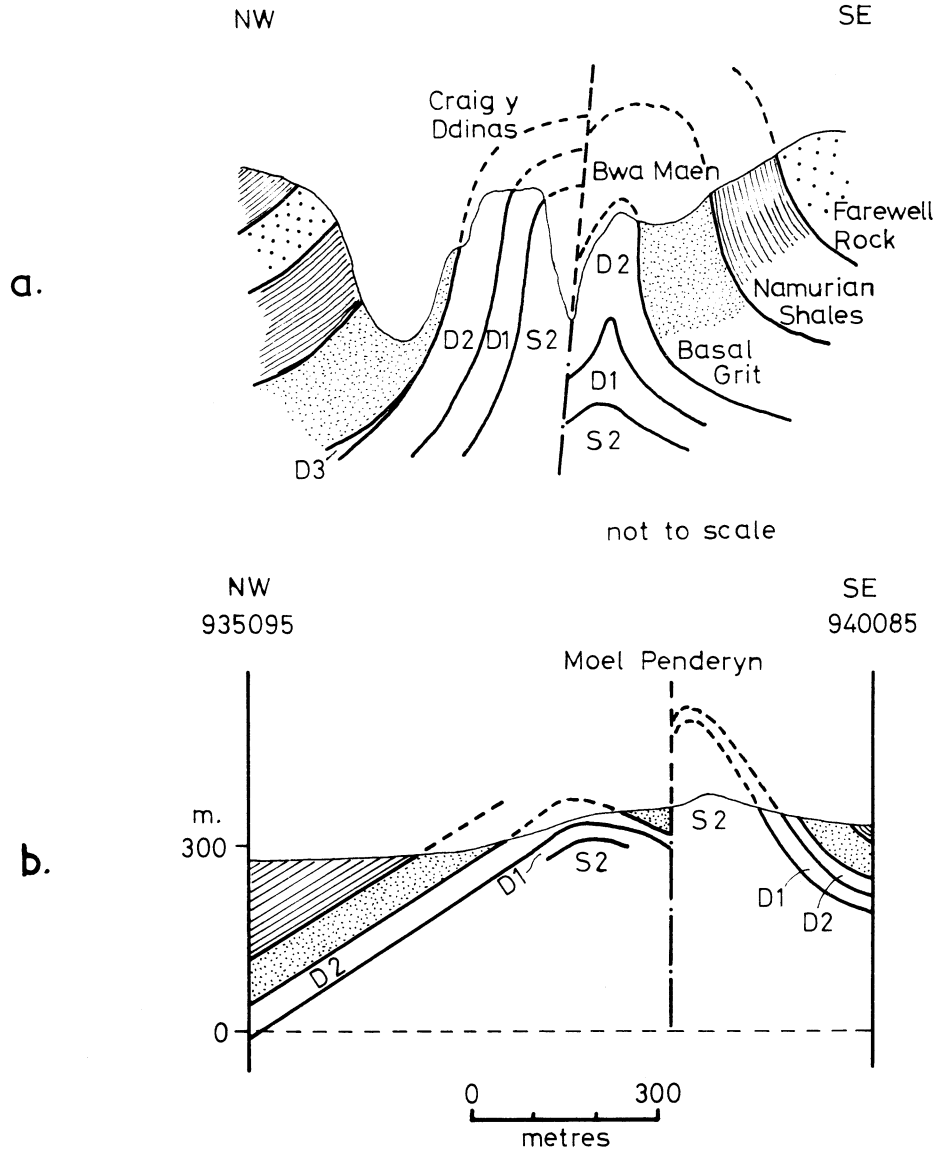


Text-fig.3. The geology of the area between Glynneath and Penderyn, at the head of the Neath Valley (after Owen, 1954).

B. Bwa Maen C. Craig y Ddinas MP. Moel Penderyn

Sunday A study was made of the Carboniferous sequences exposed in the upper part of the Neath Valley (text-fig. 3 and table 2). The party assembled at the Angel Hotel in Pont Nedd Fechan (SN 901077) and then walked up the right bank of the Nedd Fechan and examined the exposure of the basal Westphalian "Farewell Rock" and the upper Namurian shales and sandstones. Channeling, cross-bedding and load structures were observed in the "Farewell Rock" in a continuous section for about 150 m north of the Angel Hotel. At the base of the "Farewell Rock" sandstones, the *Gastrioceras subcrenatum* Marine Band, which marks the base of the Westphalian, was examined. Fragments of uncrushed *G. subcrenatum* were collected as well as bivalves including *Dunbarella sp.*; *Anthracoceras arcuatilobatum* has also been found at this locality. Within the overlying sandstones numerous plant fragments were observed, some of which were identified as *Calamites*. About 50 m upstream, underneath the prominent sandstone, the "Cumbriense Quartzite", a second marine horizon, *Gastrioceras cumbriense* Marine Band was investigated. This band yielded a rich fauna of *Gastrioceras sp.*, bivalves, brachiopods and plant fragments.

From here the party proceeded on foot along the right banks of the Afon Mellte and Afon Sychryd to Craig y Ddinas (SN 915079). In the exposures of Craig y Ddinas and Bwa Maen (bow of stone) and S_2 and D zone limestones are seen folded and steeply dipping along the line of the Dinas Fault (text-figs. 3 and 4a). Bwa Maen is seen to be an impressive anticline and like the folds along the Swansea Valley Disturbance it is related to the faulting of the Neath Disturbance.



Text-fig. 4. a. Section across Craig y Ddinas and Bwa Maen (after Owen *et al* 1965)
b. Section across Moel Penderyn

After lunch the party proceeded by car to Penderyn (SN 947089) and then on foot to Moel Penderyn (SN 939088) where a sequence of the S_2, D_1 and D_2 zone limestones and the lower part of the Basal Grit was examined on the north side of the anticline (text-fig. 4b). The S_2 limestones are exposed in two large quarries near the farm. They are composed of dark-grey limestones in the lower part of the sequence, becoming lighter in colour near the top with the development of pisolitic and oolitic horizons. The upper 20 m of these limestones yielded a rich fauna of corals and brachiopods including *Syringopora*, *Lithostrotion* and *Composita*. The base of the D_1 zone is marked by a calcareous sandstone known as the "Honeycomb Sandstone" (0.5 m thick), which weathers to give a honeycombed appearance. This horizon, which is found over a large part of the north crop of the coalfield, indicates the influx of detritus probably resulting from uplift of the land area to the north. The overlying D_1 zone limestones consist of light grey oolites with bands of productid brachiopods, mainly *Linoproductus hemisphaericus*. Continuing north westwards, outcrops of the D_2 zone dark grey limestones are seen above the track. One specimen of the trilobite *Griffithides sp.* and a number of productids were collected from these limestones. No exposure is seen of the D_3 zone and the Basal Grit quartzites and quartz conglomerates appear to lie directly on the D_2 zone limestones.

The party walked southwards over the northern side of Moel Penderyn into a large quarry, where the S_2 zone limestones are faulted against the Basal Grit (text-figs. 3 and 4b), along the line of the Dinas Fault. The Basal Grit at this locality is highly sheared and shattered.

References

JONES, D.G.	1974. The Namurian Series in South Wales. in - *The Upper Palaeozoic and Post-Palaeozoic rocks of Wales* (Ed.) T.R. Owen, University of Wales Press.
OWEN, T.R.	1954. The structure of the Neath Disturbance between Bryniau Gleision and Glynneath, South Wales. *Q. Jl. geol. Soc. Lond.*, vol.109, pp.333-365.
OWEN, T.R., RHODES, F.H.T., JONES, D.G., and KELLING, G.	1965. Summer (1964) Field Meeting in South Wales *Proc. Geol. Ass.* vol.76, pp.463-496.
WEAVER, J.D.	1975. The structure of the Swansea Valley Disturbance between Clydach and Hay-on-Wye, South Wales. *Geol. Jl.*, vol.10, pp.75-86.

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OBITUARY NOTICES

William Howson Wilcockson, M.A., F.G.S.

Many geologists, professional and amateur, will have felt as I did a sense of personal loss when they learned of the death, on 29th October 1976, of the subject of this notice.

William Howson Wilcockson was born on the 15th April 1891, the son of a Cheshire clergyman. After attending school at Alderley Edge he went to Repton, then under the headmastership of William Temple, who was later to become Archbishop of Canterbury. In view of these influences it is small wonder that, when he went as Exhibitioner and prizeman to Caius College, Cambridge, it was his intent to read Divinity with a view to ordination. There he became engrossed by the lectures in geology given by Thomas McKenny Hughes and decided instead on a career in science. His studies were so effective that he gained a double first in the tripos and was awarded the Harkness Scholarship in geology.

His career, like that of so many others, was interrupted by the First World War, during which he served for a time as scientific expert at the War Office. In 1919, however, he was appointed to the academic staff of the University of Sheffield, beginning an association that was to last for 37 years.

The Head of the Sheffield Department was also a Cambridge graduate, William George Fearnsides. Fearnsides had married the daughter of W.W. Watts, Professor at Imperial College, London and his external examiner at Cambridge; his career was very much influenced by Watts and he retained strong links with Cambridge throughout his life - stronger indeed, one feels, than he ever forged with the Sheffield Department that came under his charge. There can be no doubt that Mr. Wilcockson owed his appointment to Fearnsides' Cambridge connexions; there can equally be little question that his career was to be influenced adversely by the fact that Professor Fearnsides was so often away at Cambridge or on consulting jobs, leaving Mr. Wilcockson to run the Department in his stead. Wilcockson's first official spell as Acting Head came in 1921-22, but he was to be officially in charge for several subsequent shorter periods and unofficially so whenever the Professor was away, which became increasingly often as his consulting practice grew.

In Wilcockson's early years at Sheffield, the Department of Geology was small and it was necessary for him to present an unusually broad range of courses, indeed he lectured on just about every aspect of geology, not always perhaps with equal competance but always responsibly and with humour. University classes he taught included students from Pure Science, Mining and Civil Engineering, and Metallurgy; but he also taught, for 47 years, evening classes in geology in Sheffield and in several towns and villages in Derbyshire. He also did much to stimulate the interest of amateurs in geology through his long association with the Sorby Natural History Society and Yorkshire Geological Society, leading or participating in excursions to many parts of England, Wales and Scotland. He acted as leader of an East Midlands Geological Society excursion to Edale in 1966 (see *Mercian Geologist*, Vol. 2, p. 109-110, pl. 5, which includes a portrait).

That these heavy other duties, whether assigned to him by his superior or assumed voluntarily, adversely affected Mr. Wilcockson's opportunities for research there can be no question; but of the quality of the work he did manage to complete there can be equally little question. His studies were wide ranging, embracing stratigraphy, petrology and economic geology. His earliest work, done at Cambridge in association with R.H. Rastall, was a study of the accessory minerals in the Lake District granites; this was undertaken to establish sound foundations for the heavy-mineral analyses of sediments that were then beginning. Subsequently he undertook, at first alone and later with the help of a team of Cambridge students headed by W.B.R. King, the mapping of the pre-Carboniferous rocks of the Austwick district of Yorkshire. He also wrote on serpentines from the Sudan; made valuable compilations of records of the sections of the strata of the Yorkshire coalfield; and wrote an account of the life of that scientific polymath, Henry Clifton Sorby, in whose honour the Sheffield University Professorship in Geology was named. The quality of Wilcockson's researches was recognised in two awards from the Geological Society of London: the Lyell Fund in 1931 and the J.B. Tyrrell Fund in 1935, the latter enabling him to study the syenitic rocks of the Haliburton-Bancroft region of Ontario and to travel to the Rockies of Alberta and British Columbia.

His academic life was interrupted when the Department was temporarily closed in the Second World War (1939-1943); during this time, he served as a postal censor. A more significant event, perhaps, was the retirement of Professor Fearnsides in 1945; his interest in his Department had long waned and a "new broom" was needed. His successor, F.W. Shotton, did not stay long; and it was only when Leslie R. Moore became third Sorby Professor that energetic changes were made and the Department began to emerge from its early-20th-century twilight into the modern age. Mr. Wilcockson's contributions, not only during the long period of housekeeping under Fearnsides but also to these necessary changes, were recognised by his promotion to Reader in 1949. His energy and interest were aroused when the Department developed an interest in the igneous geology of East Africa; at the age of 62, he led the first Sheffield University expedition to Kilimanjaro, ascending that 19,340 foot peak. Four years later, on a second expedition, he remained fit enough to work on geological problems up to 15,000 feet under very arduous conditions - no mean feat for a 66 year old but one that will be readily understood byEMGS members who remember his energy on the steep slopes of Edale when 75 !

His strongly Christian principles were expressed in many other endeavours. He served on several University Committees, as Staff Treasurer for the Students Union (1924-1939) and as a founder and longtime supporter of the University Anglican Society. He was for many years Churchwarden of St. Marks, Broomhill, helping the church to overcome the problems it encountered as a result of wartime bombing. He was long associated with the Derbyshire Naturalists' Trust, (serving as its Secretary), the Peak Park Planning Board and the Council for the Preservation of Rural England. His services were recognised by election to Honorary Membership of the Yorkshire Geological Society in 1965 and by the naming by the Nature Conservancy Council in 1971 of the "William Howson Wilcockson Nature Reserve" at Duckmanton, Derbyshire, in his memory.

Like many before him, he married one of his students, Marjorie Marie Wilcockson. They had a long and very happy life together, their two children Helen and Richard Howson, being born respectively in 1933 and 1937.

I am one of many geologists who is deeply indebted to Mr. Wilcockson for his encouragement and teaching. Like so many others, I will remember his kindness, his charity and gentleness, and the inspiration of his own deep interest in my chosen subject. Many geologists make their prime mark on science through their own researches; but Mr. Wilcockson was one of those generous few who give up their own work in order to help and inspire others. The scientific fruits of their work may be less obvious, but they are perhaps even more important.

I am indebted to Mr. Peter Wilkinson, to the Secretaries of the Geological Society of London and the Yorkshire Geological Society, and to the Registrar of the University of Sheffield for furnishing the data on which this notice is based.

William A.S. Sarjeant.

EDMUND TAYLOR, 1894-1977

The East Midlands Geological Society was formally inaugurated at a meeting in Nottingham on 1st February 1964, at this meeting Edmund Taylor was elected as Treasurer, a post he held until 1967, when Mr. P.H. Speed succeeded him. Ted, as he was usually referred to, was not a geologist in the sense that the subject was his main interest, its attraction to him was a bye-product of a general interest in natural history, which in its turn was generated by his passion for rambling in the country. A man of Edmund Taylor's inquiring disposition was not the type to look at the structure of the countryside and pass it by without question, hence his entry into geology.

Ted Taylor played an active role in the Society, although he never addressed it other than to make the formal presentation of the Treasurer's report, or led an excursion; however, members will recall that when he attended a meeting, which until a few years ago he did regularly, he always asked the speaker a question, or made an apt observation. He also exhibited items at Collectors' Evenings, which he drew from his small but interesting collection of unusual rocks.

Edmund Taylor was born in Nottingham, being the eldest of five sons of a Radford greengrocer. He left school at the age of 13, but because his parents, who were Roman Catholics, hoped their eldest boy would become a priest, he received extra tuition from his parish priest. When he was 18, he entered a Jesuit seminary outside Reading in Berkshire to commence formal training; but, this was not to be his vocation and far from becoming a priest the young Ted developed into a militant atheist, and remained one for the rest of his life. With the mutual consent of his parents and presumably the disappointed Jesuits, Ted left the seminary after about two years and returned to Nottingham, where he immediately plunged into active membership of the Labour and Co-operative movements, and these became central to his life, and remained so. Ted had no formal profession, and during his long life held many jobs, the last being a representative for the Nottingham Co-operative Society. During the inter-war period Ted, in common with many others, suffered from unemployment, and he became very active in the unemployed movement, being recognised as one of its leading local spokesmen. Many a man recalls Ted through his activity at this point in history.

I would take a book to fully describe all Ted Taylor's interests and activities. He was a member or associated with a great many organisations, indeed it is probable that only he knew the full extent of his involvement in various groups. Apart from the organisations already mentioned, including the E.M.G.S., these included the Nottingham Naturalists Society, the Youth Hostels Association, the Nottingham Cosmopolitan Debating Society, the Rationalist Press Association, the National Secular Society, the Leicester Secular Society, the Nottingham and Notts. Field Club, the Union of Shop, Distributive and Allied Workers, Nottingham Trades Council, the Workers Education Association and the Thomas Paine Society. In most he played an active role, and in several held office, for example he was President of the Cosmopolitan Debating Society.

Ted Taylor had a happy domestic life, being married twice, having a daughter by his first marriage, and a son and daughter by his second. He was a great one for correspondence, and he must have averaged, according to his son, at least one letter a day. He knew many famous people and has the odd distinction of being mentioned in a poem written by an eminent Japanese poet, Dr. Hiroshi Takamine. Ted's interest in the work of John Dewey took him in 1958 to the United States as guest of the Dewey family. In contrast to this visit to the centre of capitalism, Ted in 1936, visited the Soviet Union as a member of a trade union and co-operative delegation and there met Joseph Stalin, who impressed him greatly. Apart from walking, another passion Ted had was for swimming, and until a few weeks before his final illness regularly paid a weekly visit to the swimming baths.

Those who knew Ted Taylor will be aware that he enjoyed a good debate, particularly if his opponent was a clergyman, indeed it has been said by a member of his family that one of his interests was "parson baiting," and the present writer recalls Ted going out of his way to engage a passing clergyman in a heated argument. This brings us, and it would be wrong to avoid it, to that aspect of Ted's character which many found offensive, the vitrolic and frequently vicious oral attacks he would make on those with whom he differed. Ted, I fear, looked upon diplomacy as either a sign of weakness or a sacrifice of principles.

Ted Taylor was one of that now rare breed, an articulate self-taught working man. He had the potential for intellectual brilliance, but unfortunately the circumstances and conditions of his education never permitted its full development. Had he been born later he may well have become one of the academics against which he often poured scorn. As an individual he had a commanding personality, although old age robbed him, as it does others, of much of his vigour. The long illness of his wife, who died on 4th March 1977, clearly affected him and on 13th January 1977, he suffered a heart attack, to be followed by a second some days later, and he passed away on 9th August. Ted was known by a host of people in Nottingham, and will be missed by many of them. The East Midlands Geological Society can be grateful for his work on its behalf during the important years of its formative stage.

Robert W. Morrell.

BOOK REVIEWS

FORD, T.D., (Editor) *Limestones and caves of the Peak District*

Geoservices Ltd., University of East Anglia, Norwich, 1977.

Paper Back and Cloth Bound editions. 469 pp., 99 figs., 106 photographs, 24 tables. Index. £11.50 or £15.00.

The aim of the book is a comprehensive account of the limestones and caves of the Peak District and is written by a number of contributors of whom the main author is the editor. Dr. Ford has worked on these subjects throughout his geological career. The other authors are likewise well known in geology or speleology.

The contents include a review of the area to be studied first of all geologically with chapters on the limestones and volcanic rocks and rather surprisingly perhaps also on the Millstone Grit Group, Tertiary Sands and the Pleistocene Deposits. An excellent account of the structure of the area is followed by a rather long (for the title of this book) description of minerals, mines and natural resources. After considering the ages of the rocks the hydrology is discussed and commencing on p. 231 (about the half-way stage) details of the caves are given including the palaeontology, biology, archaeology and the physical description of the caves and cave systems arranged regionally.

The book thus brings together a considerable amount of related material updating previously published data and opinion and including some original contributions. The limestone section is full of interesting topics, particularly the sediments and environments of deposition but may lack detail for some readers. The stratigraphical section could be expanded. As might be expected more information is available for the northern outcrops than elsewhere, although it is good to see some of T.D. Ford's work on the southern outcrops appearing in print. The section on the caves is well detailed and contains many maps and diagrams.

Whereas the contributions are good, the production and printing of the book is disappointing. Items of complaint - considering the price of the book - include the thin type face of the text, variable ink intensity, text-figs. lettering of different sizes, type style and illegibility (fig. 77), photographs with little or too much contrast (figs. 21, 33, 105, 106), binding of the paper-back edition which is very weak. Mercian Geologist readers will recognise photograph 11, which turned through 90° appeared in Vol. 1, No. 1, Plate 1 (no acknowledgement) and fig. 25 is almost identicle to the text-fig. 1, p. 125 of Mercian Geologist, Vol. 6, No. 2. Again having paid £11.50 or £15.00 for a book one should not find obvious proof reading errors. Without really concentrating your editor found, no explanation for letter S on fig. 41, p. 111; photograph 8, p. xv is presumably 58; and Ford and Burek 1976 (p. 127) is listed in the bibliography for the year 1977.

Thus the authors have produced a worthy publication but the publisher has not produced quite an equal effort.

F.M. Taylor

SMITH, A.G. and BRIDEN, J.C. *Mesozoic and Cenozoic Palaeocontinental Maps*

Cambridge University Press 1977. Cambridge Earth Science Series. 63 pp.
52 maps. Soft Cover, £1.95.

The theories of drifting continents need not be those of the past. This book attempts to show the outline of world continental areas in provisional positions going back in time some 220 million years. The maps show the present positions and at 10, 20 and then at 20 million year intervals. Detail is plotted on 3 projections, Mercator, N. and S. pole stereographic and Lambert Equal Area. The maps are based on available quantitative and topographic information. The continents are indicated by two lines - Ordnance Datum and the 1000 m submarine contour. No intercontinental information is given - geologists are expected to use the maps, to plot on them palaeogeographical detail as required. Lines of longitude and latitude, both for the present day and for the chosen interval of time are added and the position of plate margins, except for the Pacific area.

Two questions immediately spring to mind. (a) Why go back only 220 million years and (b) Why no information on the oceanic plate boundaries of the Pacific? On the first point, presumeable data is too inconclusive to be used although both authors have been involved in producing world maps going back approx. 600 million years. The second point presumably is that the last 220 million years is concerned with the break up of Wegener's Continent *Pangea* and the reassembly in the present land hemispheres, producing new intercontinental boundaries.

The book will be of great interest to all geologists who work on a global scale. Colour the maps, as shown on the front cover of the book, and then commence the reconstruction of a world geography at one chosen time. This could be arm-chair geology at its best.

The maps have been drawn by computer so that ideally they can be up-dated very quickly as new information is made available. At least the master-maps can be produced, no doubt the appearance of a second edition of the book is another matter.

Cambridge University Press have produced a pleasing publication (compare previous review) the only quibble I can find is that the closeness of some of the lines is confusing and it took me a long time to find the point in the text confirming the meaning of the X symbol used on all the maps. This book is a valuable guide for all interested in geological history of the world. We await maps for the period before 220 million years,- at the same favourable price.

F.M. Taylor

HALLAM, A. *Jurassic Environments* Cambridge University Press

Cambridge Earth Science Series, 1975 (Received 1976) i-ix + 269 pp., illustrated, index, boards. £11.00.

Following on the review of Smith and Briden above, this book illustrates the use of world maps although biostratigraphical stage units are used and not chronological units. The author has attempted to produce environmental or facies maps for parts of the Jurassic on an international scale. Much of the detail is from N. America, Europe, Asia and N. Africa with much less evidence from S. America, South Africa, Australia, New Zealand and Antartica. The book is concerned mainly with marine sediments and faunas with little attention given to continental interiors or vertebrate palaeontology. Dinosaurs are mentioned almost exclusively for climatic evidence.

With this breadth of geographical coverage, it is tempting to compare the book with Arkell's (1956) *Jurassic Geology of the World*. The approach to the subject is however different for whereas Arkell's is mainly stratigraphical with less emphasis on environment, Hallam's book is mainly concerned with the environment and the stratigraphy forms the introductory chapter.

Nevertheless this chapter is most important and establishes the necessary stratigraphical and chronological controls that are required for the ensuing chapters. There is a justification for the continued use of ammonites as the main stratal control and auguments are proposed to show that the ammonite zones are equivalent to time planes. Biostratigraphical divisions of the Jurassic are reviewed and those adopted in various international conferences up to 1974 are generally approved. A number of correlation charts for Western Europe are included with the British Isles featuring prominently.

The main part of the book then deals with the environments as depicted by their sediments and their location. Thus there are chapters on the arenaceous, argillaceous and ferrugineous facies of Europe. Calcareous and argillaceous facies of northern and central Europe; calcareous and siliceous facies of southern Europe and N. Africa. The United States Western Interior is considered separately. These details lay the foundations for the palaeotectonic reconstructions that follow including discussion on sea levels. In a book of this type it is refreshing to read details of the climate of the time and the summary of invertebrate fauna provides the last element given for the geography of the Jurassic.

The book is an excellent synthesis of the marine Jurassic and progresses logically to its final chapter. The scale of the book inevitably means that opinion must be expressed about subjects for which there is still incomplete or controversial evidence or opinions are included which are based on national policy which prevents acceptance of decisions made at International level. Thus will the Callovian be accepted by all as a Middle Jurassic stage? The volcanic origin for the Fullers Earth (Bathonian) is preferred despite the absence of other volcanic rocks of the same age in the same locality. Some Bathonian rocks in North Sea sequences are the nearest direct evidence. Such opinions and the auguments given for and against liven the text of the book and ensure anyone interested in the subject of the book will maintain that interest to the end.

Thus Professor Hallam (now at the University of Birmingham) has gathered a very useful text written and produced in an attractive format.

F.M. Taylor

PATRICIA PAYLORE (Ed.) *Arid lands research institutions : A world directory*.

The University of Arizona Press, Tucson, Arizona, (2nd Revision and Updated Edition)
1977, 317 pp. no illustrations (ISBN 0-8165-06.31-0) US $ 7.50 (paper).

This excellent directory supercedes the 1967 edition, and renders the former obsolete.

The purpose of this book is to list the institutions that have an active involvement in a study of arid lands. For each institution the following are listed:

nature of the institution (e.g. government, academic)
governing body
postal address and location
description of areas where field studies are undertaken
scope of interest
research programmes
finances, staff and organisation
facilities (including arrangements for visiting scientists)
publications, and history of the institution

The entries appear alphabetically within the list for each country, and countries are arranged by continent. They include national Geological Surveys and academic as well as governmental bodies concerned with geological research in arid lands. This, however is only part of the total list of disciplines represented, for these include zoology, botany, forestry, ecology, livestock farming, agriculture, meteorology, water research, pedology, geomorphology, human geography, and so on.

Clearly this volume can be no more comprehensive than the returns received to correspondence with the institutions concerned, nevertheless there are over 150 entries.

The entries listed for England are:

Centre for Middle Eastern and Islamic Studies, Department of Geography, University of Durham.

Centre for Overseas Pest Research, London.

Ministry of Overseas Development, Land Resources Division.

Overseas Development Group, University of East Anglia.

Overseas Development Institute, London.

Department of Geography, University College, London.

Department of Geography, University of Cambridge.

Department of Geography, University of Durham.

The directory concludes with name and subject indexes.

This is a well-conceived and well-presented useful volume. A comparison volume suggests itself (or a separate part of this same volume) on the fund giving organisations that support research in arid lands carried out by individuals who do not belong to the formal institutions listed in this directory.

J. C. Doornkamp.

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