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Front Cover: Cliff Quarry, Crich, Derbyshire, showing a sequence of Lower Carboniferous limestones folded into an anticline. The position of a wayboard clay seam is indicated on the photograph by vertical dark streaks on the rocks which commence at the clay seam. (See article by Dorning and Wood p.145). The fore-ground is occupied by equipment of the Crich Tramway Museum and on the sky-line is the Memorial Tower to the Sherwood Foresters.

CARBONACEOUS AND FOSSILIFEROUS MATERIAL FROM SOME DERBYSHIRE CLAY WAYBOARDS

by

N. E. Worley and K. J. Dorning

Summary

Investigations of a carbonaceous clay wayboard in the Matlock Lower Limestone at Masson Hill, Matlock, Derbyshire have demonstrated that an assemblage of miospores and plant fragments is present, comparable with similar assemblages obtained from Dinantian rocks in Northumberland and Scotland. In conjunction with stratigraphical observations it is argued that the depositional environment of the clay wayboards is related to topographical highs on the limestone shelf and that the carbonaceous material was derived from terrestrial soils on contemporaneous volcanic islands. Some other carbonaceous and fossiliferous clay wayboards are demonstrated to have been formed in a similar environment.

Introduction

Interbedded within the Carboniferous Limestone of the Peak District are a series of clay beds long referred to as clay wayboards. They have been described by Walkden (1972, 1975), who demonstrated that most of the clays were K-bentonites consisting of crystallographic mixed-layer illite/smectite with kaolinite, and accessory anatase, quartz, and pyrite. He concluded from an extensive survey that all clay wayboards were free from organic influences and contained no macro or micro-fossils. Walkden (1974) suggested that many of the erosional bases of the thicker clay wayboards represented palaeokarstic surfaces exposed to subaerial erosion for periods between 30,000 and 100,000 years. Veneers or coatings of the karstic limestone surfaces were attributed to alteration beneath a soil cover.

In the light of new findings, some of these clay wayboards noted by Walkden have been re-examined, and others not previously recorded are herein described from underground exposures in old lead mines and caves, demonstrating that numerous clay wayboards with carbonaceous and fossiliferous material occur at a number of stratigraphical horizons. Some of these have been described in the past from the Matlock area by De la Beche (1853), who noted that an impure 'coal' seam rested on a true underclay of the Coal Measures type. Similar 'coals' were also recorded in Rutland Cavern (SK 293586) in the Matlock Lower Limestone (De la Beche 1853). Green *et al.*, (1887, p.22) described a bright 'coal' which outcrops in Coombes Dale (SK 231748), resting on a potholed limestone surface. Brown (1973) noted that this coal in fact consisted largely of carbonaceous material, which occurs as a thin seam within a thick clay wayboard.

One of these carbonaceous clay wayboards in the Matlock area has been examined to determine for the first time the microfossil content and the assemblages contained therein are described. The depositional environment of this clay wayboard is assessed below in relation to the limestone massif, and the other carbonaceous and fossiliferous wayboards in Derbyshire are re-examined in the light of the new evidence.

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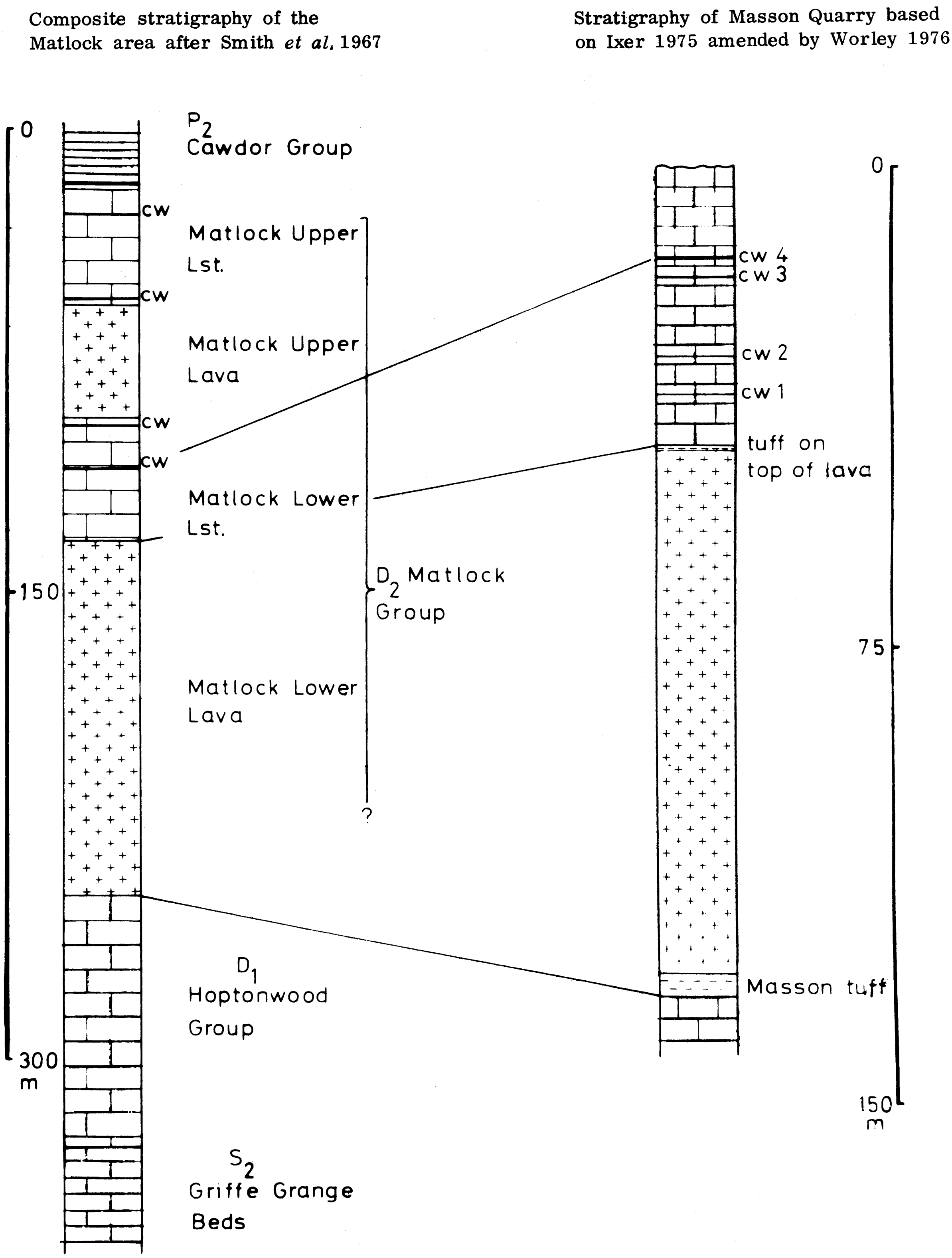
pp. 145-154, 2 text-figs. Plates 8-9.



Text. fig. 1. Correlation of strata, Matlock and Masson Quarry.

Carbonaceous and fossiliferous clay wayboards from Masson Hill, Matlock

The stratigraphy of the Masson Quarry (text-fig.1) has been described by Dunham (1952) who noted that three clay wayboards or volcanic ashes were present in the partly dolomitised Lower Matlock Limestone. He called the lower one the "little toadstone"; it attained a thickness of 0.65 m resting 5.9 m above the Lower Toadstone (= Matlock Lower Lava). Recently, Ixer (1975) revised the geology of the quarry, and established, largely from boreholes, that four clay wayboards were present (text-fig.1). He also noted that the "Masson Tuff" was intersected in boreholes at the base of the Matlock Lower Lava, which attains a thickness of about 80 metres. The clay wayboards were numbered upwards from 1 to 4, and X-ray studies showed them to be uniformly mixed illite-montmorillonite-kaolinite clays with accessory quartz, calcite, dolomite, anatase and chlorite. Clay wayboard no.4 is the highest in the succession, and lies 21 m above the Matlock Lower Lava in the quarry. The details of the stratigraphy of the clay wayboard no.4 were given in Ixer (1975, p.186), who noted that blue laminated clays occurred at the base, and that a band rich in brachiopods 0.05 m thick was developed towards the top (Plate 9, fig.1). Examination of this brachiopod band has shown that all the valves are approximately the same size, and lie with a thick (20 mm) ventral valve lying convex downwards, indicating that they were fossilised in a living position. The brachiopods are productids, too poorly preserved to be classified further. An earthy black coal, up to 20 mm thick, occurs sporadically within that part of the clay wayboard which is beneath the brachiopod band.

Palynology

Ten samples were collected from the coaly horizon and dark blue clays (text-fig.2). They were processed for palynomorphs using standard techniques; hydrochloric acid followed by hydrofluoric acid disaggregated the material to a fine slurry. The residue was macerated with concentrated nitric acid for 12 hours to clear the material. The composition of the samples is summarized in Table 1.

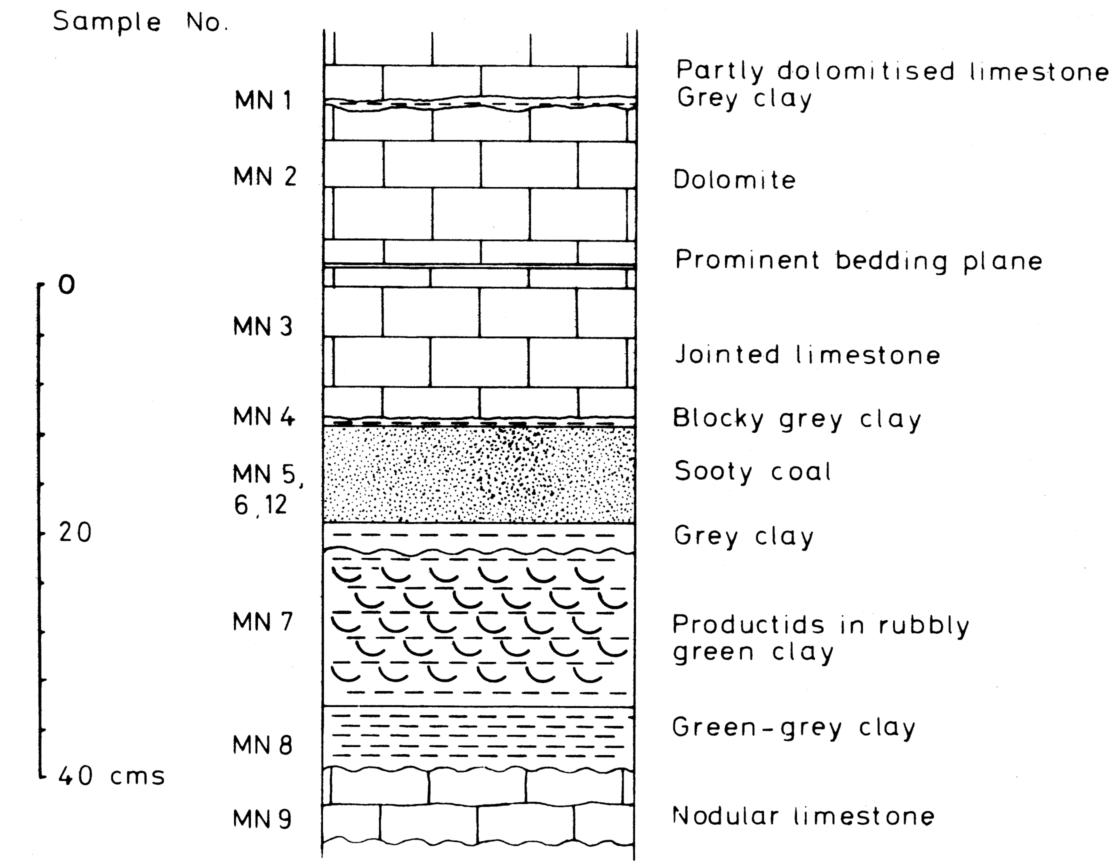
Table 1 Palynological composition of clay wayboard 4.

Sample Number

Composition	MN1	MN2	MN3	MN4	MN5	MN12	MN6	MN7	MN8	MN9
Fusinite	X	X	X	A	A	A	A	X	X	X
Inertinite	X			X	X	A	X			
Scolecodonts						X				
Miospores					X	A				

[X] present [A] abundant

Of the ten samples, only two yielded miospores (Plate 8); this is not surprising as miospores are rarely well preserved in pure limestone environments. The impure coal (MN12) yielded the best miospore assemblage, though many of the specimens are rather poorly preserved, and show distortion due to pyrite growth (Plate 8, fig.2). Brown phytoclasts of inertinite were abundant in MN5. Sample MN12 yielded the miospore assemblage listed below as well as scolecodonts.



Text. fig. 2. A generalised section through clay wayboard number 4.

Miospores from sample MN12

Acanthotriletes cf. *falcatus* (Knox) Potonie and Kremp 1955.
Acanthotriletes sp.
Apiculatisporis sp.
Dictyotriletes sp.
Granulatisporites granulatus Ibrahim, 1933
Laevigatosporites spp.

Lycospora pellucida (Wicher) Schopf, Wilson, and Bentall, 1944
Lycospora sp.
Punctatisporites sp.
Raistrickia sp.
Schulzospora elongata Hoffmeister, Staplin, and Malloy, 1955.

The miospores are the first recorded from the Dinantian of Derbyshire. None of the taxa recorded are particularly diagnostic of the Upper Dinantian in either the Midland Valley of Scotland, or Northumberland, where miospore zonation for the Lower Carboniferous has been carried out by Neves *et al.*, (1972). However, none of the taxa are inconsistent with an Upper Dinantian D_2 (Brigantian) age. (George *et al*, (1976), have recently revised the stratigraphical nomenclature of the Dinantian and the P_2 and D_2 zone limestones which include the Cawdor, Eyam, Matlock and Monsal Dale Limestones are now referred to as the Brigantian Stage).

Clay wayboard no. 4 in the Masson Quarry can be mapped underground as far west as Tearsall Farm (SK 263599). In the Jugholes Caves (SK 279596) and Oxclose Mine (SK 277598) it attains a thickness of 1 metre and contains nodules of fine-grained limestone in a green laminated clay. At Tearsall Mine the same clay wayboard contains numerous large colonies of in-situ *Lithostrotion junceum* and small brachiopods. A carbonaceous clay wayboard has been detected also in the Oxclose Mine 1.5 metres beneath the base of the Matlock Upper Lava somewhat higher in the Matlock Limestone.

The Upper Masson Tuff

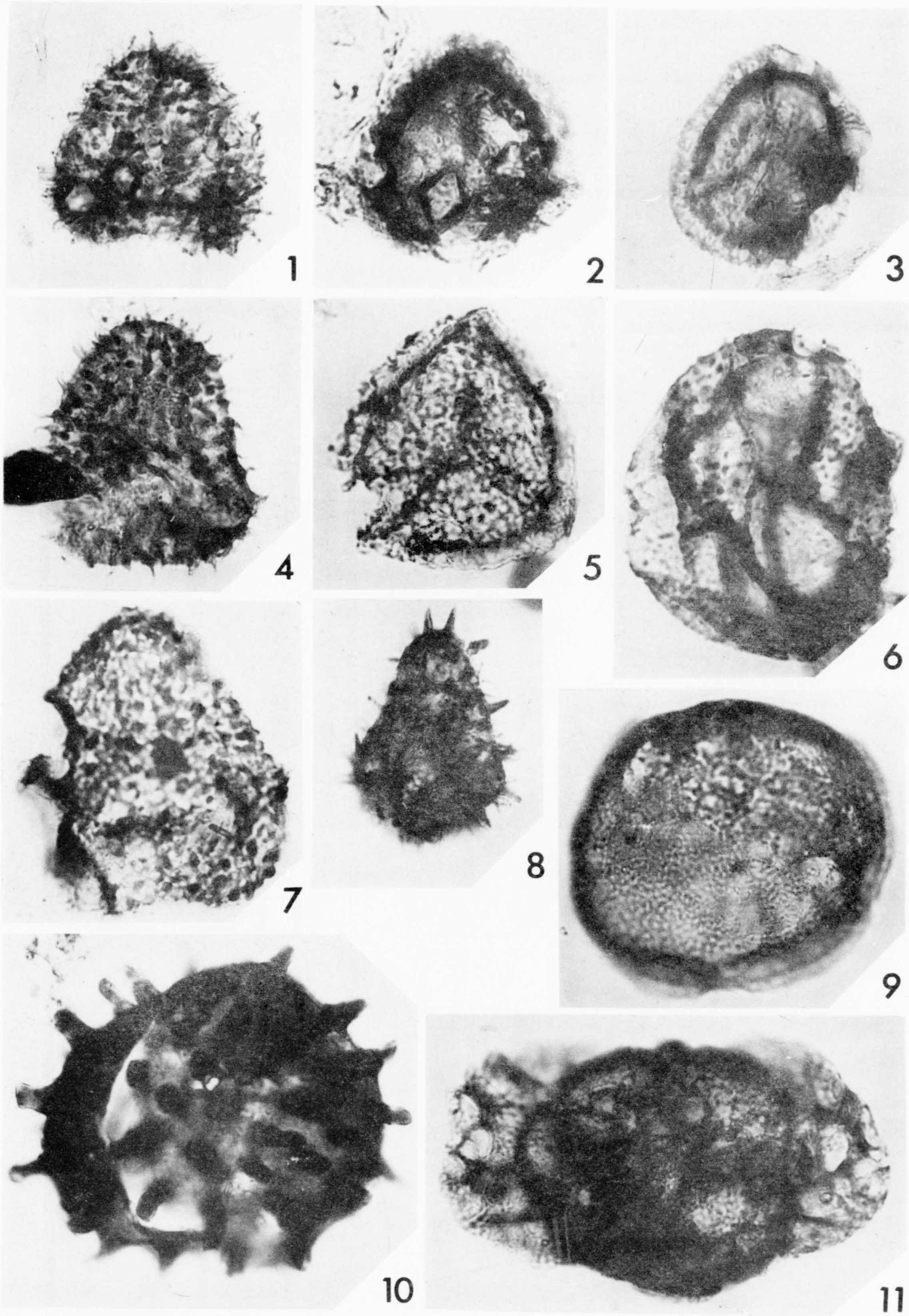
Recent workings in the quarry have revealed a tuff horizon which was not recorded by Ixer (1975) resting on top of the Matlock Lower Lava. This has now been named the Upper Masson Tuff. The full thickness is not exposed but it is probably less than 1 metre in thickness. The principal outcrops lie in the present floor of the quarry, which has recently been deepened. In fresh specimens the tuff is dark grey in colour, compact and hard to break. Pyrite as both cubes and anhedral grains is common, and occasionally small thin-shelled brachiopods approximately 20 mm wide are seen. The tuff weathers rapidly on exposure to a dark grey sticky clay, and the outcrops now consist of mainly unweathered fragments in a weathered clay matrix. In thin section (Plate 9, fig. 3) the tuff consists of 25% foraminifera 0.30 mm in diameter, with well rounded clasts of a clay mineral, probably montmorillonite, which often has a radial fibrous structure. These grains, attaining 0.012 mm, are set in a clear calcite spar matrix. Pyrite occurs as both anhedral and euhedral grains and cuts across the fabric of the rock, indicating that it has replaced the original matrix and allochemical constituents.

The Limestones

Preliminary petrographic studies on the undolomitised limestones have been carried out. Most of the limestones exposed in the quarry are pale grey thickly bedded biomicrudites (Folk, 1959). The main allochemical constituents are, in order of abundance, brachiopod spines and tests, crinoid ossicles, foraminifera, bryozoa, and algae. The limestones exhibit a mottling of dark, sometimes diffuse spots of fine-grained limestone up to 15 cms across in a paler grey matrix (Plate 9, fig. 2), which appear to represent pseudobrecciation due to animal burrowing, or calcite grain growth as suggested by Bathurst (1959). These pseudobrecciated limestones are characteristic of the lower 15 to 20 metres of the Matlock Lower Limestones. Mapping in the area on surface, and underground in old mines, has demonstrated that they outcrop over a strike length of three kilometres to the west as far as Tearsall Farm (SK 263599), Explanation for Plate 8

1.	*Acanthotriletes* cf. *falcatus*	MN12	K7	033/1
2.	*Lycospora pellucida*	MN12	K6	N42/0
3.	*Lycospora pellucida*	MN12	K7	032/2
4.	*Acanthotriletes* cf. *falcatus*	MN12	K5	043/3
5.	*Lycospora* sp.	MN12	A1	044/0
6.	*Apiculatisporis* sp.	MN12	K7	D40/3
7.	*Granulatisporites granulatus*	MN12	K5	E41/4
8.	*Acanthotriletes* sp.	MN12	A1	K44/1
9.	*Punctatisporites* sp.	MN12	K5	G30/4
10	*Raistrickia* sp.	MN12	K5	B39/3
11.	*Schulzospora elongata*	MN12	K6	B31/4

All × 1000 magnification. The last reference letter and numbers are England Finder reference coordinates. The slides are deposited in the Department of Geology, University of Sheffield.



Worley and Dorning - Derbyshire Clay Wayboards.

where the texture of the limestone has been obliterated by dolomitization. Most of the fluorite replacement orebodies known in the area (Dunham 1952), including the one at Masson, occur in this type of limestone pseudobreccia, above the Matlock Lower Lava. Similar limestones have been previously recognised by Harrison (1967) in the Matlock Upper Limestone but their distribution and significance was not described. Mapping by the authors has failed to delimit the distribution due largely to lack of exposures and absence of penetration of the limestone by mines and quarries in appropriate places.

Depositional Environment

The presence of foraminifera. algae and burrows suggests that the pseudobrecciated limestones, were deposited in a shallow marine environment where extensive burrowing and reworking of the sediment took place. The whole Brigantian (D_2) succession in the Matlock area attains a thickness of 141 m. including lavas (Smith *et al.* 1967) compared with an average 213 m. further north in the Millers Dale area (Stevenson and Eden 1976); this represents considerable southwards thinning of the stage. The attenuation is consistant with the facies changes observed within the Matlock Group and Monsal Dale Limestone, as in the Millers Dale area dark shaley limestones of a deeper water basinal aspect are common whereas the Matlock succession is a thinner shelf sequence characterised by shelly pseudobrecciated limestones. The facies and thickness changes may represent a response to contemporaneous tectonic and volcanic activity. Masson Hill forms the crest of a major east - west trending anticline where the lavas reach their thickest development, and a series of vent agglomerate exposures indicate that it was once a major volcanic centre. Uplift during deposition of the limestone occurred intermittently, and coincided with sporadic extrusive volcanic episodes; these are now represented in the succession by the clay wayboards. The miospore assemblages, phytoclasts of inertinite and fusinite, and scolecodonts imply that the wayboards were deposited in shallow marine conditions; the organic components were derived from the weathering of soils with a terrestrial plant assemblage, suggesting that there may have been a temporary island associated with the volcanicity.

The presence of a band crowded with productid brachiopods, which are bethonic filter feeders, is difficult to reconcile with a volcanic clay in a terrestrial environment. The brachiopods probably colonised the top of the clays during a lull in the volcanic activity in a tranquil marine situation, only to be buried during a later eruption. A similar depositional environment is envisaged for the formation of the calcareous Upper Masson tuff which rests on top of the Matlock Lower Lava.

Other carbonaceous and fossilferous clay wayboards

Other clay wayboards with fossiliferous and carbonaceous material occur elsewhere in Derbyshire at a variety of stratigraphical horizons, often associated with erosional bases. They probably represent deposition in similar environments to the clay wayboards in Masson Quarry and may coincide with local depositional topographic highs such as volcanic islands on the carbonate platform.

At the base of the Eyam Limestone in Coombes Dale (SK 231748) a thin coal seam 5 mm - 25 mm thick rests on a grey clay wayboard which lies on a dolomitised, brecciated limestone surface (Brown 1973). This coal was first described by Green *et al.* (1887, p.22) as a 'bright, clean coal' resting on light-grey fire-clay. Further west in the Glebe Mine, Eyam, a thick clay wayboard at the same stratigraphical horizon contains a sooty coal lying on a pot-holed limestone surface. At the Raper Quarry, Youlgrave (SK 217653), again at the base of the Eyam Limestone a thick clay wayboard with carbonaceous material has been exposed in the north face of the quarry beneath dark cherty limestones. A similar clay wayboard was also described at the Millclose Mine (Traill 1940) at the base of the Eyam Limestone ('black beds') with a 2 cm. coal seam. Also in the Millclose mine Traill described a number of clay wayboards with carbonaceous material in the 'Main' = Matlock Group Limestone which passed laterally into basalt lavas. A comparable lateral passage has been observed in the case of the Matlock Lower Lava which thins rapidly from Matlock, in the north, to Wirksworth, in the south, where it is represented by a thin (0.3 m) carbonaceous clay wayboard.

The author's underground mapping has revealed a previously unknown coal seam in the Middleton by Youlgrave area, 0.3 m thick, in a dark cherty facies of the Monsal Dale Limestones.

Carbonaceous clay wayboards also occur in the lower part of the Holkerian (S_2) Woo Dale Limestones (Cope 1933, p.129), and contain specimens of *Archaeosigillaria vanuxemi* (Göpp). A thin bed of shaley limestone outcropping near Topley Pike also in the Woo Dale Limestone was described by Arnold Bemrose (1900 p.173) who noted the occurrence of '*Calamites* sp'.

Concluding Remarks

This study serves to illustrate that there is considerable scope for future palaeontological and palynological investigation of clay wayboards. When further assemblages have been described from the Derbyshire area, a more precise correlation with other regions may be possible. Palynological determination of the age of the Brigantian limestones and the overlying shales should prove useful in refining the complex chronostratigraphic correlations at around the Brigantian/Namurian boundary.

Acknowledgements

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Explanation for Plate 9

Figure 1. Photograph of the clay wayboard no. 4. The erosional base is clearly defined and the brachiopod band can be seen in the centre of the wayboard. The coal lies on the horizon of the lens cap. Scale lens cap measures 40 mm.

Figure 2. A block of spotted pseudobrecciated limestone in Masson Quarry floor. Scale lens cap 40 mm.

Figure 3. Photomicrograph (plane polarised light, $\times 200$) of the Masson Upper Tuff with a foraminiferan surrounded by dark rounded clasts of clay minerals in a clear calcite spar matrix.

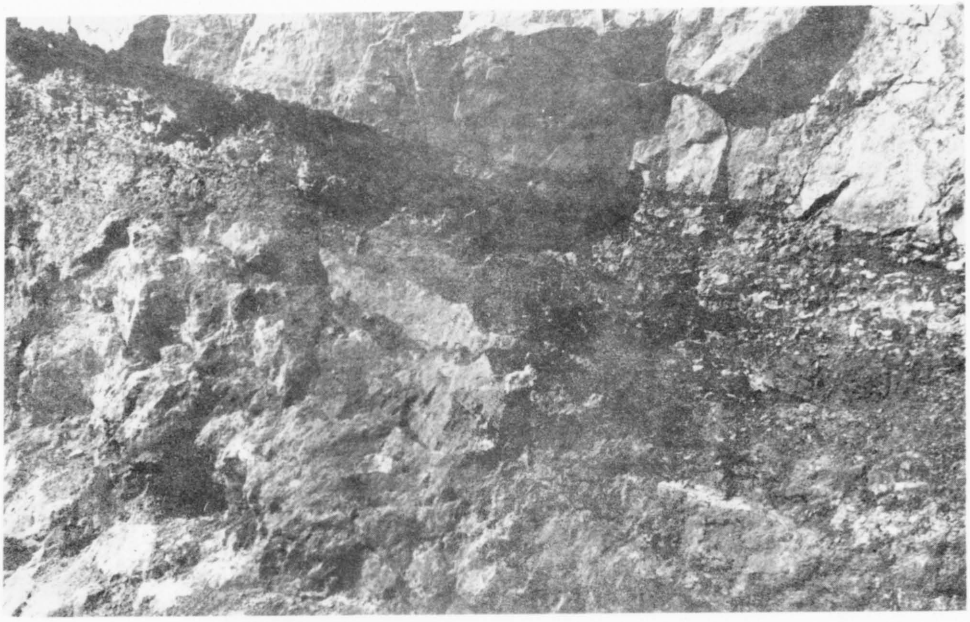

Fig. 1.

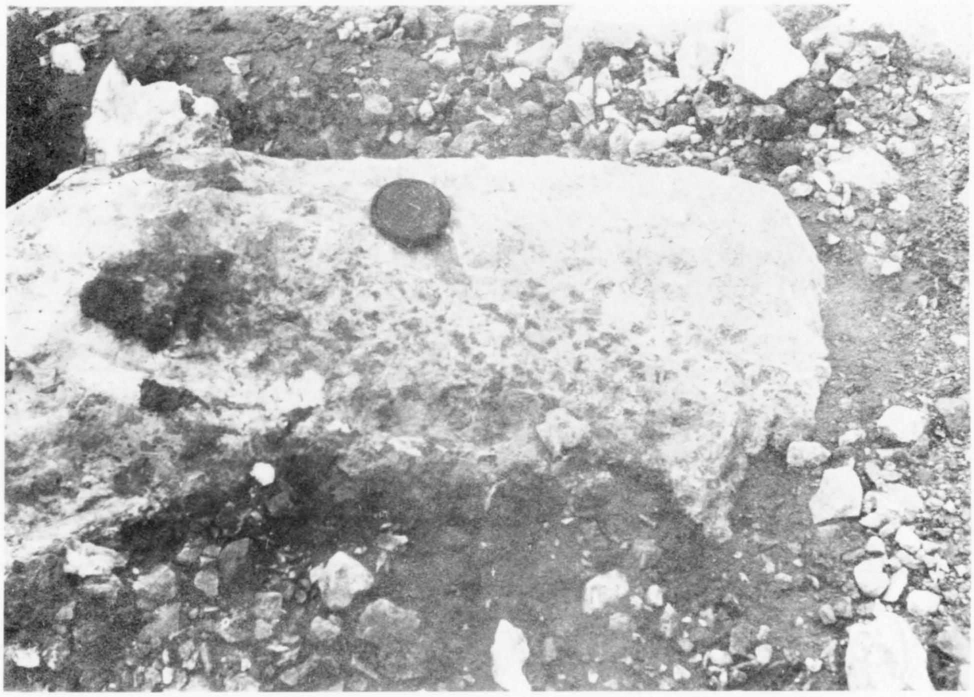

Fig. 2.

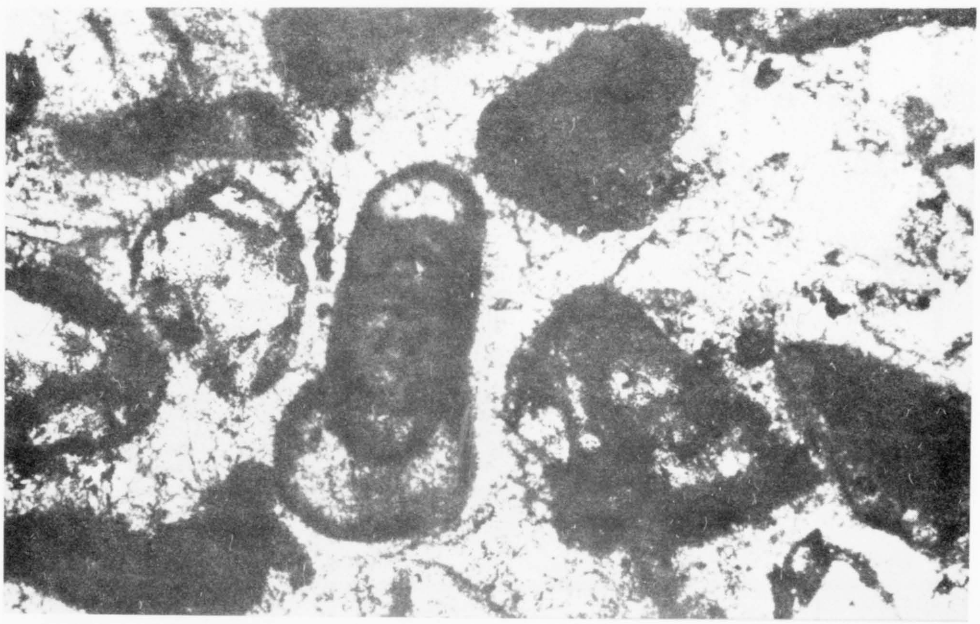

Fig. 3.

TRILOBITES (PROETACEA) FROM VISÉAN REEF LIMESTONES AT TREAK CLIFF, CASTLETON, DERBYSHIRE

by

John Wykeham Tilsley

Summary

A unique assemblage of trilobites of Upper B_2 age has been collected from a single exposure of reef limestone at Treak Cliff, Castleton, Derbyshire. The locality has yielded no less than 9 genera and 11 species belonging to the Brachymetopidae, Otarionidae and Proetidae. Descriptions of the trilobites are presented in this paper.

Introduction

Treak Cliff has long been famous for the abundant and rich variety of well preserved fossils found in the exposures of the Lower Carboniferous, apron-reef limestone complex. (Shirley and Horsfield 1940; Wolfenden 1958; Parkinson 1965, 1974; Stevenson *et al.* 1971; Broadhurst and Simpson 1969, 1973.)

The reef complex comprises algal, back- and fore-reef limestones the age of which on the goniatite evidence is Viséan, Upper Beyrichoceras (B_2) sub-zone. Fossils commonly occur in lenses or pockets within the reef, and are sometimes restricted to a particular fossil group; brachiopods, goniatites (Ford 1965) or bivalves (Shaw 1970), but more often comprise a variety of invertebrate groups.

The trilobites discussed in this paper were found by R. C. Elliott and the author during 1975-76 in weathered rubbly limestone within the fore-reef at a locality at the north-west end of Treak Cliff. A more precise indication of the locality is not given here in the interests of geological conservation, although details will be supplied on application to the author.

As with many groups of Lower Carboniferous fossils, trilobites have received scant attention in Britain this century; the most recent comprehensive monograph having been written by Woodward in 1883-84. Other references include Reed (1899, 1942-43) on *Bollandia*, *Cyrtoproetus* and *Namuropyge*; Weber (1937) - *Brachymetopus*; Osmólska (1967, 1968, 1970) featuring all the species and Hahn (1964) on *Brachymetopus*.

Trilobite morphology

The accompanying illustrations, text-figs. 1 - 3 show the parts of the trilobite exoskeleton referred to in the text. The morphology is based on Harrington *et al.* (1959).

The occurrence and preservation of the trilobites

The fossils were found in a restricted deposit, confined by soil cover. The fauna, in addition to the trilobites, contained brachiopods, bryozoa, gastropods, crinoid ossicles and rarer ostracodes, blastoids, crinoid calices, algae and goniatites. A faunal list (excluding the trilobites) is given in appendix 1 (p.169) and the relationship of the locality to other fossiliferous limestones is shown in text-fig. 4.

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pp. 155-170, text-figs 1-5, Pl. 10-13.
App. 1.

Fig. 1 *Brachymetopus ouralicus* (Verneuil, 1845)

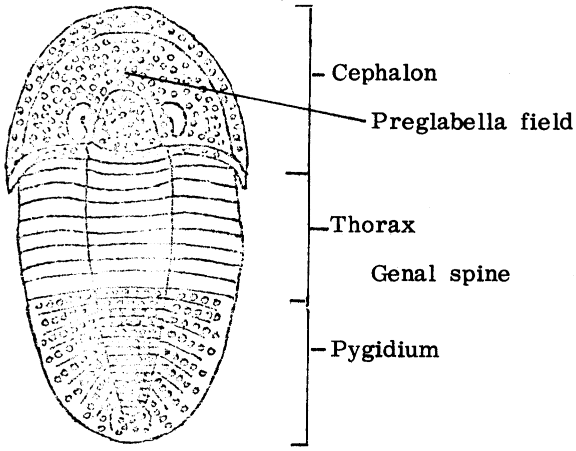


Fig. 2 *Cummingella jonesi.* (Portlock, 1843)

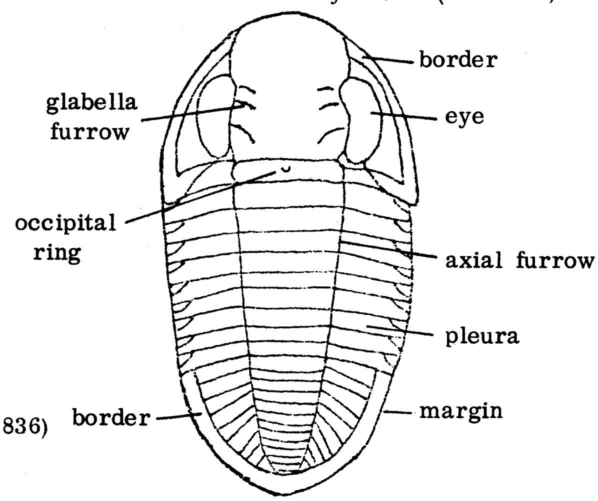
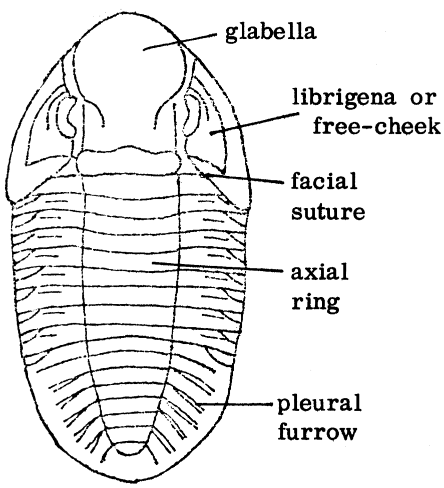
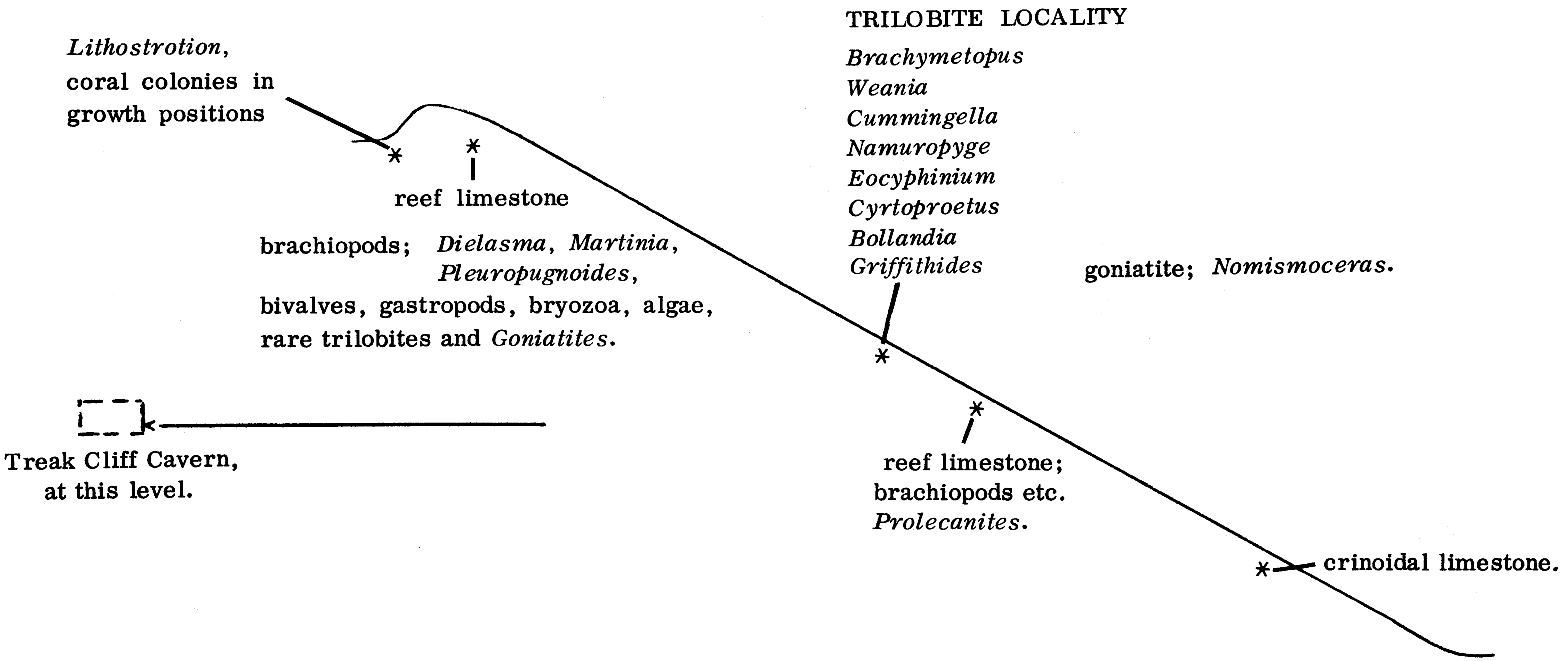


Fig. 3 *Bollandia globiceps.* (Phillips, 1836)



outline after H. Woodward (1883-84)
terminology after Harrington (1959).

Text-figs. 1 - 3 Morphology of Carboniferous trilobites.



Text-fig. 4. Faunal variations on the reef slope.
(For comparison see Broadhurst & Simpson 1973.
Bathymetry on a carboniferous reef.)

The trilobites are preserved in original relief with exoskeleton adhering, or as internal and external moulds, nearly all as isolated cephala, cranidia, librigenae (free cheeks), pygidia and rare hypostoma (Plate 12, figs. 10,11); only a few specimens were found with articulating thoracic segments attached to the pygidium. Thus it seems as if nearly all are moults; the preservation of delicate spines on *Namuropyge* specimens suggests that the assemblage cannot have been transported far and was presumably moved by gentle currents into a hollow or fissure within the reef and buried fairly rapidly by carbonate sediment.

Recognition of the species

On initial acquaintance, most Carboniferous trilobites exhibit a good deal of similarity, compared with, say, an association of specimens of Ordovician or Silurian age. Part of the reason for this is that in earlier periods, many more families, genera and species of great diversity were in existence, whilst in the Carboniferous, only three families remain, all belonging to one superfamily, the Proetacea. It was formerly customary to place nearly all Carboniferous trilobites in the genera *Phillipsia*, *Griffithides* or *Brachymetopus*, but studies over the last 50 years or so have revealed that many of these placings were artificial and based on superficial resemblance only. It is now realised that there was a good deal of parallel evolution within the Proetacea, and that the end members of many lineages took on a similar appearance because they were adapted to similar environmental niches. Consequently a number of additional genera and subgenera have been defined to accommodate these species. Because many of them superficially resemble one another, discrimination between them is difficult and requires a careful and critical examination. Thus the notes below are intended to assist with the determination of the Treak Cliff species. Longer formal descriptions of them are available in the monographs and papers mentioned above.

Description of trilobites

List of species

Superfamily: Proetacea Salter, 1864.

Family: Brachymetopidae Prantl and Pribyl, 1950.

- *Brachymetopus ouralicus* (de Verneuil, 1845)
- *Brachymetopus moelleri* Weber, 1937

Family: Otarionidae Richter and Richter, 1926

- *Namuropyge acanthina* (Coignou, 1890)
- *Namuropyge kingii* Richer and Richter, 1939

Family: Proetidae Salter, 1864

Subfamily: Cyrtosymbolinae Hupe, 1953

- *Cyrtoproetus cracoensis* Osmolska, 1970
- *Carbonocoryphe* (*Winterbergia*) Hahn and Brauckmann, 1975, sp. nov?
- *Weania anglica* Osmolska, 1970

Subfamily: Proetinae Salter, 1864

- *Bollandia* aff. *claviceps* (Burmeister, 1846)

Subfamily: Phillipsinae Oehlert, 1886

- *Eocyphinium* cf. *castletonensis* Osmolska, 1970

Subfamily:	Cummingellinae Hahn, G. and R., 1967
	Cummingella carringtonensis (Woodward, 1884)
Subfamily:	Griffithidinae Hupe, 1953
	Griffithides longiceps Portlock, 1843

Table 1 - Total number of trilobite specimens obtained from the locality

	Cephala	Cranidia	Librigenae	Pygidia
Bollandia	1	4	1	5
Eocyphinium	2	1	0	3
Cyrtoproetus	4	18	3	15
Weania	8	20	5	30
Cummingella	25	4	0	24
Carbonocoryphe	0	2	0	8
Brachymetopus ouralicus	50+	0	0	100+
B. moelleri	12	0	0	2
Namuropyge acanthina	10	0	0	6
N. kingi	0	0	0	1
Griffithides	0	1	0	0

In addition: 6 hypostoma and thoracic segments

Superfamily	PROETACEA	Salter, 1864
Family	Brachymetopidae	Prantl & Přibyl, 1950
Genus	*Brachymetopus*	McCoy, 1847.
	Brachymetopus ouralicus (de Verneuil, 1845)	
	(Plate 10, figs.1-5; Plate 13, figs. 3-6.)	

Treak Cliff specimens. The description below is made up from over 150 specimens of which 50 are cephala and the rest pygidia. No complete individuals and no thoracic segments were recovered.

Description. The cephalon has a tuberculate exoskeleton. The glabella is triangular shaped and small, extending only one-third of the distance to the anterior margin. The eyes are smooth without discernable lens detail, crescentic and extend from close to the posterior margin to over half the glabella length (Plate 10, fig. 3). The preglabellar field is greatly expanded, the genal angle is extended into a spine, directed parallel with the axis of the trilobite. There is no facial suture. The pygidium has paired pleural ribs, each with a row of tubercles, over 16 axial rings and 7 distinct ribs. The pygidial widths on 45 random selected specimens is given below:

Max. width, mm	5	6	7	8	9	10	11	12	13
No. of specimens	3	7	7	6	13	5	1	1	2

Remarks The specimens described above may be confused with those here allocated to the genus *Eocyphinium*. However, specimens of this genus possess a facial suture and a large glabella overhanging the anterior border. The pygidia are more difficult to separate but those of *Eocyphinium* have single bands of tubercles separated by a smooth zone. Thoracic segments were not found; this seems typical of the species, for at other localities, only cephala and pygidia are preserved. This suggests that thoracic pleurae were delicate and readily fragmented.

Brachymetopus moelleri Weber, 1937

(Plate 10, figs. 6-9)

Treak Cliff specimens 12 cephala and 2 pygidia have been collected.

Description The cephala are all of a small size, maximum width, 6 mm. The genal angles are rounded, a flat border with a row of tubercles is separated from the rest of the cephalon by a smooth band. The preglabellar field is steeply sloping, almost vertical. The pygidium has over 13 rings and 7 pleurae with tuberculate ornament.

Remarks This species, described here, from Britain, for the first time, is closely related to *B. moelleri parvus* Osmolska, 1970, from Poland and *B. moelleri thuringensis* Hahn, 1964, from Germany.

Cephalic comparison:

B. ouralicus	*B. moelleri*
1. Triangular glabella	parallel sided glabella
2. horizontal expanded preglabellar field	narrow, vertical preglabellar field
3. no border.	anterior border present
4. genal spines present	rounded genal angles

Family Otarionidae Richter & Richter 1926

Genus Namuropyge Richter & Richter 1939

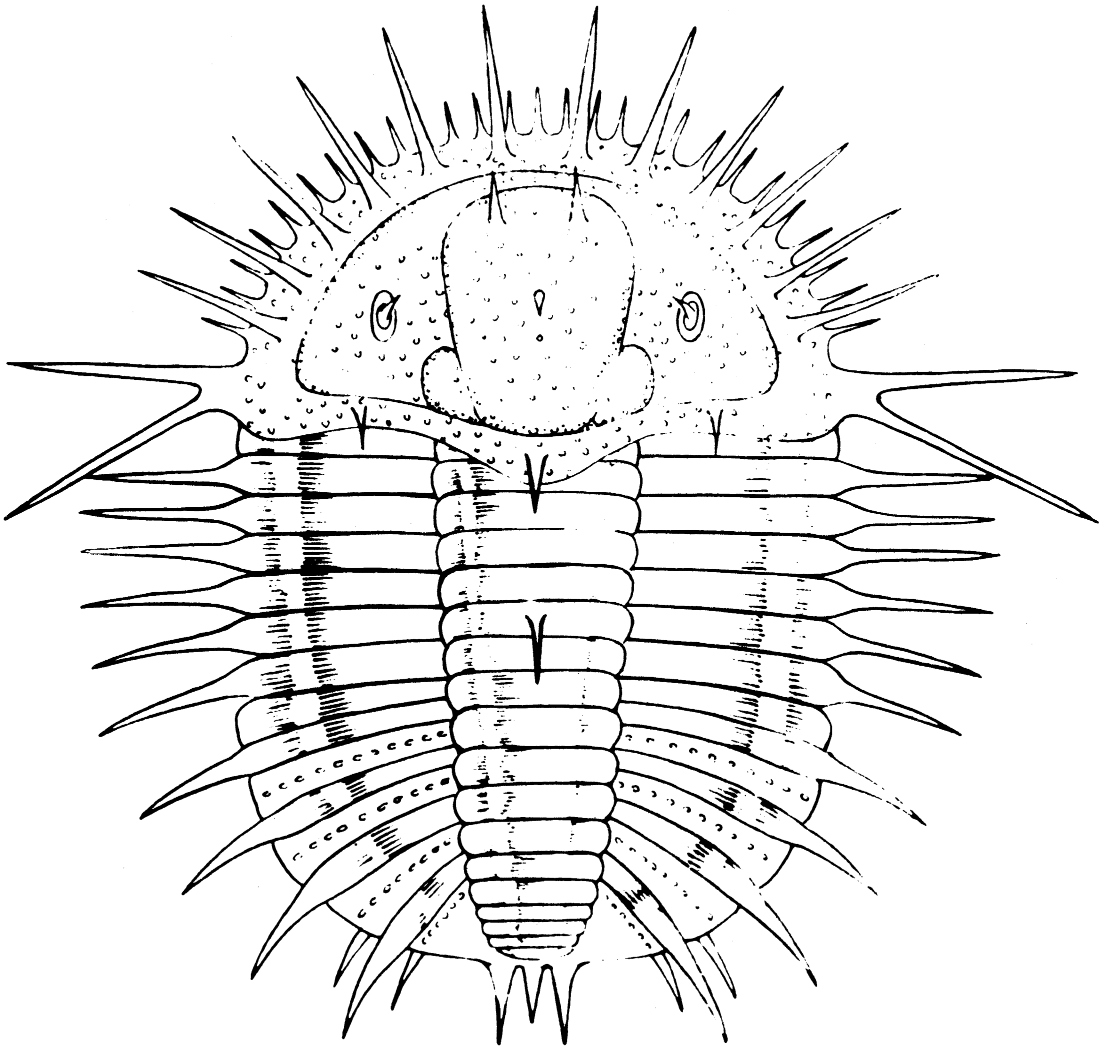
Namuropyge acanthina (Coignou 1890)

(Text-fig. 5, Plate 11, figs. 13-15; Plate 12, figs. 1-2; Plate 13, figs. 1-2)

Treak Cliff specimens This species is represented by 10 cephala, most of which are incomplete, the largest being 7 mm; and by six pygidia. The pygidia are new finds and are described for the first time.

Description The cephalon has ankylosed facial sutures and the surface is tuberculate and spinose. The glabella is inflated with prominent basal lobes and the cephalic margin has two rows of spines. The pygidia have four pleurae and about nine rings; also marginal and postaxial spines and an interpleural row of ornament.

Remarks The discovery by the author in 1975 of a complete specimen of *N. acanthina* at a nearby exposure on Treak Cliff has confirmed the long suspected association of the cephala described as *Coignovina* and the pygidia described as *Namuropyge* which occur together at several localities in Visean reef limestones; the latter name has historic precedence over the former. Although *N. acanthina* 'eyes' have no obvious visual surfaces, it is thought (Miller, 1973, that the tubercles may have borne tactile satae. Further, one specimen (TC85, Plate 11, fig. 13) clearly indicates a most unusual adaptation for the 'eye-mould' is protruded into a curved spine. The rostral plate and suture are visible on specimen TC 82 (Plate 11, fig. 15), the rostral plate is nearly vertical to this.



Text-fig. 5. *Namuropyge acanthina* (Coignou, 1890) Reconstruction of the complete trilobite. (Specially drawn by Roy Turlington, Sheffield Polytechnic.)

Namuropyge kingi Richter & Richter 1939

(Plate 12, fig. 3)

Treak Cliff has so far yielded only one pygidium, TC 88.

Description An almost semicircular pygidium with 4 ribs and at least 10 axial rings. Marginal pleurae and postaxial spines are present. The width is 5 mm.

Remarks The holotype is the only other specimen previously described. *N. kingi* differs from *N. acanthina* in overall shape, the lack of interpleural ornament and the extra spines on the pleurae. *N. kingi* is similar to *N. discors discors* but the type specimen of that species has been lost.

Family Proetidae Salter, 1864

Subfamily Cyrtosymbolinae Hupé, 1953

Genus *Cyrtoproetus* Reed, 1943

Cyrtoproetus cracoensis Osmolska, 1970

(Plate 11, figs. 7, 8, 9)

Treak Cliff material The collection comprises 4 cephala, 18 crandidia and 15 pygidia.

Description The exoskeleton is smooth. Eyes are large about half the length of the glabella which is almost parallel sided but tapering gently forwards. Its anterior part does not overhang the border which is distinctly striated. The free-cheeks are without a genal spine. There are three pairs of indistinct glabellar furrows whilst a fourth is represented only by a faint dot. The pygidium is without a border. The pleural and axial areas have poorly defined ribs, in some specimens appearing to be smooth.

Remarks This species somewhat resembles *Cummingella carringtonensis* but specimens of this latter species have a 'waisted' glabella, large eyes, genal spines and the glabella overhangs the anterior border. The pygidia have well defined ribs and a distinct border.

Genus *Carbonocoryphe* Richter & Richter, 1950

Subgenus *Carbonocoryphe* (*Winterbergia*) Hahn & Brauckmann, 1975.

Sp. nov. ? (Plate 11, figs. 4, 5, 6)

Treak Cliff material consists of 8 pygidia and 2 cranidia, questionably referred to this subgenus

Description The pygidia have 10 axial rings and 8 ribs. The pleurae are distinct and continue to the border which is slightly raised. The anterior parts of the ribs form or a characteristic ridge. The doublure is broad and is clearly discernable through the exoskeleton.

Two unusual cranidia, TC95 and TC96 were collected. They are distinct from all the other genera and may be related to the above pygidia. They have the following features; a conical glabella with four distinct glabella furrows, an occipital ring with lobes, a restricted preglabella field which is broad (transversely) and a mesial tubercle. The exoskeleton appears to be smooth but is very finely granulated. The specimens may represent a new species.

Remarks This genus is not well documented, some of the twelve species so far described are known only from the pygidia. These superficially resemble *Weania* but differ in the number of rings and the well defined pleural ribs. The cranidia exhibit similarities towards *C. hahnorum* Miller 1973. For further discussion on this point see Brauckmann 1973 and Hahn & Brauckmann 1975.

Genus *Weania* Campbell, 1963

Weania anglica Osmolska, 1970

Plate 12, figs. 4-8)

The Treak Cliff material consists of 8 cephala, 20 cranidia, 5 free-cheeks and 30 pygidia.

Description Cephalon is almost semicircular, mostly smooth and with large eyes. Width of the cephela is variable: 5.5 mm, 8.5 mm and 13.5 mm from three individuals. The anterior border furrow is deep with the border upturned in front of the glabella. The glabella has a granular ornament and is bluntly rounded towards the anterior. Free-cheeks have a characteristic 'ridge' below the eye and another joining this from the genal angle; the palpebral lobe is broad. The pygidia have 12 rings and 8 - 9 ribs, the pleurae becoming indistinct towards the posterior.

Remarks The ridges on the free-cheek and the waisted glabella distinguish the species from *Cyrtoproetus cracoensis*. A comparison is made below (p.164) with *Cummingella carringtoensis*. The species has been recorded from only one other locality at Narrowdale, Staffordshire.

Subfamily Proetinae Salter 1864

Genus *Bollandia* Reed, 1943

Bollandia aff. *claviceps* (Burmeister 1846)

(Plate 10, figs. 10, 11, 12)

Treak Cliff material The collection consists of 1 cephalon, 4 cranidia, 1 free-cheek and 5 pygidia. A rostral plate of *Bollandia* sp. is illustrated on Plate 12, fig.12.

Description The exoskeleton exhibits fine striae on the glabella but these are not visible on internal moulds. The one cephalon is over 22 mm in width. The eyes are small, about one-quarter the length of the glabella. The glabella is more or less parallel sided with a strongly inflated frontal lobe which overhangs the anterior border; preoccipital lobes are prominent. A ridge on the free-cheek runs towards the rounded genal angle. The free-cheeks are broad and steeply inclined. The doublure with terrace lines is clearly seen on the cephalon and pygidium, whilst the rostral plate and suture are present on specimen TC 125, (Plate 12, fig.12). The exoskeleton may be up to 0.5 mm thick. The pygidium is without border with moderately defined pleural ribs which are not present on the internal moulds.

Remarks The type of ornament upon the cephalon of this species suggests a close relationship with *Brachymetopus claviceps* (Burmeister, 1846) and distinguishes it from *B. globiceps* (Phillips, 1836). Dr. R.M. Owens suggests (personal communication 1976) that the Treak Cliff specimens probably represent a new species. The inflated glabella, distinct preoccipital lobes and the small eyes make the cephalon distinctive. The pygidium differs from *Cyrtoproetus carringtoensis* in lacking a border, and from *C. cracoensis* in having defined pleural ribs.

Subfamily Phillipsinae Oehlert 1886

Genus *Eocyphinium* Reed, 1942

Eocyphinium cf. *castletonensis* Osmolska, 1970

(Plate 11, figs. 10, 11, 12)

The Treak Cliff material comprises 2 cephala, 1 glabella and 3 pygidia.

Description The exoskeleton is tuberculate. The eyes are small being about one quarter the length of the glabella. The latter is slightly 'waisted' (constricted) at mid-length but continues anteriorly to overhang the anterior border, which is deep and upturned. Free-cheeks have a genal spine; ornamentation is spinose but the anterior and posterior borders are smooth. One cephalon, RE 90 (Plate 11, fig. 10) has a width of 17.5 mm and the genal spine is preserved for 1.5 mm. The pygidium has a single row of tubercles on each ring and rib.

Remarks This is a rare species at Treak Cliff. *Brachymetopus ouralicus* has a tuberculate exoskeleton but the cephala are easily distinguished as *Eocyphinium* has a facial suture, a large glabella and a restricted preglabella field.

Subfamily Cummingellinae Hahn, G. &R., 1967.

Genus *Cummingella* Reed, 1942.

Cummingella carringtonensis (Woodward 1884)

(Plate 10, figs. 13, 14; Plate 11, figs. 1, 2, 3)

Treak Cliff material The description is based on 25 cephala, 4 cranidia and 24 pygidia, two of which contained some thoracic segments. The doublure of a specimen (*Cummingella* sp.) is illustrated on Plate 12, fig. 9).

Description The exoskeleton is smooth, apart from granulated free-cheeks. The eyes are very large. The glabella is constricted slightly at mid-length and glabella furrows are faintly marked; the anterior part of the glabella overhangs the border. Free-cheeks are steeply inclined, granulose and with thin, short genal spines. The pygidium has a distinct border and there are 12 axial rings and 9-10 ribs.

Remarks A comparison has been made above (p.162) with *Cyrtoproetus cracoensis*. A comparison can also be made with *Weania anglica*, but in this species the glabella tapers forewords, the eyes are more convex with broad palpebral lobes and there is a distinct ridge on the free-cheek.

Subfamily Griffithidinae Hupé, 1953

Genus *Griffithides* Portlock 1843

Griffithides longiceps Portlock 1843

Treak Cliff collection contains only one specimen, a cranidium, TC 50.

Description A most obvious inverted pear-shaped glabella with a pair of small detatched basal lobes. Glabellar furrows are absent. The glabella is expanded frontally and is distinctly convex in longitudinal view; there is no preglabellar field or anterior border. Unfortunately the specimen is weathered and most of the exoskeleton is missing but the ornamentation present suggests a smooth surface, although there are a few small tubercles upon the posterior edge of the occipital ring.

Remarks The specimen is distinct from all the other genera at this locality.

Conclusions

The specimens of well preserved trilobite exuviae occur at all angles within the rock matrix. Ornament and fine skeletal detail are still present and the fossil population probably represents a drifted assemblage. Other reef fossils are present and include numerous single lamellibranch and brachiopod valves. Trilobites are generally uncommon fossils in the Carboniferous Limestone, so that the number and variety of species at this locality make it a unique deposit. The fossils occur in soft weathered limestone and this may have formed in a hollow or fissure within the reef. Ford (1965) concluded that the Cow Low Nick goniatite pocket deposit accumulated in, "a hollow such as an inactive surge channel or submarine cave". Miller (1972, 1973) described two new trilobite species suggesting that they may have been specially adapted for life in a fissure habitat.

Most of our knowledge of British Carboniferous trilobites is from specimens in old collections, and in many cases the range and distribution of individual species are known only in the broadest terms. This situation will only be rectified when much more detailed collecting and study has been carried out. These notes demonstrate that in the reef facies of Derbyshire a large number of specimens and species may be obtained. This has also proved to be true in areas outside Derbyshire where reef limestones are exposed, for example in the Craven district of North Yorkshire. Trilobites are rare in the massive well-bedded limestones, but are commoner in the Yoredale Shales and in the "Culm" of south-west England.

On the European continent, trilobites in the culm facies have been used for zonation, complimentary to the goniatite scheme (Hahn, 1974) and this combined approach has been applied successfully to south-west England. Further knowledge of trilobite distribution in the Carboniferous Limestone Group is required before it will be possible to test the usefulness of trilobites as zonal fossils in that facies.

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APPENDIX I

List of fossils, excluding trilobites found at the Treak Cliff locality

Brachiopoda		
	'Camarotoechia' trilatera	(de Koninck)
	Dielasma hastatum	(J. de. C Sowerby)
	Leptagonia sp.	
	'Martinia' glabra	(J Sowerby)
	Phricodothyris lineata	(J. Sowerby)
	Pleuropugnoides pleurodon	(Phillips)
	Productus sp.	
	Pugnax pugnus	(Martin)
	Retzia radialis	(Phillips)
	Rhipidomella michelini	(Leveille)
	Spirifer sp.	
Arthropoda		
	Richteria	(Jones)
Echinodermata		
	orbitremites derbienses	(J. Sowerby)
Cephalopoda	crinoid ossicles, two calyces.	
	Nomismoceras cf vittigerum	(Phillips)
Bivalvia		
	Conocardium aleforme	(J. de. C. Sowerby)
	Parallelodon bistriatus	(Portlock)
	Parallelodon verneuilianus	(de Koninck)
Gastropoda		
	Euconospira conica	(Phillips)
	Natiscopsis sp.	
	Platyceras vetrustum	(J. de C. Sowerby)
	Straparollus sp.	
Bryozoa		
Algae		

Explanation for Plates 10, 11, 12 and 13

Specimen nos. preceded by the letters 'RE' were kindly loaned by Richard Elliott; others are from the authors collection. A representative selection of the figured specimens will be deposited in the National Museum of Wales, Cardiff.

Explanation for Plate 10

Fig. 1.	*Brachymetopus ouralicus*	×5	(Spm. no. RE 45)
Fig. 2.	*B. ouralicus* (genal spine detail)	×4	(Spm. no. 40)
Fig. 3.	*B. ouralicus*	×4	(Spm. no. 40)
Fig. 4.	*B. ouralicus*	×5	(Spm. no. 47)
Fig. 5.	*B. ouralicus*	×4	(Spm. no. 49)
Fig. 6.	*Brachymetopus moelleri*	×5	(Spm. no. 73)
Fig. 7.	*B. moelleri*	×5	(Spm. no. 71)
Fig. 8.	*B. moelleri* (pygidium)	×3	(Spm. no. 74)
Fig. 9.	*B. moelleri* (genal angle detail)	×5	(Spm. no. 72)
Fig. 10.	*Bollandia* aff. *claviceps* (cephalon with cuticle preserved)	×2	(Spm. no. 125)
Fig. 11.	*B.* aff. *claviceps* (glabella)	×2	(Spm. no. RE 50)
Fig. 12.	*B.* aff. *claviceps* (free-cheek)	×5	(Spm. no. 126)
Fig. 13.	*Cummingella carringtonensis*	×6	(Spm. no. 30)
Fig. 14.	*C. carringtonensis*	×4	(Spm. no. RE 21)
Fig. 15.	*Cummingella sp.* (pygidium)	×5	(Spm. no. 34)

Explanation for Plate 11

Fig. 1.	*Cummingella carringtonensis* (tubercles on the free cheek)	×4	(Spm. no. RE 20)
Fig. 2.	*C. carringtonensis* (thorax and pygidium)	×6	(Spm. no. 100)
Fig. 3.	*C. carringtonensis* (pygidium)	×5	(Spm. no. 91)
Fig. 4.	*Carbonocoryphe* sp. nov. (cranidium)	×5	(Spm. no. 96)
Fig. 5.	*Carbonocoryphe* sp. nov. (pygidium)	×5	(Spm. no. 97)
Fig. 6.	*Carbonocoryphe* sp. nov. (cranidium)	×5	(Spm. no. 95)
Fig. 7.	*Cyrtoproetus cracoensis* (cranidium)	×5	(Spm. no. 151)
Fig. 8.	*C. cracoensis*	×4	(Spm. no. 155)
Fig. 9.	*C. cracoensis*	×6	(Spm. no. 150)
Fig. 10.	*Eocyphium castletonensis*	×4	(Spm. no. RE 90)
Fig. 11.	*E. castletonensis*	×3	(Spm. no. 110)
Fig. 12.	*E. castletonensis*	×4	(Spm. no. RE 91)
Fig. 13.	*Namuropyge acanthina* (ventral view with 'eye' spine)	×4	(Spm. no. 85)
Fig. 14.	*N. acanthina*	×6	(Spm. no. 83)
Fig. 15.	*N. acanthina* (cephalon & rostral plate)	×4	(Spm. no. 82)

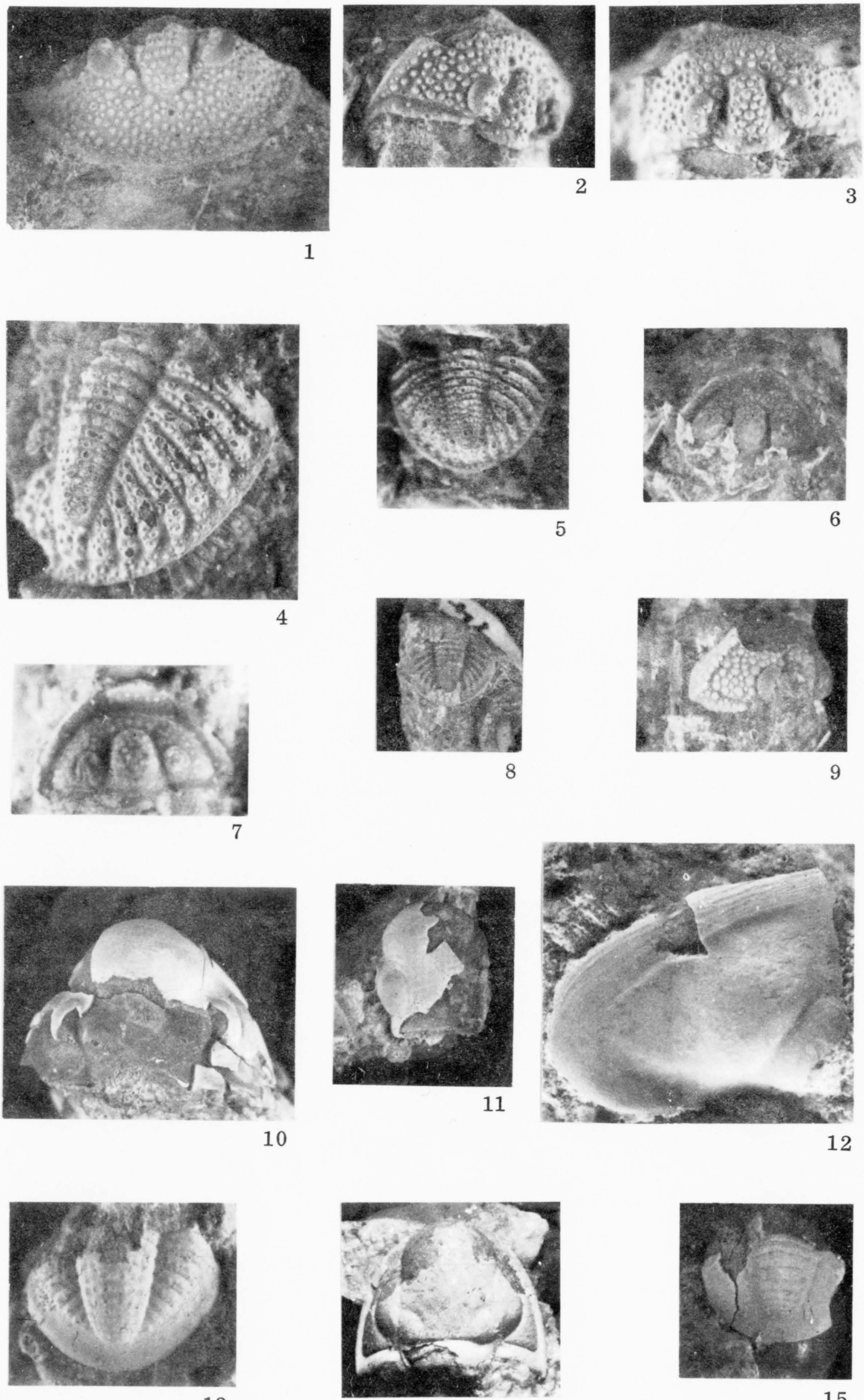
Explanation for Plate 12

Fig. 1	*Namuropyge acanthina*	×5	(Spm. no. 84)
Fig. 2	*N. acanthina*	×5	(Spm. no. 81)
Fig. 3	*Namuropyge kingi*	×6	(Spm. no. 88)
Fig. 4	*Weania anglica*	×5	(Spm. no. 38)
Fig. 5	*W. anglica*	×4	(Spm. no. 35)
Fig. 6	*W. anglica*	×5	(Spm. no. 36)
Fig. 7	*W. anglica*	×4	(Spm. no. 37)
Fig. 8	*W. anglica*	×4	(Spm. no. RE 60)
Fig. 9	*Cummingella* sp. Doublure (ventral side)	×4	(Spm. no. 23)
Fig. 10	Hypostome (species unknown)	×5	(Spm. no. 201)
Fig. 11	Hypostome (species unknown)	×4	(Spm. no. 202)
Fig. 12	*Bollandia* sp. (Rostral plate (ventral side)	×6	(Spm. no. 125)

Explanation for Plate 13

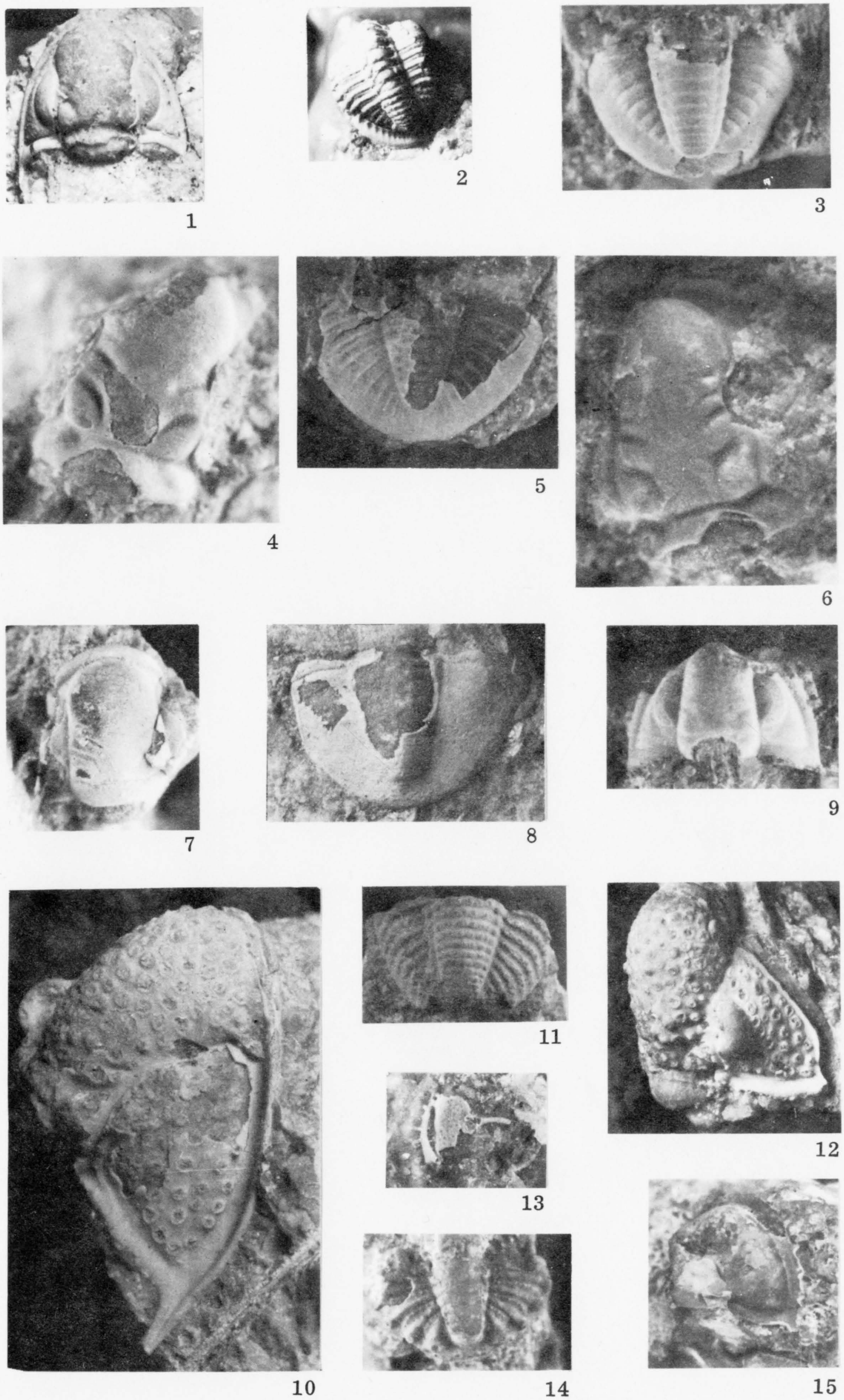
All the figs. are scanning electron micrographs.
The specimens were coated with gold palladium.

Fig. 1.	*Namuropyge acanthina* Cephalon (side-view)	×25	(Spm. no. 55)
Fig. 2.	*N. acanthina* Pygidium with pleural spine.	×10	(Spm. no. 56)
Fig. 3.	*Brachymetopus ouralicus* Cephalon.	×10	(Spm. no. 53)
Fig. 4.	*B. ouralicus* Genal spine detail.	×10	(Spm. no. 53)
Fig. 5.	*B. ouralicus*	×10	(Spm. no. 51)
Fig. 6.	*B. ouralicus* Eye detail.	×35	(Spm. no. 51)



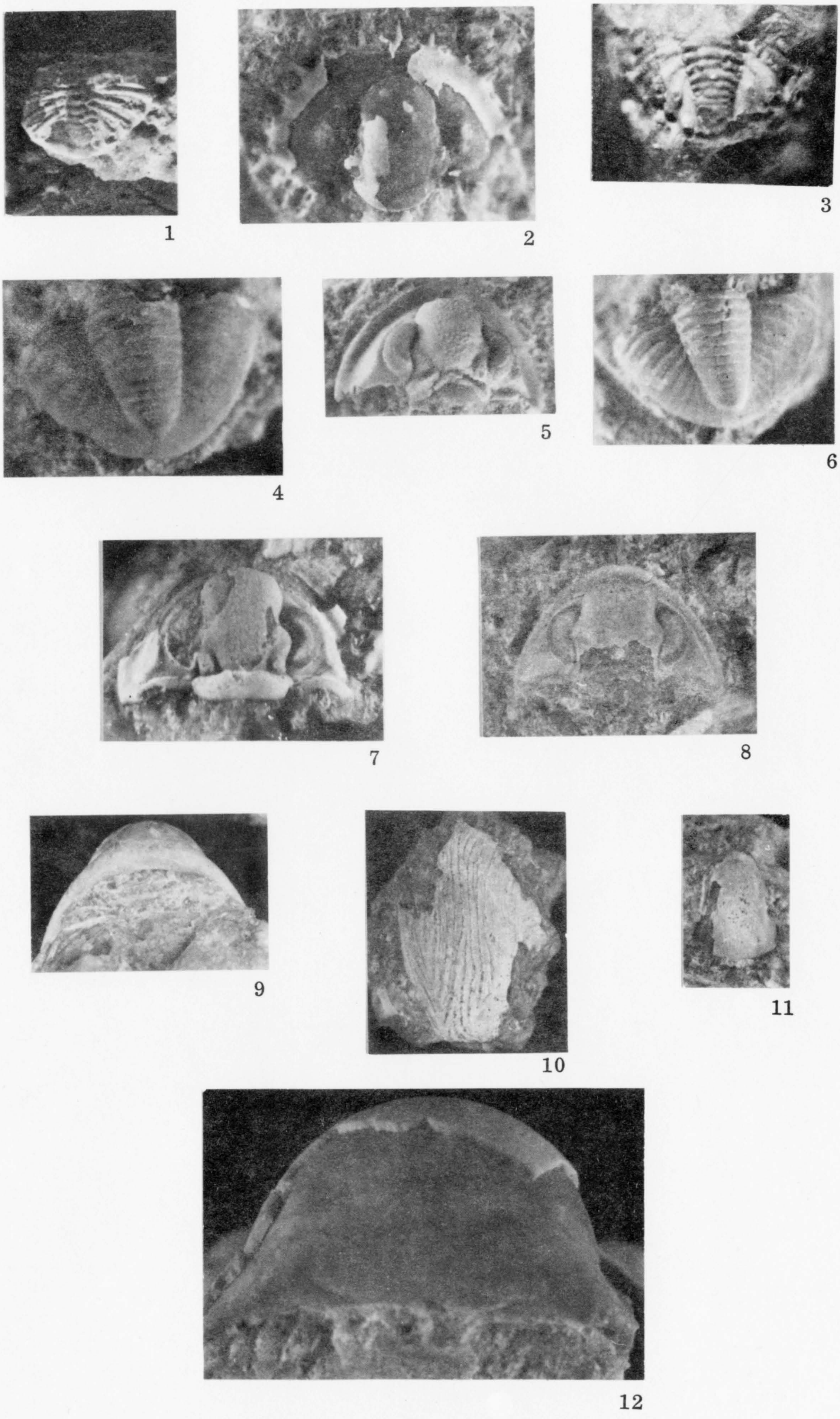
Tilsley - Derbyshire trilobites

(Explanation on p.168)



Tilsley - Derbyshire trilobites

(Explanation on p. 169)



Tilsley - Derbyshire trilobites

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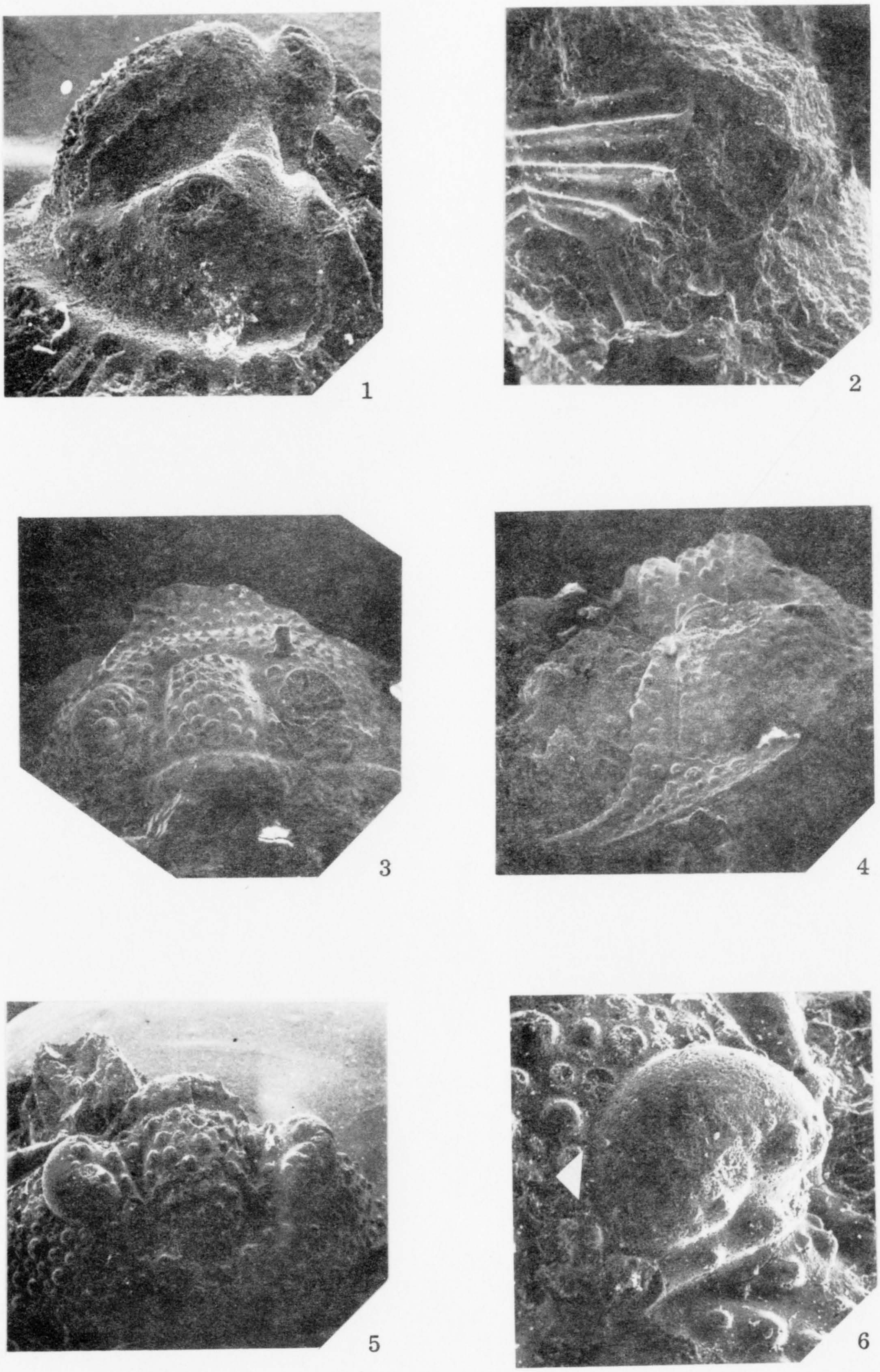

Tilsley - Derbyshire trilobites

(Explanation on p. 170)

THE DEFINITION OF GEOLOGY

by

J. Challinor

Introduction

The definition of geology - the delimitation, content, and meaning of the science - seems to be very largely left to take care of itself. Statements, in the preliminary pages of the textbooks for instance, are apt to be vague and various. Surely, however, an examination and analysis of this most elementary of all geological considerations is of some importance. In offering the following view of the matter I shall all the time be recalling those basic facts and principles which are very well known to everybody.

The material content of geology

What is Geology essentially, as one whole coherent science separate from the other sciences? It will, of course, make use of the findings of other sciences that it does not include as part of its own special content.

The word Geology is derived from the Greek *gē*, the earth, and *logos*, science; thus, on this basis, it means the science of the earth. The science of the earth, however, would include many subjects not in fact forming part of geology. First taking the earth in its widest sense, let us then restrict it until we find exactly with what part of the earth geology does deal.

The widest sense of the earth is the earth considered as a whole planet - Planet Earth. The first distinction that strikes the mind is that between the atmosphere and the rest of the planet. Of this rest of the planet (for which there is no single name) we can distinguish between the hydrosphere and what is sometimes called the 'solid earth' but better, perhaps, called the 'earth-body'. The hydrosphere, in the widest sense, includes all the water and ice (1) on the surface of the earth, (2) in the atmosphere and (3) within the earth. Neither the atmosphere nor parts 1 and 2 of the hydrosphere are themselves to be included within the matter of geology.

We are now left with the earth-body or whatever it may be called, everywhere underlying the atmosphere and about two-thirds of it underlying the main part of the hydrosphere as well.

Over most of the land there are thin veneers of materials which we must further discard. These are (1) vegetation and (2) the constructive works of man. There is also animal life. Plant and animal life are, of course, very much present in the hydrosphere and some kinds of animal life are active in the atmosphere. Plant and animal life constitute the biosphere.

Beneath all these overlying materials we come to the essential substance of the earth-body and it is this that constitutes the subject matter of geology. Again, there is no single term for it though *gee* suggests itself. We may say, however, that it is made up of mineral matter, extending for our purpose the primary definition of mineral matter: 'any substance obtained by mining' (with which operation can be associated drilling for oil and sinking wells for water). Geology thus deals with the Mineral Kingdom.

The mineral earth-body has been found by physical methods of detection, particularly by the recording and interpretation of earthquake vibrations, to consist of several concentric parts. In the first place there are two; the earth's crust or *lithosphere* and the underlying interior

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1977, pp. 171-177.

main mass of the earth, the *endosphere*, a term not much in use at present. The former occupies in average thickness only about 1/200 of the earth's radius; it is thicker under the continents than under the oceans.

The earth's crust consists essentially of various kinds of rocks and rock-materials. The endosphere comprises the *core*, extending outwards from the centre to about half the earth's radius, and the *mantle*, between the core and the crust. It is thought that the core is composed mainly of iron and nickel and that it is solid in its inner part, of radius about one-third of the whole, and fluid for the rest. The mantle is thought to be composed chiefly of silica, iron, and magnesium; it is solid but probably flows, particularly the upper part of it, given time, like pitch.

In practice, geology deals almost entirely with the earth's crust, the lithosphere. This is not merely because it is the only part to be seen or probed, or of which the structure can be directly inferred, but also because it is, in any case, the part in which nearly all the variety, activity, and interest lie.

We must now see more particularly what the earth's crust contains. In the first place, what does the geologist mean by the term rock? Although rock in the ordinary sense is a hard, compact, resistant substance, all the materials of the earth's crust that are in the solid state (as distinct from being liquid or gaseous), whether firm or loose, are included in what the geologist calls 'rock'.

We have used, above, the term 'mineral' as an adjective, defining it on the basis of occurrence; but 'mineral' as a noun is more restricted, being defined purely on the basis of its constitution. A short definition of a mineral is 'a solid of definite chemical composition formed by the inorganic processes of nature'. The vast majority of rocks are aggregates of particles of minerals, but a few are, wholly or in part, in the form of natural glass. Some important kinds of rock are composed of organic carbonaceous matter (e.g. coal), the remains of plants.

There are also certain fluid substances entering into parts of the earth's crust. We can call molten matter (*magma*) and also petroleum rock material, and with them must be classed the respective gaseous emanations - magmatic gases and the gaseous hydrocarbons (natural gas). The water in the earth's crust derived from the atmosphere (meteoric water) is a part of the hydrosphere, but it must also be regarded as an integral part of the earth's crust and be placed within our mineral kingdom.

The materials of the sea floor can be sampled, and drilling at particular spots can probe deeply. Modern quantitative physical methods allow a degree of inference about composition and structure over wide areas. Geology is, however, ordinarily practised on land.

We can in a general way make a preliminary convenient sorting of all the rocks entering into the substance of the land areas into two groups according to their manner of occurrence: (1) the superficial deposits (soils, gravels, sands, muds, etc.) and (2) the underlying 'solid masses', everywhere present but usually covered by superficial deposits. The superficial deposits may be loose but are often coherent and may be hardened in places. The solid masses are usually more or less hard, but some may be quite friable.

Under the waters of the oceans there are also two groups of rocks: the marine deposits and the underlying solid rock.

We are, here again, at a loss for a suitable term: for what we are calling the solid masses or solid rock as opposed to the superficial. *Bedrock* is a term sometimes used for this.

The accompanying table summarizes the foregoing analysis.

Table 1: The material content of geology

- Planet Earth
  - Atmosphere
  - The rest of the planet
    - Hydrosphere (the part on the earth's surface)
    - Earth - body
      - Veneers (on land) of vegetation and man's works.
      - Mineral earth-body (Mineral kingdom, *Gee*)
        - Lithosphere (see below)
        - Endosphere
          - Mantle
          - Core

- Lithosphere
  - Rocks
    - Aggregates of minerals (including glass)
    - Organic (coal, peat, etc.)
      - Superficial
      - 'Solid'
  - Liquid and gaseous 'rock material'
    - Magma and associated emanations
    - Petroleum and natural gas
  - Meteoric water (also a part of the hydrosphere)

Geological processes

The essential elements of the science of geology are to be found in a study of the solid rocks. These rocks are exposed, naturally or artificially, from beneath the veneers and superficial deposits, in places such as sea-cliffs, stream beds, mountain sides, and in quarries and cuttings.

The first fact to be observed about the solid rocks is that they are of different kinds in different places. This difference lies chiefly in (1) the particular constituent minerals, (2) the kind of texture, and (3) the inherent structure of the rocks as seen in the field.

Observation, record, mapping, and description lead to reasoning. How were the various kinds formed? The generalization emerges that there are two sharply contrasted kinds of (solid) rock, the *sedimentary* and the *igneous*. The former rocks are, clearly, hardened ordinary sediments (e.g. sandstone, mudstone, limestone). Of the latter some are as clearly the products of old volcanoes (e.g. basalt, fragmented pyroclastic rocks), while others, typically formed of a mosaic of crystals, can only have been produced by the more or less slow cooling of molten rock material within the earth's crust (e.g. granite, dolerite). A third kind of rock gives proof of having been profoundly altered - the *metamorphic* kind (e.g. gneiss, schist).

The sedimentary rocks usually show stratification; they are disposed in *strata*. Most of them contain *fossils* (sparsely or abundantly), the remains of the hard parts of organisms. By far the commonest fossils are those of invertebrate shelled marine animals. The inference is, therefore, that for the most part these rocks, now perhaps far and high inland, were laid down as sediments, layer on layer, in the sea. The sedimentary rock-masses (in particular) nearly always show that they have been to some degree deformed, bent into *folds* and broken by *faults*.

What can be seen happening at the present day of significance to our reasoning? We can see the rivers carrying down mud and we realize that this (or most of it) must finally come to rest on the sea floor. We can see volcanoes in action. Changes, comparatively recent, in the relative levels of land and sea, and earthquakes, give some evidence of crustal instability. But the occurrence and cooling of molten matter within the earth's crust, the potentiality of severe forces deforming the rock masses, and conditions of heat and pressure causing metamorphism - these can only be imagined, but they are certainly to be inferred.

All these operations constitute the geological processes, which can be grouped as follows:

(1) Erosion and transport of rock material, on and from the land, chiefly by running water, and also by the action of waves along the coast; all this resulting in a wearing away and a lowering of the land.

(2) Deposition of rock material on the sea floor.

(3) Deformation of rock-masses, with movements of parts of the earth's crust and uppermost mantle, producing interchange of land and sea areas. (Such recent conceptions as continental drift, sea-floor spreading, and plate tectonics find their place here).

(4) Igneous action.

(5) Metamorphism.

The first two of these processes are complementary. The atmosphere has a large concern in weathering, the preliminary stage of erosion, particularly if we include atmospheric moisture: and the wind can transport weathered material, with consequent abrasion of exposed rock. The paramount importance of the hydrosphere in effecting erosion, transport, and deposition is obvious. Thus the atmosphere and the main parts of the hydrosphere, while not in themselves part of the domain of geology, are media within, and by means of which, these two geological processes operate.

Geological time

The geological processes, certainly those of erosion and deposition, demand a very long time to operate in order to produce results on a large scale.

The concept of time enters into geology to a much greater degree than into any other science. Although the present day is just one day in the continuing passage of time, in practice we inevitably come to distinguish roughly between geologically recent conditions and happenings, covering the last few thousand (or few ten-thousand) years or so, and the conditions and happenings of past geological ages which stretch back, according to present calculations, through four or five thousand million years. On the present land surface the superficial deposits have been laid down more or less recently, while the underlying solid masses were formed in past geological ages and, with few exceptions, under conditions totally different from those now prevailing where we now find them.

It was not until towards the end of the eighteenth century that it began to be realized that there was such a thing as geological time. It was this realization, more than anything else, that caused geology to become established, rather late, as a rational major science and, indeed, it was at this time that the word 'geology' first came into general use.

A crucial question now arises: does the passage of time reveal itself in the rocks as we now see them and, if so, to what extent? Can we put the rocks in a time-order?

From what has been said as to the manner of formation of rocks there emerge two possible criteria of relative age among the rocks of a limited region: (1) in a normal stratal sequence of sedimentary rocks the upper are the newer, and (2) if an igneous rock A is found to have intruded into another rock-mass B, then A must be younger (to some degree) than B. Of these two criteria it is (1) that is much the more important.

How can local relative ages be extended and combined to give general relative ages and ultimately produce a time-classification of all rocks? Can we recognize a rock in one place as being of the same age as a rock in a separated, perhaps far distant, place? We cannot do this by means of the mineralogical and textural character (the lithological character) of the rocks themselves because a mudstone (say) in one region may be of the same age as a sandstone (say) in another, and similar rocks may be of any age. The character of an igneous rock in itself does not signify any particular age. It is by means of the fossils contained in the sedimentary rocks that a relative chronology of all rocks can be made out.

The principle, reduced to its simplest terms, is this: rocks can be identified and correlated, as regards age, by means of the particular kinds of their contained fossils. This was at first, during the early part of the nineteenth century, a purely empirical hypothesis, but it was found on application to produce order out of chaos. No biological considerations were involved, but it was soon seen to be in accordance with an independent and rational theory of more or less gradual change (evolution) in the kinds of life inhabiting the earth during the course of geological time.

The rocks of the world could then be classified into a stratigraphical table, into which the igneous and metamorphic rocks could to a large extent be fitted.

It was still impossible to make anything but guesses as to the actual periods of time involved, because the various kinds of evidence were all extremely unreliable. During the early part of the present century, however, the radioactive decay of certain isotopes of certain elements, at an unchangeable measureable rate in each case, was discovered, with the result that the absolute age, in years, of certain minerals, and thus of the rocks first containing them, could be determined. The stratigraphical table can now be placed alongside a standard scale of millions of years.

Group (era)	System (period)	Approximate age of the base in millions of years
Cainozoic		70
Mesozoic	Cretaceous	135
	Jurassic	180
	Triassic	225
Upper Palaeozoic	Permian	275
	Carboniferous	350
	Devonian	400
Lower Palaeozoic	Silurian	435
	Ordovician	500
	Cambrian	600
	Precambrian (undivided)	4,500

Geological History

Obviously the mere passage of time cannot produce or change anything. The course of events and the transformation of conditions within, and on the surface of, the earth's crust result from the geological processes working through time. Though the facts of geological structure, in the widest sense, are in themselves of the greatest interest and, incidentally, of the greatest economic importance, and though the inferences as to process are eminently scientific, it is the revelation of the history of the earth that sets geology among the few great departments of Natural Philosophy.

The superposition, correlation, and lateral extent of strata of different kinds, the structural discordance (*unconformity*) between one stratigraphical formation and an underlying one, the deformation undergone by the several formations, the occurrence of igneous rocks, extrusive and intrusive - these are the main things to be observed throughout a whole region, such as northern England for example, and which allow the geological history of that region to be reconstructed.

It must be mentioned that the lowest rocks contain practically no fossils useful in correlation so that any detailed world-wide history of those earliest times, some six or seven times as long as all the rest, is at present impossible.

A generalization that emerges from the reading of regional geological histories is that of the *geological cycle*. This, in essence, is as follows (omitting igneous activity, which occurs less regularly): (a) deposition and, at least partial, consolidation of sediments, most abundantly in a sinking part of the sea floor, a *geosyncline*, not very far from land, (b) pressure within the earth's crust squeezing the deposited rocks as in a vice, causing deformation within them and at the same time raising them to form land, (c) erosion of the land, providing material for the deposition of sediments in a neighbouring sea on the eroded surface of rocks formed in a previous cycle.

This kind of outline of the geological history of a region can be filled in according to the local details.

The study of the more or less recent superficial deposits of all kinds, and of the visible geological processes, provides a direct view of geological history in progress. We seem, however, to be by chance now living under rather peculiar, though doubtless not unique, conditions; that is, in an interglacial, possibly a truly post-glacial, period. Boulders, gravels, sands, and clays laid down by ice and associated streams in regions, such as Britain, now enjoying a temperate climate are conspicuous among the superficial deposits. The study of this Glacial Period (Ice Age), stretching back through a million years or more, is thus a specially apparent and interesting episode in geological history.

The principle that underlies all our ideas of time, process, and history is that of Uniformitarianism. This is the principle of the continuity of the action of the various forces and the continuity of the resulting changing conditions, in contrast to the idea of world-wide violent catastrophes interrupting the orderly course of nature.

We have now arrived at the final definition of geology: the Science of the Mineral Kingdom of the Earth; its composition, structure, processes, and history.

But there is still a note to be added. Recent exploration of outer space has suggested such titles as Lunar Geology, Martian Geology, Planetary Geology.

Concerning the divisions of geology

There are certain subordinate sciences which either definitely form part of geology or whose status in that respect is to be considered. The following are the chief of these.

Stratigraphy The study of strata. This in the first place requires a description of their occurrence, lithology, succession, and mutual relations, and their fossil content. The study of the manner of their original deposition is sedimentology. The study of the fossil content of strata from the points of view of (1) their identification and correlation, and (2) indication of conditions prevailing where they were deposited, is biostratigraphy. From all these studies we can infer something, at least, of the distribution of land and sea and of the variation in space of marine conditions at any one time - that is, we can study palaeogeography. We know much more about the palaeogeography of the marine areas than we do of the land areas, the evidence concerning these latter having been destroyed to provide the more lasting evidence of the former.

Structural geology. This is the study of the architecture of the earth's crust; the disposition and mutual relations of all kinds of rocks (sedimentary, igneous, metamorphic) on every scale, from the world-wide to the microscopic. Structures are primary, resulting from the manner of the original formation of the rocks, and secondary, deformations due to subsequent forces applied to them. It is the secondary deformations that demand the more intensive and detailed study. Structural geology is also called tectonic geology, the latter term being used particularly for the secondary deformations.

Mineralogy. Minerals have already been defined and have been seen to be the ultimate visible particles of the vast majority of rocks, so that the study of them is obviously of fundamental importance in geology. However, there are a great many minerals and geology is mainly concerned only with certain of them, the rock-forming minerals and the ores and their associates occurring in pockets and veins. The geologist is also mainly concerned with certain physical properties, such as colour and hardness, and with optical properties, particularly those seen under the microscope. Chemical composition is given to him from the chemical side of the subject. Crystallography is something of an exercise in solid geometry; atomic structure can be examined by x-ray analysis. Thus the science of mineralogy is one that can be studied in detail in several directions, beyond the more immediate requirements of the ordinary geologist.

Petrology. The science of the rocks in themselves. The descriptive part of it, petrography, is the study of the mineral composition and texture of rocks of all kinds. Their origin and mode of formation is petrogenesis, a term applied particularly to the igneous, and also metamorphic, rocks. Volcanism here finds a place. While many broad facts of petrology can be observed in the field, and more can be seen in hand-specimens, the details, which provide the most important information, can be studied only in thin sections (slices) under the microscope.

Palaeontology. This is the science of the life of past ages; it is a department of biology, not one of geology in the strictest sense - a sense we are trying to define. The evidence concerning palaeontology lies in the fossils; but the fossils are at the same time geological material. They are ingredients of the sedimentary rocks and are thus a part of the mineral kingdom as well as being parts of the animal and plant kingdoms. They may determine the lithological character of a rock, for example coral limestone, shelly sandstone. The geologist, finding the fossils, has for his own particular purposes to discriminate carefully between the different kinds. But when he attempts to infer the character of the soft parts from the mineralized remains, to establish biological relationships, and to reconstruct the life and habits of the animals and plants themselves, he is doing work of a biological kind, as he is also when he tries to trace evolutionary lines from the time-succession of the fossils in the rocks. Geologists are often led to do this, particularly with fossils of invertebrate animals, as an extension of their work into another domain of science. They will also, purely as geologists, make use of what is known about the distribution of life at the present day to throw light on the environment in which certain rocks were originally deposited.

Geomorphology. The science of the earth's surface features: their distribution, character, origin, and evolution. The description and cartographical delineation of these features constitute the most important part of physical geography. The earth's surface features are, however, entirely due to geological processes and geological structure, and include the superficial deposits. The form of the surface of the earth's crust, in addition to its internal structure, may be said to be in itself a geological, as well as a geographical matter. Thus geomorphology as a whole lies within the domain of geology, the descriptive aspects of it being at the same time geographical.

Geophysics and Geochemistry. These sections of geology result from the application of physical and chemical principles and methods to geological problems.

Finally, geology has many applications in the service of man: thus Agricultural Geology, Engineering Geology, Geology of Water Supply (Hydrogeology), Petroleum Geology, Mining Geology.

While geology remains firmly as a clearly defined individualized science, its investigation expands ever more widely and penetrates ever more deeply. As studies proceed it seems that there is a limitless amount and variety of things to record and from which to derive geological thought. Is there any region, in any part of the world, that has been fully explored? New techniques, such as that of the scanning electron microscope, enable minute but significant details to be examined, and wide-ranging, even revolutionary, conceptions such as that of plate tectonics emerge from generalizations based on new knowledge of the earth's crust and its behaviour. The riches of the Mineral Kingdom are indeed inexhaustible!

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SOME ASPECTS OF THE PALAEOECOLOGY OF THE E_1b ZONE OF THE EDALE SHALES (NAMURIAN) IN THE EDALE VALLEY, DERBYSHIRE

by

David D. J. Antia & Brian A. Wood

Summary

The sediments and faunal composition of the E_1b zone of the Edale Shales at Edale were examined and recorded. The faunal diversity was plotted by means of a rarefaction graph, the value of which in palaeoecological interpretations is questioned. It is concluded that the sediments were deposited in the bathyal marine zone under either aerobic or anaerobic conditions. The posidonoid bivalves are considered to have led an epifaunal benthonic existence as suspension feeders. They are further analysed to determine (1) the opportunistic and specialist species, (2) the natality and mortality structuring of their populations, and (3) the variation of death rates with sexual maturity and age within each population.

Introduction

The Namurian Edale Shales of north Derbyshire form a sequence of dark grey mudstones and limestones, often carbonaceous, containing disseminated pyrite. They vary in thickness from about 200 m in the type area (the Edale valley) to about 400 m in the Alport valley (Hudson and Cotton, 1943, 1945; Stevenson & Gaunt, 1971), and have been interpreted as a sequence of basinal marine shales formed by the deposition of mud from the suspension load in a low energy environment. The marine nature of these sediments is indicated by the presence of goniatites, and the disseminated pyrite suggests stagnant bottom conditions (Walker, 1966; Collinson, 1969; Selley, 1976).

The 7 m of sediment which comprise the *Eumorphoceras pseudobilingue* zone (E_1b) of the Edale Shales (Table 1) in the Edale valley, are exposed in the banks of the River Noe at the core of the Edale anticline. The top of this zone has not been defined by Hudson and Cotton (1945), but it is taken by the authors of this article to be represented by a thin band of extensively burrowed argillaceous limestone exposed in the River Noe, (SK 10858481). The burrows in this band represent a number of organisms which displayed a complex behaviour pattern in their excavating or burrowing activities. The upper 6 m of the sequence consist of flaggy, well bedded carbonaceous, paper shales, while the lower 1 m is a fossiliferous black shale containing some rounded calcareous nodules.

All the lithologies examined were fossiliferous, with the calcareous fossils occuring in small lenses, less than 1 m in diameter, and irregularly distributed. No trace fossils or sedimentary structures, other than parallel laminations, were observed in the entire sequence, and all the macrofossils examined possessed a crushed recrystallised calcareous skeleton.

For the purposes of this study the distribution, composition, and population structure, in terms, for example, of size and numbers of the faunas, were examined both laterally and vertically through the sequence.

Mercian Geol., Vol. 6, No. 3, 1977, pp. 179-196, 6 text-figs.

Table 1 Faunal zones of the Pendleian (E_1), Arnsbergian (E_2), Chokierian (H_1) and Alportian (H_2) stages present in the Edale Shales of North Derbyshire.

Stage	Zone No.	Goniatite index fossil
Alportian	H_2c	*Homoceras magistrorum*
	H_2b	*Homoceras undulatum*
	H_2c	*Hudsonoceras proteus*
Chokierian	H_1b	*Homoceras beyrichiacum*
	H_1a	*Homoceras subglabosum*
Arnsbergian	E_2d	*Nuculoceras nuculum*
	E_2c	*Nuculoceras stellarum*
	$E_2b(2)$	*Cravenoceratoides nititoides*
	$E_2b(1)$	*Cravenoceratoides edalensis*
	$E_2a(2)$	*Eumorphoceras bisulcatam*
	$E_2a(1)$	*Cravenoceras cowlingense*
Pendleian	E_1c	*Cravenoceras malhamense*
	E_1b	*Eumorphoceras pseudobilingue*
	E_1a	*Cravenoceras leion*

Composition of the Fauna

Comprised either goniatites and/or bivalves, between 3% and 5% of the latter occurred as articulated valves, both gaping and closed.

The macrofauna observed is listed as follows, and its distribution through the succession is illustrated in text-fig. 1:

(1) Bivalvia

Posidonia corrugata (Etheridge)

Posidonia membranacea (McCoy)

Posidonomya radiata (Hind)

Posidoniella laevis (Brown)

Posidoniella variabilis (Hind)

(2) Ammonoidea (Goniatites)

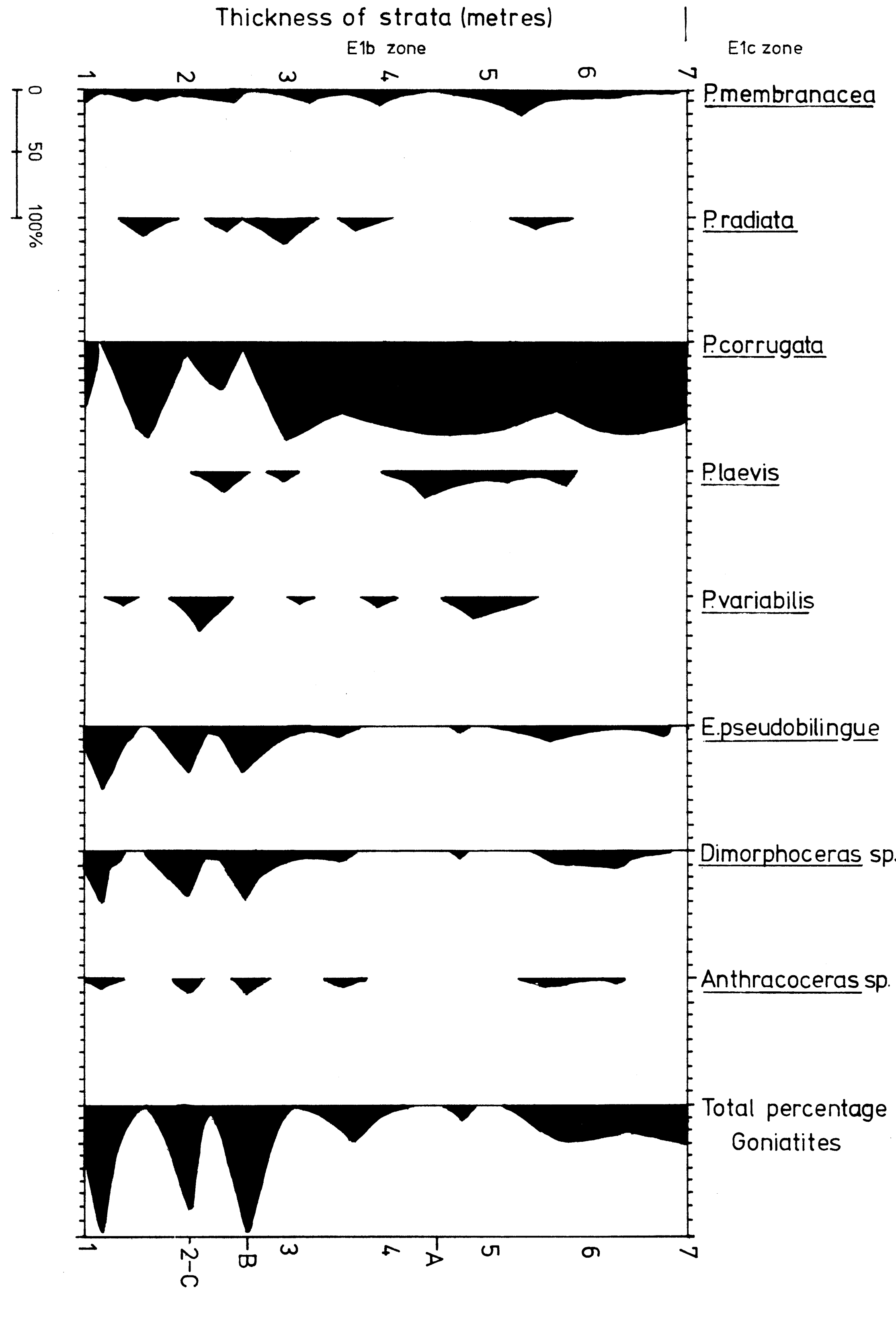
Anthracoceras sp.

Dimorphoceras sp.

Eumorphoceras pseudobilingue (Bisat)

(3) Others

Fish fragments and plant debris constitutes from 0.1% to 1% of the rock by volume as particles greater than 1 mm.



Text-fig. 1. Distribution of the fauna through the E_1b zone.

A rarefaction graph has been drawn for the fauna as a measure of faunal diversity (text-fig. 2). No broad interpretations in terms of climatic provinces and depth, such as those produced by Duff (1975) and Calef and Hancock (1974), have been made from the graph because we have doubts as to the validity of its usage, for the following reasons:

(1) The current ecological rarefaction curves which are used as a basis for palaeoecological interpretations are drawn using both the soft bodies and the calcareous shelled members of the fauna (Sanders, 1968). Among fossils, examples of soft bodies organisms preservation are a rarity, and even burrows are no real indication of the actual diversity of the soft bodied content of the benthonic substrate (Davis, 1964, 1965, 1967). These factors must be considered when comparing past and living faunas.

(2) Rarefaction curves from modern shell deposits are rarely comparable with those of the fauna from which the deposit was derived (Antia, in press, and text-fig. 2).

(3) Rarefaction curves from adjacent beds deposited under similar conditions may be vastly different, reflecting sedimentological processes rather than biological diversity (text-fig. 2). As Antia (in press) has shown changes in this diversity, in both its gradiational and varietial components, are mirrored in the fossils only when sedimentological transport of the sediment is minimal. Since the species composition of the live and dead faunas at a given locality tend to be dissimilar, (Antia, in press) except where both the fossils occur in life orientation, little reliance can be placed on an ecological interpretation of faunal diversity when the fossils are dispersed.

An examination of relative percentages of Bivalvia left and right valves reveals that although they occur in approximately equal numbers throughout the sequence, occasionally some lenses may be almost completely devoid of left or right valves. Such biased concentrations are rare, and indicate that some differential sedimentological sorting has taken place (Van Straaten, 1952; Craig, 1967). All the single valves were orientated concave down.

Numerical Analysis of the Fauna

1. Size Frequency Distributions

Biogenetic growth rings of the bivalves proved impossible to differentiate, so size has been used as a measure of age (Hallam, 1972). The reliability of external growth ring analysis in palaeoecology, has been questioned by Farrow (1971 a, b; 1972).

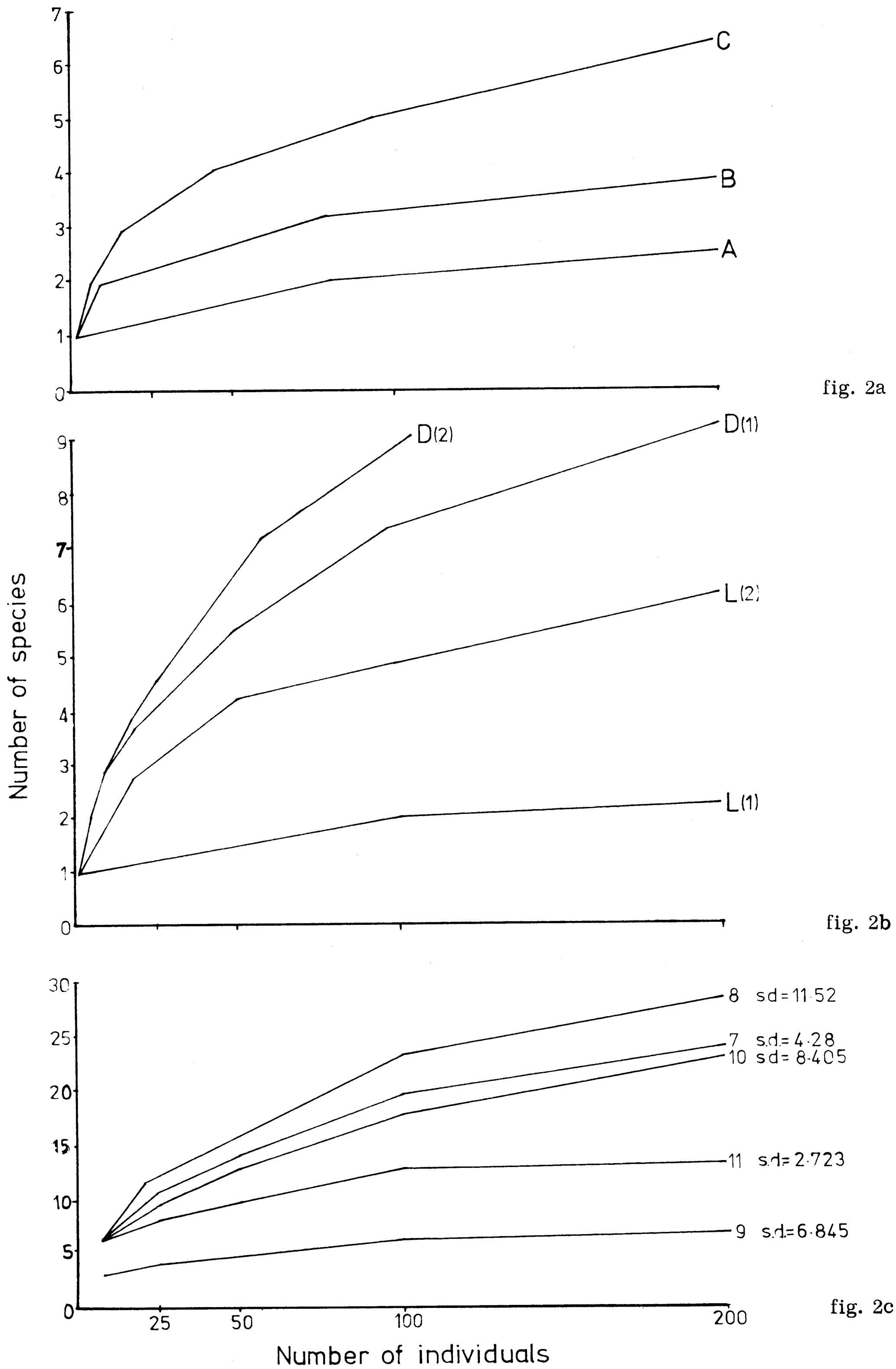
As bivalves are often without a calcareous skeleton for part of their first year of life and achieve their highest mortality rates in that year, no truly representative trace of their first year of life can be expected to occur in the fossil record. A representative sample of the population later in life can be expected as fossils, if it is first assumed that little sedimentological sorting of the bivalves has taken place and secondly that all mortalities were preserved. In reality, both assumptions fail.

Explanation of text-fig. 2.

Fig. 2(a) for selected beds in the E_1b zone (letters correspond with those given in Fig. 1).

Fig. 2(b) for the molluscan faunas of (1) the littoral mudmound topography of Sales Point, Bradwell, Essex (see Greensmith and Tucker, 1967) (2) for the subtidal benthonic muds seaward of the offshore shell bank at Sales Point. In both instances the prefix "L" by a curve indicates that it represents the actual diversity of the living molluscan community, the prefix "D" indicates the dead molluscan fauna represented on the benthos at the same location at which the community was sampled.

Fig. 2(c) for the top five beds of the shelly Waltonian Red Crag, at Walton on the Naze, Essex, representing beds 7 - 11 of Kendall (1931). The beds are labelled with Kendall's lettering on the graph, s.d. is the standard deviation from the mean of the collections. A total of 14,000 individual specimens were considered.



Text-fig.2. Rarefaction curves (Explanation on facing page).

The size frequency distribution of the bivalve faunas of the Edale Shales are shown in text-fig. 3 alongside similar distributions for (1) a sedimentologically unsorted life assemblage of *Anodonta* sp., collected by Miss C.E. Rodgers at Stoney Cove Quarry, Leicestershire (SP. 495952), and (2) a sedimentologically sorted death assemblage of *Glycimeris glycimeris* (Linn) from the Waltonian Red Crag (Pleistocene) at Walton on Naze, Essex, (collected by D.D.J.A.). These graphs suggest that the Edale Shale bivalve fauna has undergone minimal sedimentological sorting and may be regarded as representative of the original life population.

As it is not possible to conduct detailed population growth studies on fossils, their populations will be discussed in terms of a life-table. Detailed explanations of the applicability of such tables to fossils are given by Reyment (1971); the tables form a convenient and informative way of presenting geological data on population deaths and numbers in the fossil record in a manner which allows conclusions on the probabilities of death and survivorship to be made. Life-tables for the fauna under consideration are given in Table 2, while their age pyramids and survivorship curves are given in text-fig. 3 and 4 respectively.

Table 2 Life Tables for the Bivalve fauna of the E_1b zone of the Edale Shales, Edale, Derbyshire. (Continued on the opposite page).

Key to the interpretation of the colums of the tables:

1. Age interval in standard time-spans x to x+1 (where x is given in terms of shell length in mm.)
2. Age interval in standard time units x to x+1 (where x is given as the number of age intervals lived)
3. Proportion dying in interval (x, x+1)
4. Number living at age x (represents number of survivors at each age x)
5. Number dying in interval (x, x+1) expressed as 3 (m) x 4 (m)
6. Number of time-spans lived in interval (x, x+1) expressed as 4 (m) - ½ (5 (m))
7. Total number of time-spans lived beyond age x, expressed as the total sum of the number standard time-spans lived in each age interval beginning with age x
8. Observed expectation of life at age x. This is the average number of time-spans yet to be lived by an individual, now aged x.
9. Proportion of survivors over the age interval (x, x+1)

Life table for *Posidonia corrugata* (Etheridge)

Sample Size	1	2	3	4	5	6	7	8	9
29	2-4	1	0.193334	10000	1933	9034	21203	2.1203	0.81
48	4-6	2	0.396694	8067	3200	6467	12169	1.5085	0.60
43	6-8	3	0.58904	4867	2867	3434	5702	1.17156	0.41
19	8-10	4	0.63333	2000	1267	1367	2268	1.134	0.37
7	10-12	5	0.63636	733	466	500	901	1.229	0.36
1	12-14	6	0.25	267	67	234	398	1.4906	0.75
1	14-16	7	0.33333	200	67	167	167	0.835	0.67
2	16-18	8	1.00000	133	133	-	-	-	-

Life table for *Posidonia membranacea* (McCoy)

Sample Size	1	2	3	4	5	6	7	8	9
9	4 - 5	1	0.2143	10000	2143	8929	16547	1.65	0.7875
18	5 - 6	2	0.5455	7857	4286	5714	7618	0.97	0.4545
14	6 - 7	3	0.9335	3571	3334	1904	1904	0.53	0.0665
1	7 - 8	4	1.0000	238	238	-	-	-	-

Life table for *Posidoniella laevis* (Brown)

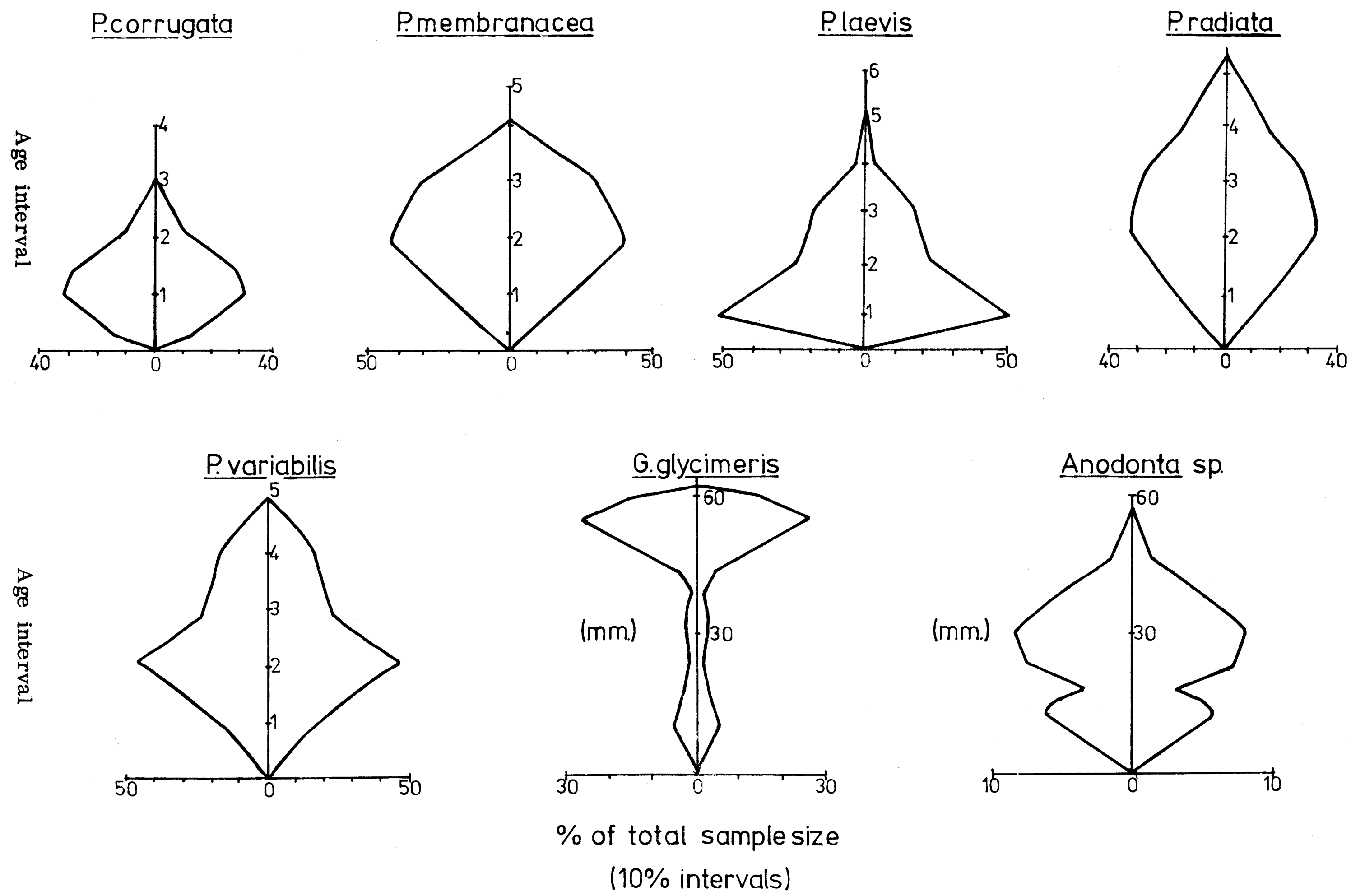
Sample Size	1	2	3	4	5	6	7	8	9
46	2 - 4	1	0.5652	10000	5652	7174	14156	1.42	0.4348
20	4 - 6	2	0.2001	4348	870	3913	6982	1.61	0.7999
16	6 - 8	3	0.7985	3478	2777	2090	3069	0.88	0.2015
4	8 - 10	4	0.5000	870	435	653	979	1.13	0.5000
2	10 - 12	5	0.5011	435	218	326	326	0.75	0.4999
1	12 - 14	6	1.0000	217	217	-	-	-	-

Life table for *Posidoniealla variabilis* (Hind)

Sample Size	1	2	3	4	5	6	7	8	9
9	2 - 4	1	0.128	10000	1280	1360	17360	1.736	0.972
24	4 - 6	2	0.6471	8500	5500	5750	8000	0.9417	0.3329
9	6 - 8	3	0.5000	3000	1500	2250	2250	0.750	0.5000
9	8 - 10	4	1.000	1500	1500	-	-	-	-

Life table for *Posidonomya radiata* (Hind)

Sample Size	1	2	3	4	5	6	7	8	9
13	0 - 2	1	0.1711	10000	1711	9145	20790	2.08	0.8289
25	2 - 4	2	0.39679	8289	3289	6645	11645	1.40	0.6032
22	4 - 6	3	0.579	5000	2895	3553	5000	1.00	0.421
10	6 - 8	4	0.6251782	2105	1316	1447	1447	0.69	0.375
6	8 - 10	5	1.000	789	789	-	-	-	-



Text-fig. 3. Size frequency distribution (age pyramids) of the bivalve faunas referred to in the text compiled from data in Table 2.

By comparing the age pyramids produced from the life-table with those of recent age (Clapham, 1972, p. 94) certain conclusions can be reached about the bivalve fauna, provided it is first assumed that only limited sedimentological size sorting has occurred. These conclusions are summarised in Table 3.

From a comparison of the survivorship curves for the bivalve faunas (text-fig. 4) and the hypothetical patterns for organism survivorship outlined by Deevey (1950) and Valentine (1973), the following conclusions can be drawn about the mortality within the Edale Shale bivalve species:

(1) *Posidonia membranacea* initially has a low mortality rate which then increases rapidly over a narrow time span.

(2) *Posidonia corrugata*, *Posidonomya radiata* and *Posidoniella variabilis* have constantly increasing mortality rates with age.

(3) *Posidoniella laevis* has a constant mortality rate at all ages.

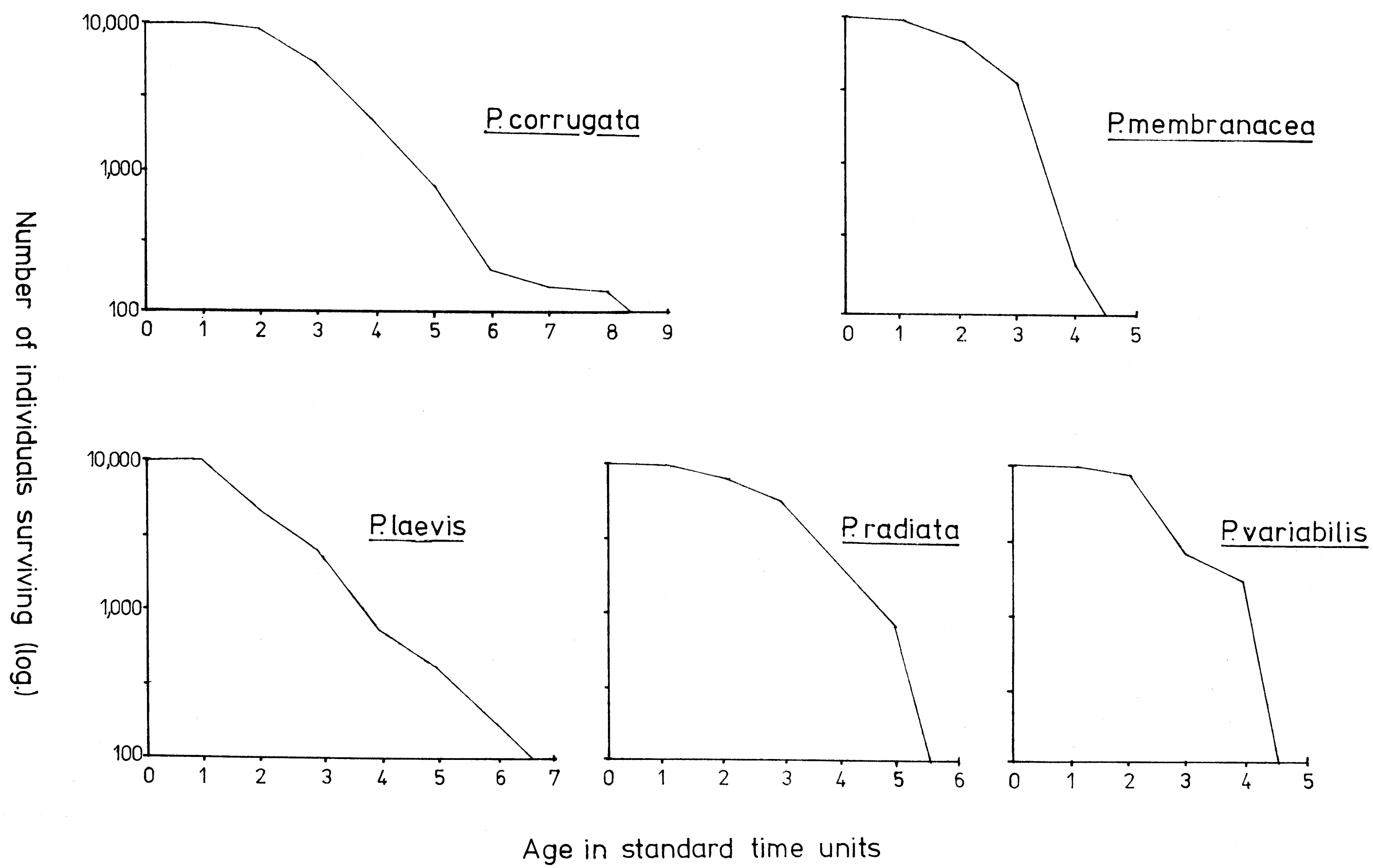
Text-fig. 5 depicts the age mortality distributions of the bivalve faunas. It is assumed that a high juvenile mortality rate exists in these species during the larval planktonic stage. Although some of the graphical irregularities of the various population figures (Table 2) may be due to sample error, they will be treated here as if such error was non-existent, according to the principles outlined by Sellmer (1967). A benthonic mode of life (to be discussed later) is assumed throughout for these bivalves.

Table 3. An age structure table to illustrate relative natality and population structure. (Interpretation based on the graphs in text-fig. 3.

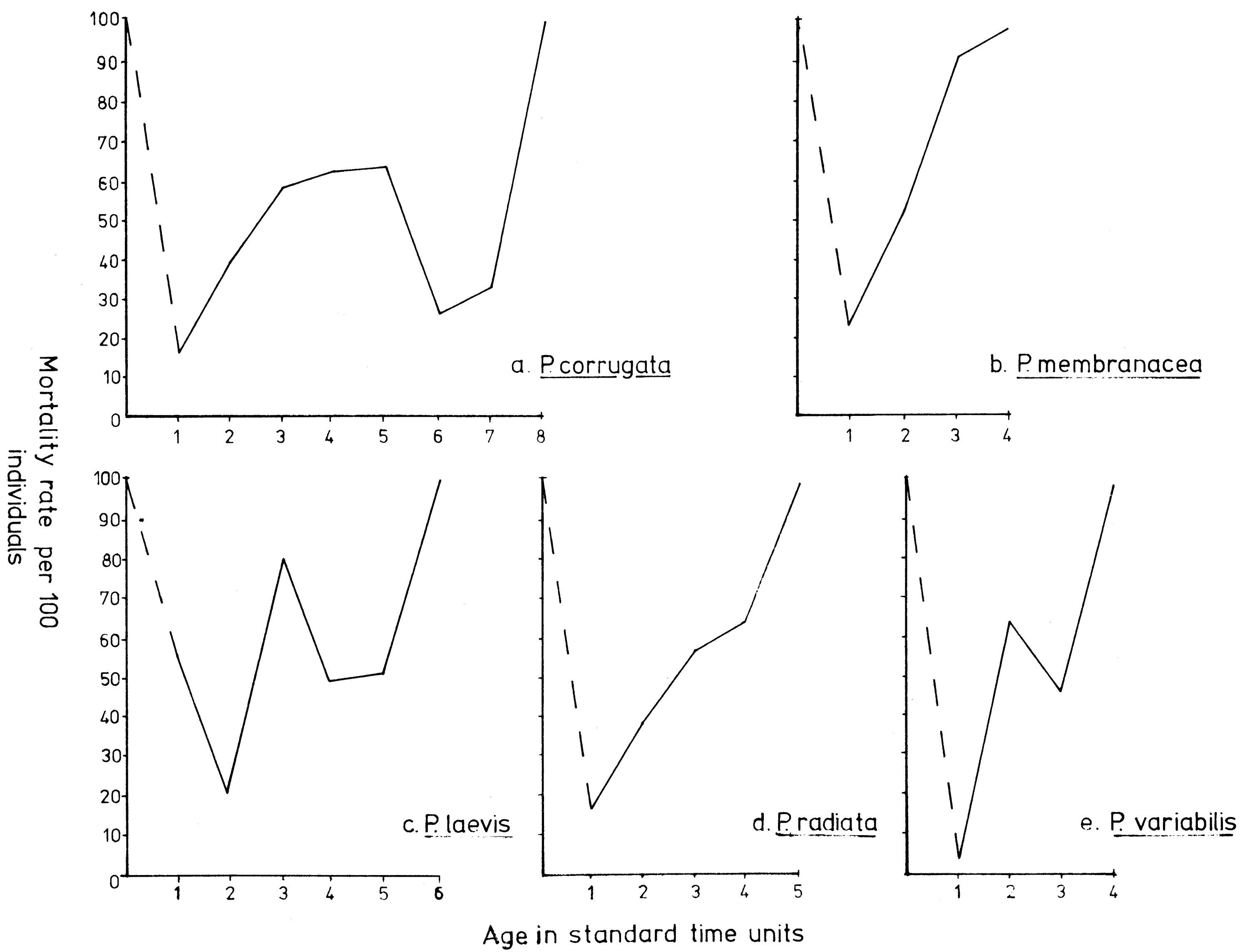
	Age distribution of:	Species producing: Very few young	intermediate number of young	Many young
1.	Stable population	-	-	*P. laevis*
2.	Expanding population	-	*P. membranacea*	*Anodonta* sp.
3.	Contracting population	-	-	*P. radiata*
4.	Over exploited population	-	-	*P. corrugata* *P. variabilis*
5.	Sedimentologically sorted population	-	*Glycimeris glycimeris*	

(1) *Posidonia corrugata* (text-fig. 5a) The mortality rate at time unit 1 may represent the normal death rate, due largely to predation on sexually immature animals. The increasing mortality rate between time units 1 and 3 may reflect the sexual maturation of the species, with the increased death rate being a by-product of a drain on the animals physiological resources due to reproduction. The higher constant mortality rates of time units 3, 4, and 5 may result from the combined effects of a population of sexually mature adults and the environment (including predation) acting together possibly in equilibrium on the death rate. The removal of the reproductive survivorship constraint, due to senility, may explain the lower mortality rate in time units 6 and 7. The high mortality rate during time unit 8 presumably represents physiological breakdown due to gerontism.

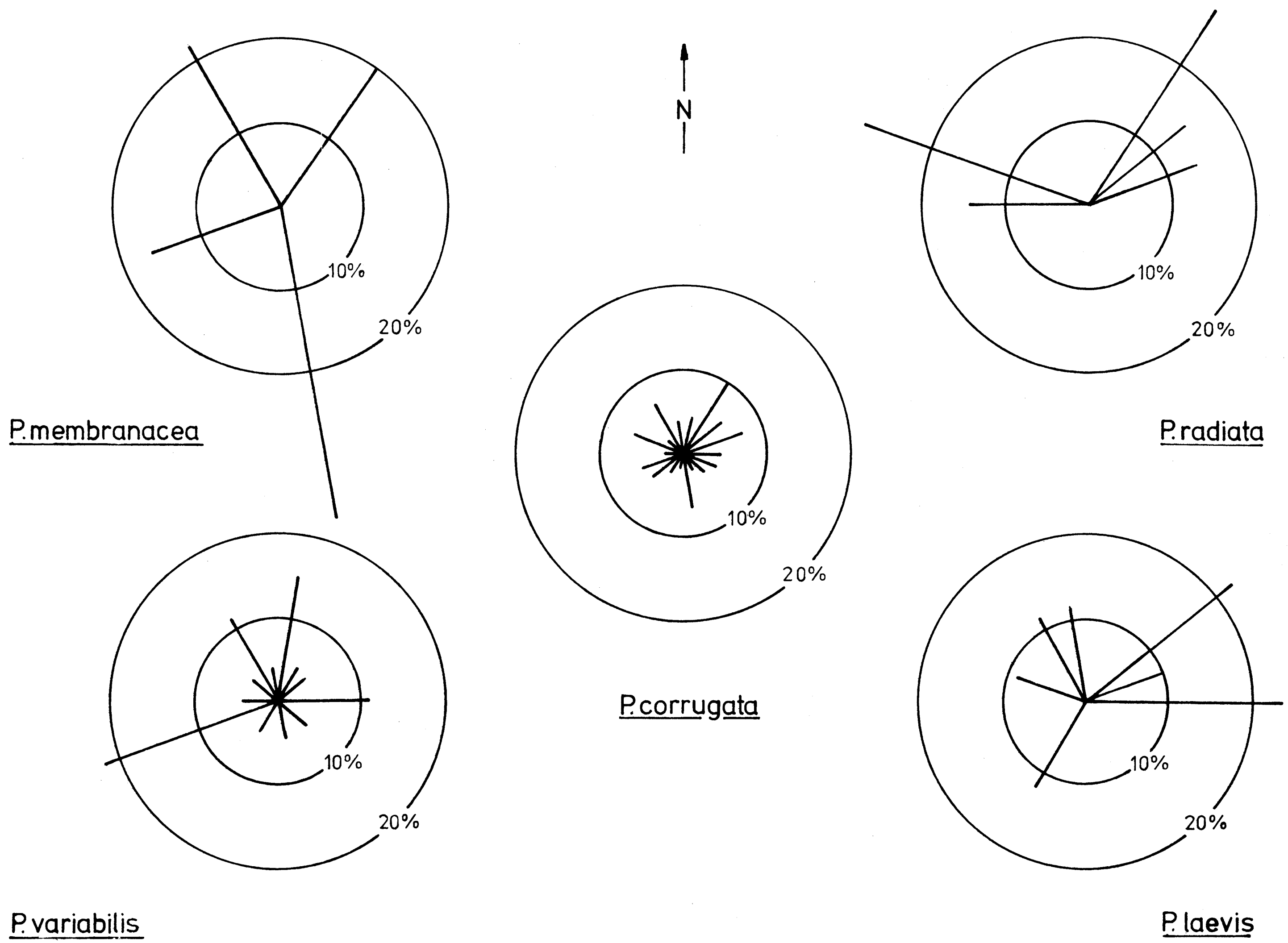
(2) *Posidonia membranacea* (Fig. 5b) Time unit 1 again represents the mortality rate of a sexually immature population. The constraints on survivorship are emphasised by the increased mortality rates in time spans 2 and 3, resulting, presumably from the sexual maturation of the population and associated fatalities, and in time span 3 from the additional burden of deaths due to ageing; the latter being the prime cause of the high mortality rate in time unit 4.



Text-fig. 4. Survivorship curves for the bivalve fauna of the Edale Shales compiled from data in table 2, pp. 184-5).



Text-fig. 5. Age mortality graphs compiled from data in table 2 (p.184-5).



Text-fig. 6. Orientation of the bivalves. Plot represents dorso-ventral axis.

(3) *Posidoniella laevis* (Fig. 5c) The decrease in the mortality rate between the first and second time units may be due partially to the physiological adjustment of the stresses and strains of an independent life on the benthos. The mortality rate at time unit 2 probably represents the natural mortality rate for a population of sexually immature individuals suffering from normal predation and physiological wastage. The increased mortality rate forming a peak in time unit 3 may result from a readjustment of the animals physiology on reaching sexual maturity, and its levelling off to an even rate during time units 4 and 5, may represent the equilibrium mortality rate of a sexually mature population. The increase in mortality depicted in time unit 6 again indicates physiological breakdown of the population due to ageing.

(4) *Posidonomya radiata* (Fig. 5d) A low mortality rate at time unit 1 suggests a population of sexually immature individuals. As the population becomes sexually mature the mortality rate increases (time units 2 and 3) until a steady state equilibrium is reached between mortality due to strains on the physiological resources caused by reproduction, and other normative mortality causes (time units 3 and 4). Due to gerontism, this "equilibrium" is disturbed by the physiological breakdown of the population, causing an increase in the mortality rate (time unit 5).

(5) *Posidoniella variabilis* (Fig. 5e) Following previous examples, time unit 1 probably represents the mortality rate of a sexually immature population, caused primarily by predation. The increase in the mortality rate in time unit 2 reflects an increase in mortality due to primary alterations in physiology, the result of sexual maturation. The subsequent decrease in the mortality rate (time unit 3) suggests either equilibrium readjustment of the population or an increase in senility. Physiological breakdown due to ageing is invoked as the primary cause of the increase in mortality in time unit 4.

2. Numerical Frequency Distributions

(1) *Temporal.* The faunal species population variation with time illustrated in text-fig. 1 (p. 181) shows that when bivalves are present goniatites tend to be rare, and that the bivalve *Posidonia corrugata* tends to represent between 83% and 50% of the fauna and is the most successful specialist in this environment (Valentine, 1973), while the "explosive" increases in abundance of some other species, *Posidoniella variabilis*, *Posidoniella laevis* and *Posidonomya radiata* for example, is the criterion used to indicate that they are opportunistic species. The remaining bivalve species, *Posidonia membranacea*, is regarded as a less successful specialist. All the goniatites are regarded as specialist species. The significance of layers composed entirely of goniatites and the mode of life of the bivalve will be discussed later.

(2) *Spatial.* The fossils are distributed in three modes, the first as scattered, randomly distributed skeletons, most of which are bivalves. The second and most common mode of occurrence is as ovoid lenses distributed randomly over the surface of the bedding planes and the third and rarest mode, is that of thin (4 - 9 cm thick) perched shell gravel banks. Such faunal modes of occurrence are known to the authors in close proximity in the lower Lias of Houghton-on-the-Hill, (Leicestershire) in association with the bivalve *Posidonia* sp., and in the Holocene sediments of the River Blackwater, Essex. Here they form either as a result of current activity, or as *in situ* bivalve reef growths.

Mode of Life of the Fauna

Previously the goniatites are considered to have led a planktonic existence (Selley, 1976), while the posidonoid type bivalves are thought to have led a pseudoplanktonic or even bethonic mode of life. The latter are now discussed.

(1) The bivalves may have been pseudoplanktonic, occurring as organisms which were byssally attached to drift wood or seaweed, as suggested by Hudson and Cotton (1943, pp. 149 - 150). It would be difficult to prove that they had been attached byssally during life, and that the wood had been floating rather than lying on the sea floor (Craig, 1954, p. 119). None of the

bivalves seen in this study occurred in intimate association with driftwood or organic remains.

(2) They may have led a planktonic existence, as suggested by Jefferies and Minton (1965). The evidence for this hypothesis is restricted to the presence of anterior and posterior gapes, thin shells, experimental hydrodynamic evidence, and the wide angle of opening of the valves in life. However, much of the interpretation of the evidence used in this hypothesis is speculative.

The thin shelled nature of the shells may be due to a swimming adaptation similar to that found in Pectinacea (Yonge, 1938, p. 81), indicating an adaptation to a shallow benthonic (less than 450 m) (Craig, 1954), or a nectoplanktonic, (Jefferies and Minton, 1965, p. 164), or it may represent an adaptation to a deep basinal (greater than 2,000 m depth) benthonic mode of life, (Lemche and Wingstrand, 1959, p. 63).

Anterior and posterior gapes in the recent Pectinidae and Limidae serve to release the swimming jets, and as a general rule the larger the gapes the greater the swimming ability of the animal (Jackson, 1890; Verrill, 1897). Jefferies and Minton claim that large posterior gapes occur in posidonoid bivalves, but since it is difficult to establish the existence of a nonplanar commisure, an essential attribute of a swimming bivalve, such claims should be treated with caution, especially after suggestions that the commisure can deform, due to the thin elastic nature of the shell, both before and after death (Jefferies and Minton, 1965).

If these gapes do exist they by no means prove a swimming ability, as similar gapes are also found in the benthonic burrower *Mya* where the foot protrudes through the anterior gape and the siphons through the posterior gape. On taxonomic grounds it is unlikely that the posidonoids were burrowers, but their shape, when analysed by the functional morphological methods outlined by Stanley (1975), suggests that they could have survived successfully as such; indeed the vertical orientations recorded for specimens of *Bositra buchi* Romer (a posidonoid) by Hess (1960, p.377) and Jefferies and Minton (1965, p. 168) could be taken as conclusive evidence for a burrowing habitat in some posidonoids.

Jefferies and Minton (1965, p. 157) regard the nature of the sediments in which these bivalves occur to be indicative of an anaerobic benthos which was unable to maintain a molluscan or annelid fauna. Studies of recent sediments, have shown that both hydrogen sulphide and pyrite may be formed in anaerobic conditions which are confined to the subsurface, for example the estuarine muds of the River Blackwater, Essex, and that their presence does not necessitate a foetid benthonic environment for the Edale Shales (Bruce, 1928; Craig, 1954) The fallacy of this facies argument is highlighted by Davis (1967, p. 7) who has found annelids and bivalves living in a foetid environment. Jefferies and Minton suggest that articulated posidonoid valves are nearly always gaping and orientated on the bedding plane concave up. They also suggest that the valve-open position is indicative of swimming ability, yet other bivalves which commonly occur in a similar position on the benthonic muds and beaches of Essex today, *Cerastoderma edule*, *Barnea* sp., and *Scrobicularia* sp. do not possess this ability.

71 articulated bivalves, 56 of which possessed closed articulated valves, orientated with their commisures aligned roughly parallel to the bedding, were recorded in the E_1b zone. This observation is contrary to the posidonoid orientations recorded by Jefferies and Minton (1965, p. 168). Their specimens were orientated with the commisure perpendicular to the bedding. Such orientations can be used as evidence for a burrowing ability, as suggested earlier, but have been interpreted (Jefferies and Minton, 1965, p. 168) as posidonids that fell into a liquid anaerobic mud, closed up and died. If this idea is correct and posidonoid bivalves were nectoplanktonic, then the vertical orientations must, by analogy with the cephalopods, be indicative of a "shallow" benthos, since Weaver and Chamberlain (1976) suggest that vertically orientated ammonoids will not occur if the benthos was deposited at a depth greater than 10 m.

(3) A third hypothesis suggests that *Posidonia corrugata* led a benthonic existence in near foetid conditions (Craig, 1954) and by analogy this mode of life could be extended to the bivalve fauna of the E_1b zone, as a whole and will be briefly discussed along with the environment of the zone.

The currently accepted hypothesis for the environment and ecology of the fauna of the Edale shales suggests a deep basinal environment with foetid bottom conditions containing a planktonic fauna (Hudson and Cotton, 1943, 1945; Selley, 1976; etc. The Edale shales may not have presented foetid bottom conditions. They were certainly marine, deposited in the bathyal zone, above the carbonate compensation depth, shown by the presence of thin shelled calcareous bivalves and in low latitudes, indicated by the nearby Castleton reef complex; (Stevenson & Gaunt, 1971) and from palaeomagnetic data.

The substratum was swept by currents capable of disarticulating bivalved shells, but the absence of shell fragments, despite the fragility of the shells, suggests that the currents were weak, possibly following a north-east to south-west trend as determined by valve orientations (text-fig. 6). *Posidonia membranacea* was orientated both parallel, to and normal, to the direction of current flow.

The goniatites occur throughout the sequence (tex-fig. 2) and are thought to have led a planktonic existence. The bivalves are absent from certain beds which may be due to changes in the conditions operating on the sea floor from time to time, for example fluctuations in the anaerobic nature of the benthos. The bivalves could well have led a benthonic life.

Craig and Jones (1967) suggest that the predominant benthonic organisms on shallow muddy substrates are infaunal, but we saw no evidence for this except in the basal bed of the *Cravenoceras malhamense* (E_1c) zone. In oceanic basins, bivalves may be distributed patch-wise on a dark muddy substrate, where they are epifaunal and possess thin shells (Lemche and Wingstrand, 1959). This is comparable to the distribution and nature of the bivalve fauna of the Edale Shales. We conclude posidonoid bivalves of the E_1b zone were motile benthonic swimmers or nestlers rather than nectoplanktonic swimmers or pseudo planktonic attached forms.

Although *Posidonia corrugata* is a specialist species in this environment, the evidence presented by Craig (1954) suggests that in a shallow subtidal environment it is an opportunistic species inhabiting semi-foetid muds. Thus it can be shown that some posidonoids have a wide tolerance range in benthonic environments. If they are benthonic, then they can be described as eurybathic (pertaining to a wide depth range, *Posidonia corrugata* for example) and stenoecious (pertaining to a narrow habitat range), as most prefer a similar habitat of dark (?) semi-foetid muds.

The bivalve trophic nucleus of the E_1b zone (where the trophic nucleus is defined as those species which numerically comprise 80% of the fauna (Neyman, 1967) contains *Posidonia corrugata* as its prime species, with occasional influxes into the nucleus by the opportunistic species. It is thought likely that all the bivalves examined were epifaunal suspension feeders since there is no evidence of bioturbation within this zone. If this is so then the influxes of opportunistic species could be a response to variations in some aspect of environment, such as nutrient content, temperature, salinity or oxygen.

Conclusion

Throughout this study we have tried to produce a palaeoecological interpretation of the fauna, which, although factual in content, is not sacrosanct. In doing so we have appealed to "Occums razor" (as in the instance dealing with the bivalve mode of life) and used techniques which assume that the observed fauna is truly representative of the original, for instance in natality and mortality interpretations. The latter assumption we admit may be invalid but we feel some interpretation of both natality and mortality rates is required from a palaeoecological study such as this, where the operation of bottom currents and hence sedimentological sorting of shells on the benthos was minimal.

The 7 m of sediment which represent the E_1b zone of the Edale shales at Edale, possess a low diversity fauna of bivalves and goniatites, occurring in thin interbedded carbonaceous shales and limestones. The sediments contained no primary sedimentary structures, other than parallel lamination, and no evidence for bioturbation of the substratum. The distribution of the fauna through the sequence, and along individual bedding planes, along with their morphology, and the nature of the sediments leads us to suggest that the bivalves led an epifaunal benthonic, rather than a pseudoplanktonic or nectoplanktonic, existence, in an ocean basin, situated in the bathyal zone, possessing an aerobic or anaerobic benthos. (Davis (1967) has demonstrated that bivalves do live in both types of benthos.)

The individual bivalve species were considered, to determine whether they were specialist or opportunistic species. A life-table has been used to help determine the natality, mortality and age structuring of the population. Further analysis of the mortality rates has enabled discussion of sexually immature and mature populations, and enabled predictions to be made about the size at which the bivalves become sexually mature.

Although we have not been able to prove that our faunal assemblages are life assemblages, we hope that the methods (natality and mortality rate interpretation) introduced in this study will become more widely used by palaeoecologists in the analysis of faunal assemblages found either as life assemblages or as assemblages suffering from minimal sedimentological sorting, thus enhancing our understanding of the organism and its ecology.

Acknowledgements

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BRITISH RHAETIC BONE-BEDS

by

J.H. Sykes

Summary

An account is presented of the origins, occurence, and formations of British Rhaetian bone-beds from re-examination of present exposures and from a review of others published in literature.

Introduction

The British Rhaetic rocks (Penarth Group) is an easily distinguishable set of strata situated at the top of the Triassic System. The Group can be divided into Lower and Upper Rhaetic formations. Almost all the Rhaetic bone-beds are to be found in the Westbury Formation of the Lower Rhaetic and the paper is generally restricted to that part of the sequence. A further restriction is made in that only that part of the Westbury Formation which contains bone-beds is considered in detail.

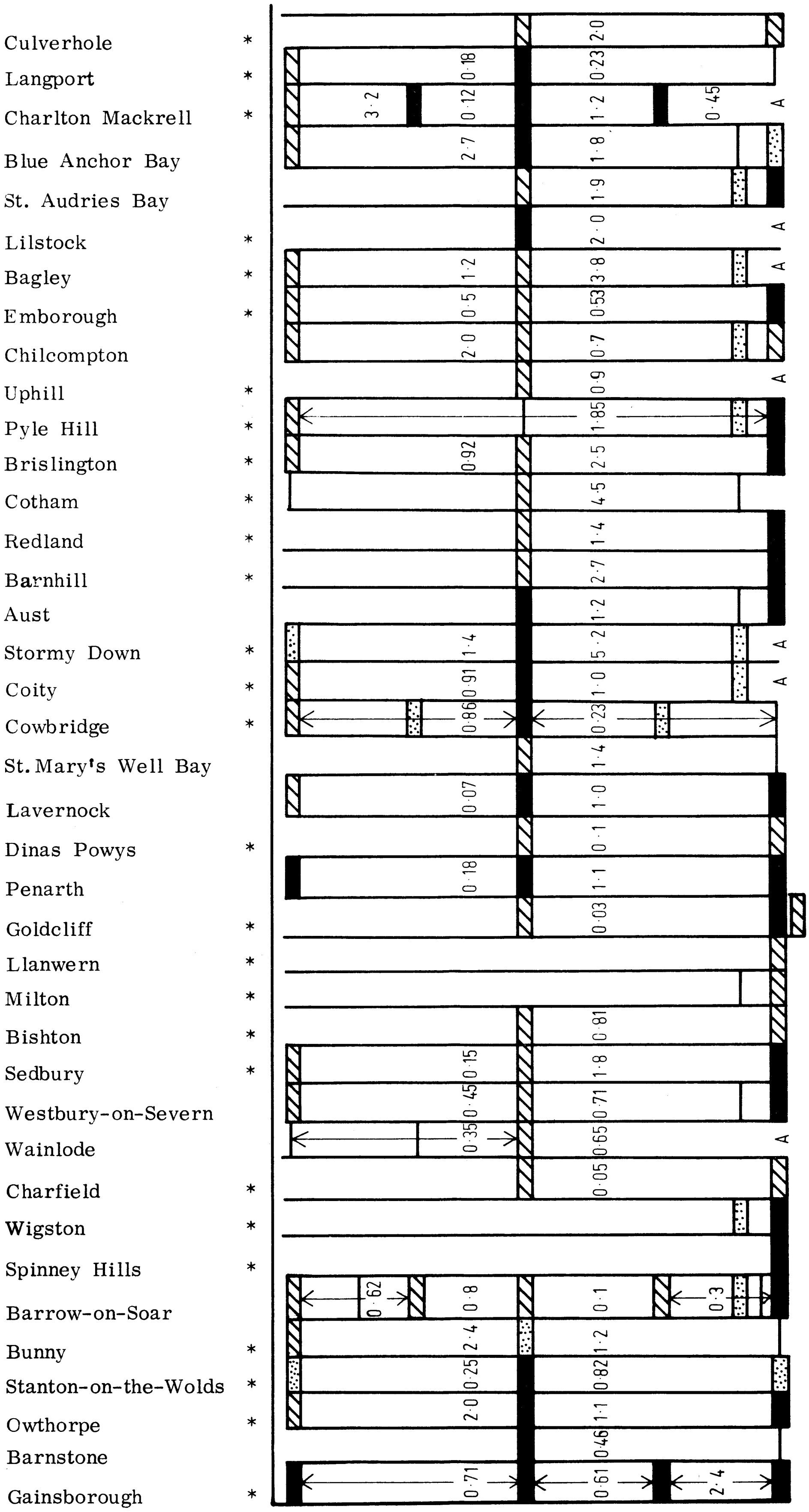
Eleven sections of Rhaetic rocks have been examined to determine all aspects of bone-bed deposition especially to observe the close relationship between the sandy content and the vertebrate fossils. Details of 31 other sections, now no longer readily available for examination, have been obtained from the literature. 39 localities are shown on text-fig.1, those described by previous writers are marked by an asterisk and acknowledgements made in the text.

Attempts have been made to correlate individual bone-beds lithologically but because of the variation in thickness of the Westbury Formation and the discontinuous development of bone-beds, even over a short distance, correlation has proved to be difficult.

Method

Some of the bone-bed samples were well-cemented and these have been sectioned and their mineral contents determined. (Plates 14, 15, 16). Others, especially more friable ones, have been crushed to separate their constituents. 100 gm bulk samples were taken and, after crushing, the sample was washed in petroleum spirit to clean the grains and further aid the disintegration process. The grains were then passed through a sieve set, mesh sizes 850 to 63 microns (1000 microns = 1 mm). Particles less than 63 microns, mainly silt and clay minerals, were discarded. Those retained by the sieve screens were examined and the contents of each determined. Ten random portions of each sieve fraction were spread over a representitive area, 1 sq.cm. for particle sizes 250 and above and a 2 sq. mm. for the smaller sizes. An estimate number of grains was made by counting across the graticulate along several lines and squaring the mean. The grains of the least representitive materials were counted individually. The portions of the sieve fractions taken were weighed, each gram representing 1% of the original bulk sample. From this information the respective weights of each mineral could be determined in each sieve fraction and the percentage of the residue calculated (Tables 4-25). In naming the grade sizes, reference has been made to that part of the Wentworth (1922) scale reproduced overleaf.

Mercian Geol. Vol. 6, No. 3, 1977. pp. 197-239, 3 text-figs. Plates 14, 15, 16.



Top of Tea Green Marl or Sully Beds.

Text-fig.1. Sections of British Rhaetic Localities

Thickness of intervening beds are noted in metres but not drawn to scale. Trace and scatter bone-beds are not taken into account in the measurements. Localities taken from literature are indicated by an asterisk. Their classification is made arbitrarily from the information available.

Bone-beds are indicated thus: ■ = part primary, ▨ = secondary, ⁙ = scatter, —— = trace, A = absent

Table 1 Particle grade sizes and terms used

2 - 1	mm	very coarse sand
1 - 0.5	"	coarse sand
500 - 250	microns	medium sand
250 - 125	"	fine sand
125 - 63	"	very fine sand
63 - 32	"	coarse silt
32 - 16	"	medium silt

Criteria for primary and secondary depositional characters in beds

In order to comment on the origin of the bone-beds, criteria was required to decide if the bed resulted from original, primary deposition of the bone-bed sediment and fossils (referred to hereafter as the bone bed content) or if subsequent movement and transportation had taken place with redeposition (secondary) resulting in a natural concentration of bone-bed content.

Pettijohn (1957, p. 393) in dealing with limestones, states that the criteria for distinguishing between primary and secondary deposits are related to the sorting of grains, to current structure, to the state of articulation of the skeletal material (bivalves and etc.) and to the content and size of the non-carbonate detritus. A number of additional characteristics have been observed during field and laboratory examination and the following tables list features of primary and secondary deposition.

Table 2 Criteria for primary bone-bed deposits

1.	Unsorted material	- the current carrying the clast load, is checked and the load deposited before travelling far and before sorting takes place.
2.	Poor bedding	- the result of deposition of unsorted or rapidly deposited material.
3.	Shells with unbroken and articulate (joined) valves	- burial before erosion and transportation.
4.	Random orientation of shells	- lack of current action and quiet deposition *in situ*.
5.	Unbroken delicate fossils complete with fine surface detail	- burial takes place with little rolling or transportation.
6.	Coprolites, long, slender, unbroken	- lack of transport and abrasion.

The corresponding list for secondary deposition is given in Table 3.

Table 3 Criteria for secondary bone-bed deposition

1.	Well-sorted material	- a prevailing current of certain velocity will deposit a selected size of particles for a period, removing the smaller grades.
2.	Graded bedding	- velocity of the transporting current decreases and the finer particles are laid.

3.	Current bedding	- deposition by transporting currents, which may change direction producing 'cut and fill' structures.
4.	Fossil fragmentation	- movement of fossils for some distances.
5.	Fossil wear and abrasion	- transportation and rolling.
6.	Oolites and pisolites	- occurrence indicates current action.
7.	Ripple marks	- current action.
8.	Infilled fossil cavities	- tightly packed sand and finer fossils imply movement and compaction within the larger fossil.
9.	Mixed land and marine fossils	- implies lengthy transportation of the land fossils in a marine environment.
10.	Aligned fossils	- orientation on bedding planes in the direction of the current.

Classification of bone-beds

Application of the above criteria to the field examination of bone-beds has resulted in four different categories or types, which are described below:

1. Part primary bone-beds. All Rhaetic bone-beds have some features which suggest that they have been derived from a previously deposited source, although some primary depositional features may also be retained. These primary features are chiefly concerned with the condition and orientation of the fossils also the poorly bedded, unsorted deposits.

2. Secondary bone-beds. Well developed bone-bed layers, where all the depositional characters are secondary. The most common of these are concerned with the sorting and current bedding of the sediments and also the abrasion and fragmentation of the fossils.

3. Scatter bone-beds. Most sediments of the lower Rhaetic are devoid of coarse fragments although some layers of mudstone may contain a comparatively coarse bone-bed content (quartz and vertebrate remains) disseminated through the bed. A close inspection of these beds is necessary to observe their constituents. When the clay and silt elements are removed it is noticeable that the concentrations of sand and vertebrate fossils are definitely linked.

4. Trace bone-beds. Extremely thin layers, or pellets or patches of bone-bed, often only a single layer of grains, are designated 'trace bone-beds'. They are often found in association with the horizon of a major bone-bed such as at the base of the Westbury Formation. They can also be found isolated, when coarse grades of sand are present.

Descriptions of bone-beds at British localities

The localities of text-fig. 1 are described following the outcrop in a general north to south direction. Only that part of the sequence containing bone-beds is considered. Details of the bone-beds at the various localities are tabulated (tables 4 - 25, commencing on p. 204 reference to which is made in the text. The final synthesis of the evidence begins on p. 234. Previous authors measurements have been converted to metres and millimetres. National Grid References are given after each locality.

Thornton-le-Beans, Yorkshire, SE 397902. Tate and Blake, 1896, p. 32.

"A well sinking revealed black, pyritic shale with Rhaetic bivalve fossils and a 75 mm thick, granular, whiteish, pyritic, grey sandstone which contained fish remains."

	metres
Lea Cutting, Gainsborough Lincolnshire, Burton (1867, p.316)	
Shale, black	0.1
Hard, grey sandstone with pyrite, bivalves, fish, reptiles and coprolites.	0.43
Shale, black.	0.71
Sandstone, fine-grained, pyritic; with fish reptiles and coprolites.	0.15
Shale, black.	0.61
Second bone-bed, loose texture, coprolites.	0.012
Shale, black.	2.4
Bone-bed with upper part a loose micaceous sandstone; lower part with pebbles and pyrite matrix, fish reptiles and coprolites.	0.1
Tea Green Marl.	

Barnstone, Nottinghamshire, SK 739358 Sykes, Cargill and Fryer 1970.

Sandy beds, black shales with layers of ferruginous siltstone, some very pyritic.	1.4
Shale, black, with thin layers of silt and, near the base, patches of fine and coarse sand with bone bed fossils.	1.8
Bone-bed, friable upper part with pebbles, coarse and fine sand, small and large vertebrate fossils in a mudstone matrix which also has patches of black shale. The lower part is of similar composition though cemented with pyrite. The fossil content is variable with worn, broken specimens also delicate fin spines and pieces of well preserved jawbones. There are numerous coprolites. The black shale parts are unfossiliferous.	0.076
Shale, black, containing varying amounts of sand and vertebrate fossils scattered through the rock. This course content is greatest near the base being transitionally rarer up to the bone bed. There is a thin, cemented bone-bed, up to 13 mm thick, near the base also traces of bone bed material in the basal layer.	0.5
Tea Green Marl.	

Remarks

A trace bone-bed is found at the base of the Rhaetic at Barnstone and a typically, gritty, thin, cemented, impersistent bone-bed a short way above. The whole of the black shales below the main bone-bed constitute a scatter bone-bed. If this is the redistribution of scattered previous bone-bed content (see discussion p.234), it is significant that the influence declines upwards and is rare in the upper part of these fairly well-bedded shales.

The main bone-bed is an example of a part primary bed. The evidence for primary deposition includes the presence of many coprolites, mostly unbroken and some elongate. There are fragile fossils such as fin spines and teeth with attached delicate roots also unworn fossils with their ornamentation intact. The deposits are unsorted, ranging from the very minute up to large fossils and pebbles. There are also thick patches of quietly deposited shale.

Criteria for secondary deposition include the many fragmented, rounded and worn fossils with all the surface ornamentation removed. The cavities of larger fossils are tightly packed with minute sand grains and fossils. There is a mixture of land and marine fauna also a few bivalves with phosphatised shells and calcareous interiors, on a horizon that does not generally contain bivalves and is non-calcareous.

In the first 25 mm of the black shales above the bone-bed there are thin, isolated patches of bone-bed material; sometimes only one layer of grains thick. In these trace bone-beds the fossils are always accompanied by sand. If they are laid independent of the main bone-bed, the minute fossils could have become incorporated with sporadic deposition of sand. Their confinement to the lowest 25 mm of shale above the bone-bed makes it more likely that they are small amounts of redistributed material from the main bone-bed elsewhere.

There is no further development of bone-bed above this horizon at Barnstone. The 'Sandy Beds' contain a few, minute, phosphatic fossils and the 'sandiness' is of silt grades.

	metres
Owthorpe, Nottinghamshire, SK 666336, Ivimey-Cook & Elliott (1969, p.147)	
Mudstone, greenish grey.	1.5
Mudstone, with a layer of fine sand and fish fragments.	2.7
Mudstone.	0.9
Mudstone.	1.1
Mudstone, coprolite layer and pyritised, sandy bone-bed layer.	0.8
Bone-bed, quartz granules, bones teeth, scales.	0.025
Shale, black, non-calcareous.	1.1
Bone-bed, black shale with large quartz grains and vertebrate remains infills burrows penetrating 25 - 30 mm into green marl below.	0.0
Tea Green Marl.	

Stanton-on-the-Wolds, Nottinghamshire, SK 637312, In Lamplugh, (1909, p.20.)	
Shale.	1.6
Pyritic sandstone.	0.06
Shale.	0.9
Pyritic limestone with fish scales.	0.025
Shale, black, fissile.	0.25
Bone-bed, white sand, pebbles, fish and reptile remains, coprolites.	0.025
Shale, black, fissile and earthy.	0.4
Coprolite seam, coprolites at wide intervals.	0.025
Shale, black, laminated, with occasional reptile bones.	0.4
Tea Green Marl.	

Bunny Cutting, Nottinghamshire, SK 578281, Kent (1953, p.134).	
Shale, black, crumbly.	1.5
Shale, sandy, micaceous, with many fish fragments.	0.075
Shale, crumbly and fissile, fish scales.	2.4
Shale, black with fish scales and probable coprolites.	1.8
Shale, black crumbly.	1.2
Sand bed, weathering brown, rare fish remains.	0.025
Tea Green Marl.	

East Leake, Nottinghamshire, SK 538281, Browne (1895, p. 688)

"There is no actual and massive bone-bed as at Aust and etc., although, most curiously, one piece - and one piece only, identical with Aust breccia - was picked up at the tip."

Barrow-on-Soar, Leicestershire, SK 573173, H. G. Fryer (in prep.)

	metres
Shale, fissile, black, with fine sandy layers and patches of coarser sand, some of which contain vertebrate remains.	1.0
Limestone, nodular, dark grey and unbedded.	0.15
Shale, black, fissile with fine sandy layers.	0.37
Limestone, nodular, embedded in black shale and overlain by grey clay. On the same horizon and surrounding the nodules there is a thin sandy bone-bed.	0.62
Fourth bone-bed, distinct sandy bone-bed layers interspersed with mixed sand and shale. Some cemented bone-bed is also present (table 4).	0.025
Shale, black fissile with occasional thin patches of bone-bed.	0.825
Third bone-bed, one part consists of quartz grains and vertebrate fossils in a mudstone matrix, one part is cemented quartz and fossils and a third is of unfossiliferous, bedded, siltstone.	0.025
Shale, black, fissile with occasional traces of bone-bed.	0.1
Second bone-bed, a thin typical bone-bed and a thin, bedded, pyritic siltstone.	0.3
Shale, black, lumpy poorly bedded, with some quartz grains and vertebrate fossils scattered throughout (table 5).	0.15
Shale, black, fissile with occasional bone-bed patches.	0.16
First bone-bed, a thin bed with three distinct parts. At the top is a pyritic, bedded, unfossiliferous siltstone, below is discontinuous, cemented layer of quartz and fossils and at the base is a mudstone with many scattered quartz grains and fossils (Plate 14, fig. 1; table 6).	0.050
Tea Green Marl.	

Remarks

A feature at Barrow-on-Soar is the rapid changes in the nature of a bone-bed from a crumbly mudstone scatter bone-bed with a low phosphatic content (table 6) to a cemented, clean quartz and fossil bed to a fine-grained rock minus fossils. This gradation to finer deposits shows how the bone-bed content is affected (Plate 14, fig. 1) the sequence also illustrates the rapid changes that can occur in the depositional environment of a single bed.

Within the black shales of the Lower Rhaetic there are occasional fin rays, scales and other fragments found at any horizon. However, in the 'lumpy' shale a short way above the base there is a sufficient concentration of bone-bed content to regard it as a 'scatter' bone-bed (table 5).

A 100 gram sample of the fine-grained part of the second bone-bed was crushed and examined. Only a few grains of fine sand were found with a few phosphatic grains, some of which were distinctly fossil. There was a small fraction of very fine sand which also yielded some phosphatic remains. The rest was of silt grade. This helps to show that the fine-grained rocks are only capable of retaining fossils of a comparable grade.

Explanation of the Tables 4 to 25

Each element of the bone-bed fragments are listed showing first their weight in each sieve, next their percentage of the sieve fraction and then the deviation for random sampling. In the next to the end column the weights from each sieve of each individual element are added together showing their percentages of the original 100 gm sample. The end column gives their percentage of the residue.

The bottom line gives the weights of each sieve fraction, which are added together in the next to the end column to give the weight of the total residue.

Barrow-on-Soar, Tables 4, 5 and 6

Table 4, fourth bone-bed

	850 microns +	Fraction percentage	Deviation ± percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz				0.08	0.34	0.006	1.54	5.56	0.152	12.71	68.87	1.347	9.49	80.10	23.82	28.04
Phosphatic				20.15	74.32	0.214	1.54	5.64	0.069	4.71	25.50	0.540	0.33	2.82	26.73	31.47
Shale				6.76	25.34	0.041	24.56	88.80	3.436	1.04	5.63	0.036	2.03	17.08	34.39	40.49
Totals in gms.				26.99			27.64			18.46			11.85		84.94	

Table 5, lumpy shale

Quartz				0.02	0.94		0.07	1.16	0.009	.56	7.53		8.44	68.13	9.09	32.31
Phosphatic				0.02	1.25		0.06	0.90	0.004	.11	1.52		0.29	2.37	0.48	1.71
Pyrite				0.02	0.52		0.01	0.16	0.000	0.00	0.00		0.00	0.00	0.02	0.07
Shale				1.73	97.25		6.43	97.78	1.704	6.81	90.95		3.66	29.50	18.63	65.91
Totals in gms				1.78			6.48			7.48			12.39		28.22	

Table 6 lowest base

Quartz	0.95	4.15	0.020	0.57	3.24	0.020	4.13	22.53	4.004	3.42	34.3		0.96	36.09	10.02	13.98
Phosphatic	0.96	4.15	0.013	0.48	2.70	0.018	0.58	3.15	0.049	0.50	5.1		0.13	4.89	2.06	3.70
Tea Green Marl	0.82	3.56	0.025	0.96	5.41	0.049	1.03	5.62	0.159	0.71	7.0		0.11	4.13	3.65	5.09
Mudstone	20.30	88.14	1.731	15.68	88.65	1.493	12.66	68.70	12.94	5.32	53.6		1.46	54.89	55.35	77.23
Total in gms	23.03			17.69			18.34			9.95			2.66		71.67	

Only a part of the Rhaetic was exposed at Barrow-on-Soar but the whole of the section shows a development of thin and 'trace' bone-beds when there is a deposition of sediments coarser than silt. Table 4 illustrates the high content of sand and phosphatic content in the highest bone-bed.

	metres
Spinney Hills, Leicestershire, SK 406044, Harrison (1876, p.213)	
Shale, black.	0.6
Sandstone.	0.025
Shale, black.	0.75
Bone-bed, pebbly and sandy with fish, reptile remains and coprolites.	0.07
Tea Green Marl.	
Wigston, Leicestershire, SK 603991, Richardson, (1909, p.368)	
Limestone nodules.	0.08
Shale, black, somewhat sandy with fish scales.	1.2
Rust coloured layer.	0.025
Shale, black with fish scales and teeth.	0.75
Bone-bed, gritty sand with fish, reptiles and coprolites.	0.07
Charfield, Gloucestershire, ST 723924, Richardson (1904, p.532)	
Limestone, dark grey, arenaceous.	0.7
Shale, black.	0.33
Limestone.	0.7
Shale, black.	0.85
Sandstone, pyritic, fish and reptile remains.	0.025
Shale, black, sandy.	0.05
Sandstone, grey, calcareous and sometimes pyritic, bivalves and fish remains.	0.075
Tea Green Marl.	
Wainlode Cliff, Gloucestershire, SO 845257	
Marl, blocky with bivalves.	
Pectin limestone, grey to black with fibrous layers, shelly.	0.025
Shale, black and fissile with bivalves.	1.5
Mudstone, black, poorly bedded.	0.75
Sandstone, light grey, pyritic, calcareous, fine-grained with occasional vertebrate fossils.	0.05
Shale, black and fissile with some thin, calcareous siltstone lenses which have occasional, minute fossils.	0.35

	metres
Sandstone and siltstone, calcareous, divided into six groups 'a' to 'f' at the top.	0.17
f Black shales with thin, calcareous siltstones.	
e Fine, calcareous, pyritic sandstone with some medium sand concentrated in association with many boney fossils (Plate 14, fig. 2).	
d Fine, calcareous sandstone and siltstone with scattered fine bone-bed remains.	
c Fine, calcareous, micaceous, light grey sandstone pyritic in parts with occasional fossils (Plate 14, fig. 3).	
b Fine, calcareous light grey sandstone with much pyrite. There are some small vertebrate fossils with occasional larger specimens and coprolites (table 7).	
a Calcareous, micaceous, unfossiliferous, light-grey siltstone.	
Shale, black, fissile with occasional layers of silt.	0.5
Mudstone, black, poorly bedded with some clay and some silt layers. There is no sandiness at the base.	0.1
Tea Green Marl.	

Remarks

In the absence of sandy deposits, no vertebrate fossils are found at the base.

The series of hard beds which contains 'the bone-bed' show a variety of transitional forms of deposition. The lowest is a siltstone without fossils. The next above (table 7) has a very few coarse sand grains and some comparatively graded fossils though the rest of the phosphatic content is small with a high percentage of sand. The next two beds up (Plate 14, fig. 3) are secondary bone-beds with current bedded, well sorted sediments; the fossil fragments are typically larger than the quartz grains. These beds also demonstrate the critical limits of grade below which vertebrate fossils are not associated with quartz.

The bed next to the top is quite different being 'intermediate part primary' in origin, coarser and highly fossiliferous (Plate 14, fig. 2). Alternating unfossiliferous siltstone and black shales are trasitional back to a shale environment. There are trace bone-beds in the ensuing shales and, a sparsely fossiliferous sandstone ends the bone-bed influence.

Westbury-on-Severn, Gloucestershire, SO 717130

Shale, black, fissile, with some layers of white silt.	0.5
Pyrite, bedded, crystaline on upper surface, with layers of medium sand which contain vertebrate fossils.	0.025
Shale, black, fissile with grey, calcareous, thin siltstones and thin limestones.	0.45
Sandstone (upper '*Pullastra*' bed) medium and fine. The finer upper part contains rare minute phosphatic fragments (table 8) and the lower, medium sandstone has more and proportionally larger fossils (table 9).	0.3
Shale, black, fissile calcareous, with bivalves and some layers of siltstone.	0.6
Siltstone (lower '*Pullastra*' bed) calcareous with bivalves.	0.4

(Continued p. 209)

Wainlode Cliff, Table No. 7, Westbury on Severn, Tables 8, 9 & 10

Table 7, Sandstones & Siltstones (part b)

	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Deviation ± percentage	Fraction and % of 100 gms	Percentage of residue
Quartz	10.003	1.22	0.001	0.00	0.00	0.000	27.04	84.43	0.863	21.12	92.68		48.19	76.5
Phosphatic	0.17	5.39	0.005	0.32	6.25	0.010	0.33	1.02	0.165	0.07	0.30	0.001	0.89	1.5
Pyrite	2.87	93.39	0.513	4.72	93.75	0.809	4.66	14.65	0.165	1.60	7.02	0.140	13.85	22.0
Totals in gms	3.07			5.04			32.03			22.79			62.93	

Table 8, upper *Pullastra* bed, upper part. Small amounts of mica not taken into account

Quartz				0.101	13.44		1.04	27.24		40.14	93.13		41.28	86.6
Phosphatic				0.001	0.12		0.026	0.7		0.02	0.05		0.05	0.1
Pyrite				0.648	86.44		2.744	76.06		2.95	6.82		6.34	13.3
Totals in gms				0.75			3.81			43.11				

Table 9, upper *Pullastra* bed, lower part. Small amounts of mica not taken into account

Quartz	0.01	2.13		0.05	3.5	3.322	7.32	0.86		34.62	88.9		42.00	84.43
Phosphatic	0.07	14.89		0.25	17.5	0.029	0.17	0.2		0.79	0.2		1.28	2.58
Pyrite	0.39	82.98		1.11	79.0	0.782	1.02	0.12		3.94	10.9		6.46	12.99
Totals in gms	0.47			1.41			8.51			39.35			49.74	

Table 10, base. Minor amounts of pyrite and selenite not taken into account.

Quartz	4.79	17.5	0.126	4.09	14.0	1.080	4.25	65.50		2.27	69.63		15.40	23.21
Phosphatic	6.30	23.0	0.461	3.95	13.5	0.780	2.18	33.63		0.95	29.00		13.38	20.14
Tea Green Marl	0.69	2.5	0.010	0.44	1.5	0.011	0.06	0.87		0.04	1.37		1.23	1.85
Mudstone	15.61	57.0	1.110	20.73	71.0	8.856	0.00	0.00		0.00	0.00		36.34	54.80
Totals in gms	27.39			29.21			6.49			3.26			66.35	

(For explanation see pages 204, 205-209).

Explanation of Plate 14

Fig. 1. Barrow-on-Soar, 'Base'.

The lower part consists largely of very fine to medium sand with bone-bed fossils ranging from the minute up to 2 mm, in a calcareous, silicified matrix. It is not bedded but elongate fossils are laid horizontally. It is poorly sorted though the range of grades is narrow. Above, there is bedded siltstone with only a few minute fossil remains. This is an intermediate part primary bed.

Fig. 2. Wainlode Cliff, 'Sandstones and siltstones', part 'e'

The lower part consists of very fine sand with some fine sand in a calcareous matrix; there are also a few minute phosphatic fossil remains. In a similar matrix, the middle part contains sand ranging from very fine to medium; it has numerous bone-bed fossils from minute size up to 3 mm. It is poorly sorted within a fairly narrow size range and is poorly bedded but the platey fossils are well orientated horizontally. The upper part contains less medium sand and phosphatic fossils and is pyritised irrespective of the bedding. The bed is an intermediate part primary bone-bed.

Fig. 3. Wainlode Cliff, 'sandstones and siltstones', part 'c'

The lower part is a bedded siltstone which is truncated and overlain unconformably by a less bedded, very fine sandstone which contains pyritised shell fragments and minute bone-bed fossils. It illustrates the lower limits of sand grade for the presence of bone-bed fossils and also the relationship of sand and fossil sorting. This is a current bedded, secondary bone-bed.

Fig. 4. Lavernock, 'Bone-bed', part 'c'

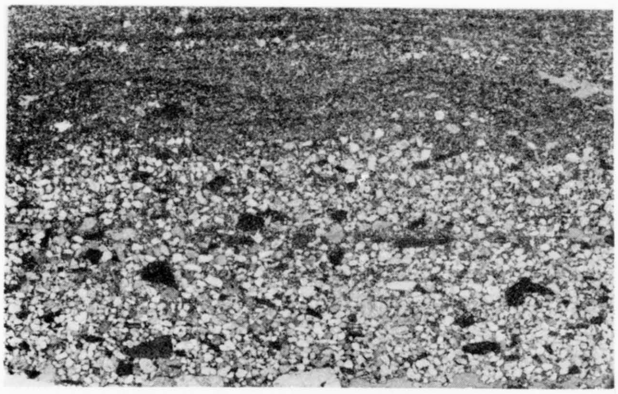
The lower part is made up of poorly bedded, compact, shelly fragments, some being pyritised. There are a few scattered quartz grains and phosphatic remains in this 'scatter' part of the bed. The upper part has a calcareous matrix with some whole and fragmented shells though its chief constituents are quartz and bone-bed fossils. The quartz varies between very fine and very coarse sand and the fossils are of corresponding sizes. Although the lower part is secondary, the upper part is unbedded, unsorted, with coprolites and unbroken shells; a part primary bone-bed.

Fig. 5. Lavernock, 'Limestone below bone-bed'

The rock has a mass of shells, quartz and bone-bed fossils in a lime mud matrix with patches of unfossiliferous, argillaceous limestone. Most of the shells are detached and unbroken. The quartz is unsorted between fine and coarse sand and the fossils also are unsorted, being distinctly associated with the sand; in parts both are absent. The lack of sorting along with randomly orientated, unbroken shells deposited in lime mud, show this as a part primary bone-bed.

Fig. 6. St. Audries Bay, 'sandstones and shales', part 'a'

This consists of fine to very fine sand and phosphatic fossils in a fine grained calcareous matrix. There is a large limestone inclusion with flow structure of the finer sediments around it. The matrix has many specks and strands of pyrite and some fragmented shells. A sorted, secondary bone-bed with an 'out of context' inclusion (see text).



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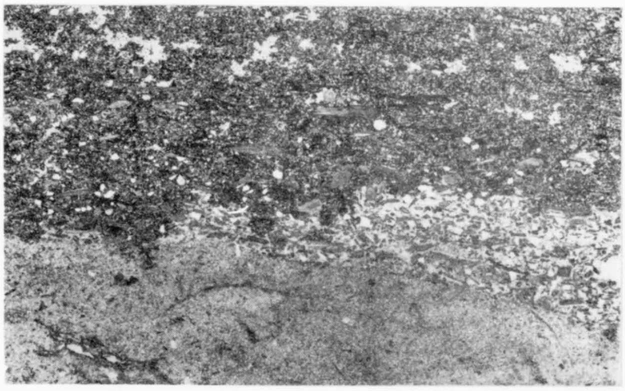

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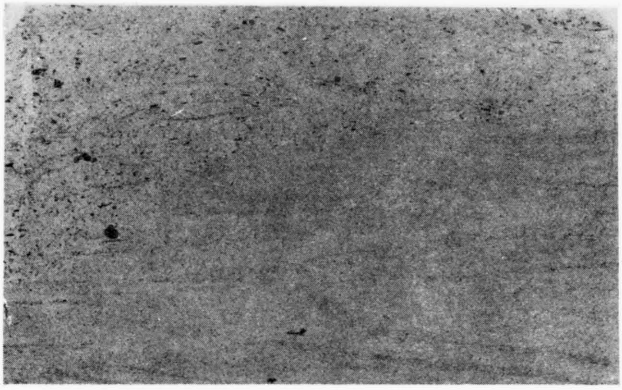

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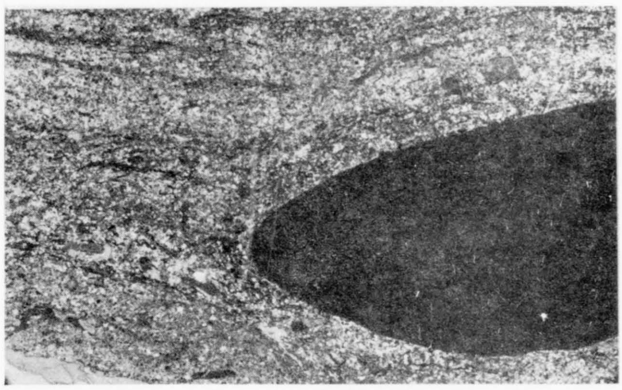


6

	metres
Shale, black, fissile, three parts '*a*' to '*c*' at the top.	0.4
(100 mm) shale with bivalves and sandy patches, with some bone-bed constituents.	
(150 mm) shale with some fine sand patches.	
(150 mm) shale without sand, laid directly on Tea Green Marl. There are silt patches also flakes and pellets of the marl Tea Green Marl in the lowest 25 mm.	
Bone-bed, with coarse and fine sand, large and small fossils including bones and coprolites, there are also patches of Tea Green Marl. The bed is discontinuous over a short distance (table 10).	0.05

Remarks

The basal bed is part primary with an unsorted quartz content ranging between silt and pebbles (5 mm). Unsorted fossils of varying grades, including coprolites, are deposited with random orientation; some having surface details unworn. The bedding is slightly flexed in places but there is no current bedding. In table 10 the inclusion of 1.85% of Tea Green Marl shows the disturbance of the underlying bed. Where the basal bone-bed is absent there is no coarse sand but the current action along this horizon is shown by the inclusion of rolled Tea Green Marl clasts in the basal beds.

Higher in the sequence there is a comparatively large amount of quartz deposits but most of it is of siltstone grade and does not contain fossils. There is a varying amount of phosphatic content within the layers of the upper *pullastra* bone-bed. Tables 8 and 9 show how the fossil phosphatic content is smaller in relation to the finer-grade sandstone.

As at many other localities there is a third bone-bed on a higher horizon.

Sedbury, Gwent, ST 555930, Richardson (1903a, p.394)

	metres
Shales, black.	0.7
Limestone 75 mm to 200 mm, some fish remains and bivalves.	0.12
Shale, black, fissile.	0.15
Limestone, pyritic, fish remains and bivalves.	0.15
Shale, black, earthy and fissile.	1.83
Pebbly sandstones and shales alternating. Fish remains, coprolites.	0.2
Bone bed, conglomeratic, coarse sandstone with fish, reptile remains and coprolites.	0.1
Tea Green Marl.	

Bishton, Gwent, ST 390873, Richardson (1903b, p.378)

Sandstone, pyritic.	0.02
Shale, black, with much shell debris, fish scales and coprolites.	0.08
Shale, black.	0.66
Quartz sand, reddish brown.	0.05
Clay.	0.025
Quartz sand, black.	0.05

Continued p. 211

Explanation of Plate No. 15

Fig. 1. Penarth. Text-fig. 2, bone-bed sample locations 'a- g', sample 'a'

This has a dense bone-bed content in a calcareous matrix. It has sand from fine to coarse and boney fossils from minute to 5 mm. There are no shells present. The material is poorly sorted and contains coprolites; a part primary bone-bed.

Fig. 2. Penarth. Text-fig. 2, bone-bed sample locations 'a- g', sample 'b'

This has a similar content to as fig. 1, though the bone-bed content of 'b' is more diffuse and the matrix now contains some randomly orientated shells.

Fig. 3. Penarth. Text-fig. 2, bone-bed sample locations 'a - g', sample 'g'

This is a limestone with a bone-bed band in the middle consisting of many shells with some quartz and phosphatic fossils in a muddy-limestone matrix. The sand is medium to coarse-grained with corresponding fossil grades. This bone-bed content is poorly sorted and diffuse in a declining bone-bed which ends a short distance laterally. A 'part primary' bone-bed.

The upright division of the bone-bed is probably later a solution feature as 'ghost' shell remains may be seen in it.

Fig. 4. Penarth. Text-fig. 3, bone-bed sample locations 'a - r', sample 'a'

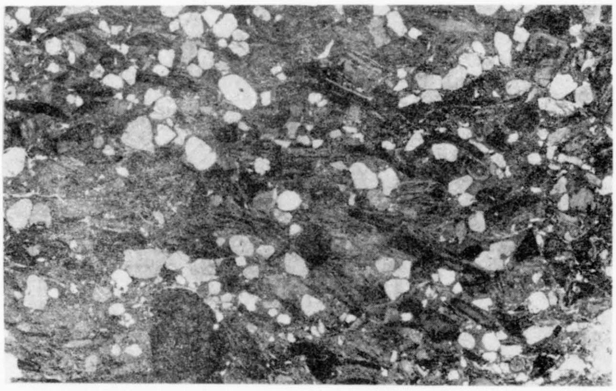
This is a limestone with shells scattered at random, many of them unbroken and some attached. At the top and the base it is an impure lime-mud which has a bone-bed content; the upper part being the coarser with quartz from very fine up to coarse sand and correspondingly sized fossils. There are occasional quartz grains and phosphatic fossils associated with the shelly middle part. A 'part primary' bone-bed.

Fig. 5. Penarth. Text-fig. 3, bone-bed sample locations 'a - r', sample 'b'

The rock has a similar composition to 'a' (fig. 4) but the bone-bed layers are thinner and generally of a finer grade. At the base there is a layer of limestone with some silt in its upper part. A thin layer of limestone also interupts the bone-bed near the top. The shelly middle part has fewer and more fragmented shells also occasional quartz grains and phosphatic fossils. A 'part primary' bone-bed.

Fig. 6. Penarth. Text-fig. 3, bone-bed sample locations 'a - r', sample 'i'

This consists of scattered quartz, phosphatic fossils and bivalve shells in a muddy-limestone matrix. The quartz and fossils are associated with one another though being generally rather diffuse. There are areas without quartz which are also devoid of phosphatic fossils. Both the 'bone-bed' and shell fossils are laid with random orientation, many of the latter being unbroken A 'part primary' bone-bed with a diffuse, declining bone-bed content.



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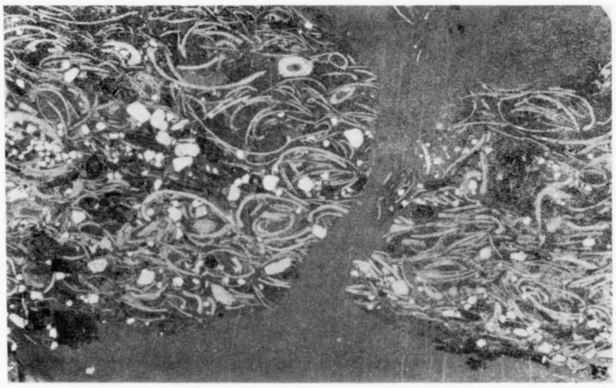

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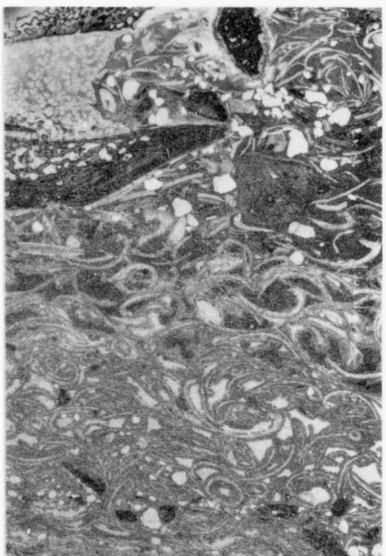

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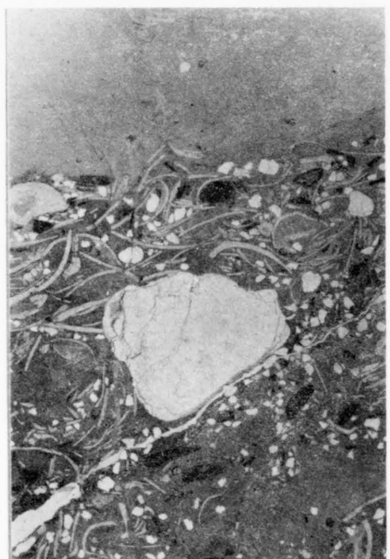


6

J. M. Sykes - British Rhaetian Bone-beds

	metres
Limestone, slightly arenaceous with fish remains and coprolites.	0.08
Tea Green Marl.	

Milton, Gwent, ST 367884, Richardson (1903b, p.381)

Shale, black.	
Shale, clayey with sandstone layers which contain fish scales.	0.38
Limestone, arenaceous with fish remains and bones.	0.075
Tea Green Marl.	

Llanwern, Gwent, ST 353878, Richardson (1903b, p.380)

Shale, black.	
Quartz sand with fish remains.	0.2
Grit, with fish scales.	0.13
Tea Green Marl.	

Goldcliff, Gwent, ST 366831, Richardson (1903b, p.374)

Shale, black.	0.61
Grit, very coarse, pyritic, calcareous, with fish remains.	0.15
Shale, black.	0.025
Pebbly sandstone with bones and fish remains.	0.15
Tea Green Marl.	1.52
Quartz sand with calcareous cement and bone-bed fossils.	0.15
Red Marl.	

Penarth, Glamorgan, ST 186697

General Section

Shale, black.	1.52
Third limestone, with fibrous calcite and black shale.	0.13
Shale, black, fissile.	0.45
Second limestone (*Pecten* bed) with bivalves.	0.18
Shale, black.	2.44
First limestone, gritty with shell fragments and vertebrate fossils.	0.13
Shale, black, unevenly bedded with some channel fillings which vary in size from 40 to 250 mm long and 8 to 20 mm deep. They contain quartz grains and bone-bed fossils.	0.18
Bone-bed, a discontinuous bed which varies laterally in its thickness and its nature. Two exposures are studied in detail.	0.025
Shale, black, fissile, on Sully beds at the base, where there are occasional, teeth, scales and coarse quartz grains also some small patches of cemented bone-bed.	1.07
Sully beds.	

Detail of bone-bed exposures 'a' to 'g' (text-fig. 2)

a. 20 mm thick and typical coarse-grain bone-bed with vertebrate fossils and coarse-sand in a matrix of fine sand and calcite (Plate 15, fig. 1).

b. 0.15 m north from 'a' 15 mm thick is similar to sample 'a' though there is some development of mudstone in the matrix and also some detached whole bivalves present (Plate 15, fig. 2).

c. 3 m north from 'a' 56 mm thick:

Calcareous mudstone	17 mm
Bone-bed	4 mm
Shale layer	2 mm
Bone-bed	5 mm
Muddy limestone	28 mm

A band of typical bone-bed is split by a thin layer of shale. There are no bivalves in the bone-bed which is less coarse than the previous samples. Above is a muddy limestone with some detached bivalves, scattered vertebrate fossils and occasional coarse grains of quartz. The lower muddy limestone is similar with less bivalves.

d. 0.53 m north from 'a' 82 mm thick:

Muddy limestone	25 mm
Shale layer	2 mm
Muddy limestone	13 mm
Bone-bed	30 mm
Muddy limestone	9 mm
Bone-bed	3 mm

The uppermost limestone contains shells which are almost absent from the two lower limestones. Near the middle there is bone-bed material with the same coarseness as at point 'c' though far more diffuse with fewer fossils and less sand. There is another thin layer of similar bone-bed at the base.

e. 0.8 m north from 'a' 26 mm thick. Muddy limestone with a diffuse bone-bed (6 mm) passing obliquely from top to base of the sample (85 mm long) this contains fossils and sand with a less muddy limestone matrix.

f. 1.1 m north from 'a', 25 mm thick is a shelly bone-bed with a muddy limestone matrix. Where there is a predominence of shells there are less fossils than in the parts containing quartz grains.

g. 1.35 m north from 'a' 25 mm thick; a muddy limestone with a thin (5 mm) sandy and shelly bone-bed near the middle (Plate 15, fig. 3). Here the bed passes laterally into black shale.

Bone bed exposure 'a' to 'r' (text-fig. 3)

a. 40 mm thick:

At the base there is a 4 mm layer of fibrous calcite. Above is a fairly coarse bone-bed then a brown, shelly layer with a coarse bone-bed layer at the top (Plate 15, fig. 5).

north

Muddy limestone with a sandy, shelly bone-bed in middle (pl. 15, fig. 3)

Muddy limestone with a diffuse, thin, shelly bone-bed

Muddy limestone with a diffuse bone-bed and black shale layer

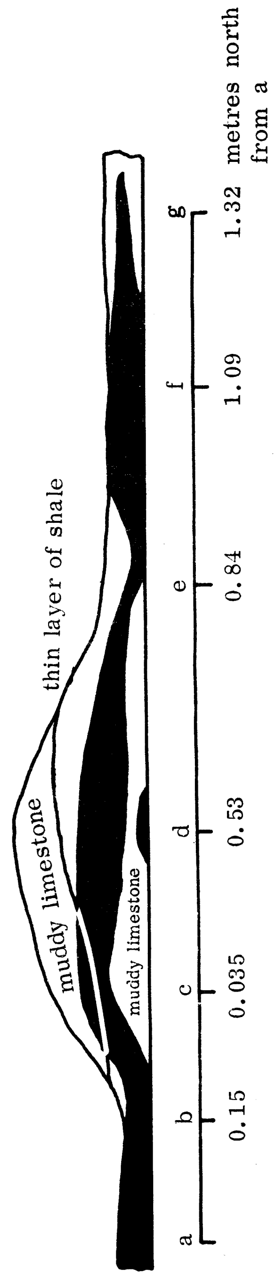
Muddy limestone with bone-bed split by layer of black shale

Muddy limestone with bone-bed split by layer of black shale

Coarse bone-bed with bivalves and some mudstone matrix (pl. 15, fig. 2)

Coarse bone-bed (pl. 15, fig. 1)

south



Text-fig. 2. Penarth bone-bed exposure 'a' to 'g'

b. 45.15 m north from 'a', 22 mm thick, is a bone-bed with a shelly middle part which contains fewer phosphatic fossils. It is fine-grained near the base and there is an unfossiliferous argillaceous layer at the top (Plate 15, fig. 4).

c. 54.9 m north from 'a', 6 mm thick is a hard, dark grey, non-calcareous, cemented mudstone in which there are embedded numerous, detached, unbroken bivalve shells laid convexly downwards.

d. 55.2 m north from 'a', 24 mm thick: Cemented, dark grey, noncalcareous mudstone, weathering reddish brown. It contains pyrite and whitish, speckled inclusions.

e. 55.5 m north from 'a', 6 mm thick: Dark grey, cemented, non-calcareous mudstone with a slightly calcareous, broken shelly content.

f. 55.815 m north from 'a', 25 mm thick: A bone-bed with vertebrate fossils and coarse sand in a calcareous matrix containing shell debris.

g. 56.42 m north from 'a', 25 mm thick: A bone-bed in a calcareous matrix with many fossils, including coprolites, also a small amount of coarse sand.

h. 56.88 m north from 'a', 20 mm thick is a bone-bed, a coarse-grained rock consisting of coarse sand and vertebrate fossils in a calcareous matrix with a small number of bivalves.

i. 57.65 m north from 'a', 22 m thick: Bone-bed with coarse and fine sand, unsorted vertebrate fossils also fragmented and unfragmented shells in a calcareous matrix. (Plate 15, fig. 6).

j. 58.1 m north from 'a', 20 mm thick: Fine, non-calcareous sandstone.

k. 58.5 m north from 'a', non-calcareous sandstone with pyrite.

l. 58.7 m north from 'a', 5 mm thick: Mudstone dark grey, cemented, non-calcareous with calcareous inclusions.

m. 58.85 m north from 'a' 3 mm thick: Mudstone, dark grey, calcareous.

n. 59.17 m north from 'a' 20 mm thick: Siltstone, fine grained with pyrite.

o. Between 59.2 and 61.3 m north from 'a', 25 mm to 25 cm thick: Limestone which bulges upwards to 25 cms and thins again over a distance of 2.1 metres.

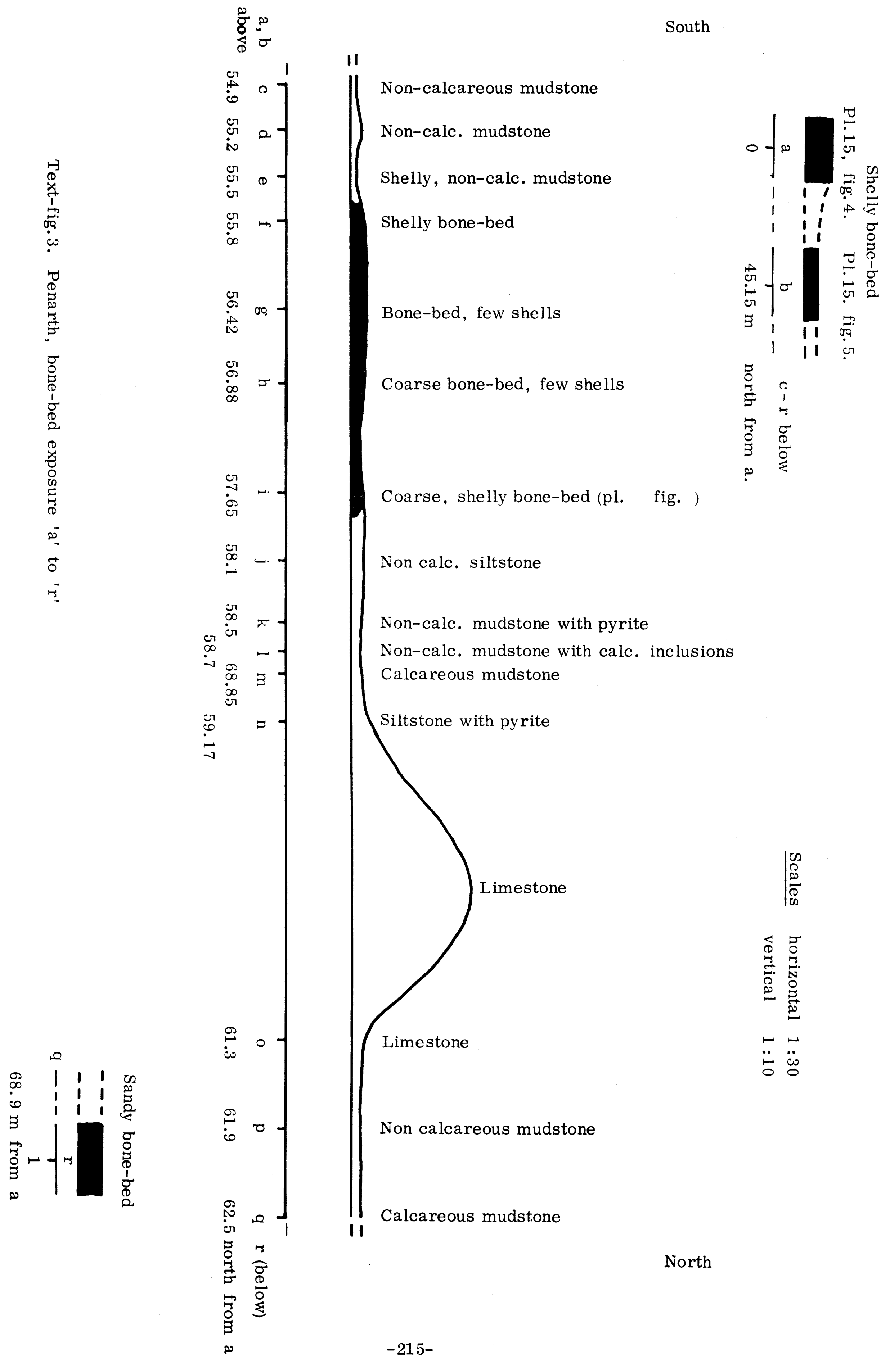
p. 61.9 m north from 'a', 8 mm thick: Mudstone, dark grey, cemented, non-calcareous. Near the base and at the top there are bands which are slightly calcareous and shelly though the shells have been replaced by pyrite, there is some pyrite and sand.

q. 62.5 m north from 'a', 8 mm thick: Mudstone, dark grey, cemented, calcareous, containing pyrite. The bed then passes laterally into black shale for a distance of 6.4 metres when the bone-bed reappears.

r. 68.9 m north from 'a', 38 m thick: Bone-bed with a predominance of medium grade sand and a scattering of small vertebrate fossils. The matrix is calcareous.

Remarks

No sample was found of the discontinuous bone-bed which has been noted by previous authors (Richardson, 1905, p.391) at the base of the Rhaetic at Penarth though its influence, in the deposition as a trace bone-bed is present.



Text-fig.3. Penarth, bone-bed exposure 'a' to 'r'

The lengthy exposure of the main bone-bed provides an excellent opportunity for the study of its lateral development. It is discontinuous and many cm thick. It varies between being a sandy bone-bed, a sandy and shelly bone-bed, limestone, calcareous mudstone, non-calcareous mudstone and a siltstone. It also has combinations of these elements. The vertebrate fossils are directly related to the sandiness and also slightly to the shelly content. This may occur as a coarse horizon in a fine-grained rock or through the whole of the bed.

This is a part primary bone-bed, a striking feature being bivalves which are orientated at random, unbroken, attached and filled with lime mud showing that they were buried quietly, *in situ* before transport separated them or abraded them.

The isolated bone-bed channel fillings in the black shale above could indicate that currents bearing such material, swept past and left some of their load trapped in the hollows.

The first limestone above the bone-bed is a part primary bed with unsorted material and a deposition of bivalves in a calcareous matrix.

Dinas Powys, Glamorgan, ST 155712, Richardson, (1905, p.396).

	metres
Shale, black.	0.9
Limestone with quartz sand below containing fish remains.	0.12
Shale, black.	0.1
Sandy layer, chocolate colour with fish remains.	0.025
Sully beds.	

Lavernock, Glamorgan, ST 188682

Shale, grey near the top.	1.7
Limestone with fibrous calcite layers.	0.05
Shale, black.	0.5
Limestone with a fibrous calcite layer.	0.012
Shale, black.	app. 1.2
Limestone.	0.1
Shale, black.	1.3
Bone-bed, with shaley partings; Five parts 'a' to 'e' at the top.	0.165

e 25 mm thick

Shale, black with an impure limestone at the top.

d 20 mm thick

Shale, black with light scatter bone-bed and trace bone-bed in patches.

c 65 mm thick

Limestone, sandy. The upper part contains coarse and fine quartz, boney fossils and coprolites. The lower part has a compact shelly fauna with rare vertebrate fossils (Plate 14, fig. 4).

b 15 mm thick

Dark grey, impure limestone.

a   40 mm thick   metres

Mudstone, cemented, pyritic, with scattered coarse grains and vertebrate fossils.	
Shale, black.	0.075
Limestone, arenaceous, intermittant up to 25 mm thick with quartz grains, vertebrate fossils and bivalves (Plate 14, fig. 5).	0.025
Shale, black.	1.00

In the lowest 100 m there are patches and scattered elements of trace bone-bed. Some of the black shale is laid directly upon, and filling cracks in the Sully Beds.

Remarks

There is a well known pebble bone-bed, of patchy occurence, at the base of the Rhaetic at Lavernock. In the section examined this is reduced to a trace bone-bed and in places is completely absent.

The first bone-bed above the base is a part primary one and it may correlate with the main bone-bed at Penarth as they have similar features (Plate 14, fig. 5, Plate 15, fig. 4).

The bone-bed at the higher horizon has varying modes of deposition from limestone, arenaceous limestone to black shale and pyritic mudstone. There are also differing types of bone-bed though they are only associated with the sandy deposits. The lower part 'a' is a scatter bone-bed, part 'c' is a part primary bone-bed (Plate 14,fig. 4) part 'd' contains trace and scatter bone-bed material in the black shale and the argillaceous limestone is unfossiliferous.

It is interesting to compare this section with the one measured by Richardson (1905,p.392).

Richardson	Metres	Present author		Metres
Limestone.	0.2	Limestone.		0.012
Shales, black, lower earthy.	1.0	Shale, black.		1.2
Limestone, lower part, shelly.	0.1			
Limestone, arenaceous bone-bed.	0.075	Shale, limestone at top.	(e)	0.025
Sandstone, hard, pyritic.	0.025			
Shale, parting.	0.025	Shale, black scattered bone-bed.	(d)	0.C25
Sandstones, shale & 'beef'	0.1	Limestone, sandy bone-bed.	(c)	0.06
Black shales.	0.075	Shale parting, thin.		-
Limestone, dark, pyritic.	0.025	Limestone	(b)	.012
Shales, black.	0.1	Shale parting, thin.		-
Bone-bed.	0.025	Mudstone scatter bone-bed.	(a)	.025
Shales, black.	0.18	Shales, black.		0.075
Limestone bone-bed.	0.04	Limestone bone-bed.		0.025
Shales, black.	0.33	Shales, black.		1.00
Fish Bed, pebbly bone-bed.	0.025	Trace bone-bed.		
	2.325			2.464

Up to the second bone-bed above the base the beds correlate well though there are remarkable differences in their thicknesses. Hard beds of Richardson's section correlate with the parts 'a' to 'e' of the present section, though, over what must have been a short distance, the shale partings are equivalent of shale beds and the lithology differs. Both record two hard bone-bed horizons, though, in Richardson's section he finds one at the top on the same horizon as the unfossiliferous limestone in the present measurements. This comparison gives another instance of the striking lateral changes in a bone-bed.

Saint Mary's Well Bay, Glamorgan, ST 175676	metres
Third limestone, muddy, black, with layers of fibrous calcite.	
Shale, black.	0.9
Second limestone with black mudstone and limestone shale.	0.1
Shale, black.	2.14
First limestone, dark grey, muddy.	0.12
Shale, black.	1.8
Bone-bed, three parts, 'a' to 'c' at the top.	0.04

c 8 mm thick

A thin bed of pyritic limestone.

b 6 mm thick

A thin discontinuous layer which consists of cemented sand and vertebrate fossils.

a 26 mm thick

A discontinuous layer of limestone devoid of bone-bed content. It contains many bivalve shells detached and unbroken.

Shale, black, the base being laid directly on Sully Beds. The lowest 25 mm contains a trace bone-bed in places.	1.4

Remarks

Saint Mary's Well Bay gives another example of a trace bone-bed occuring along the horizon of a major bone-bed at the base of the Rhaetic.

The bone-bed contains only a thin layer of fossiliferous material in the section measured. Specimens of a thicker, more developed bone-bed were found at the foot of the cliff, indicating its changing nature laterally.

Significantly, the thin bone-bed layer was coincident with the only coarse sand found. Richardson (1905, p.394) found the bone-bed in sandstones and limestone on the horizon of the third limestone in the present section.

Cowbridge, Glamorgan, SS 999745, Richardson (1905, p.400)	metres
Shale, black	0.35
Limestone with mica and fish remains.	0.025
Shale, black.	0.10
Limestone, often arenaceous with coprolites.	0.025

	metres
Shale, black with gritty layers and conglomerate at the base, fish, reptile remains and coprolites.	0.74
Limestone, slightly sandy with few fish remains.	0.23
Marl with lumps of hard limestone and rare fish remains.	0.4
Sully Beds.	

Coity, Glamorgan, SS 925814, Francis (1959, p.167)

Sandstone, fine-grained with clay, shale and vertebrate remains	0.91
Shale and clay, green and black.	0.91
Pebble bed with vertebrates	0.075
Sandstone, white, medium-grained with vertebrate fragments.	1.00
Keuper grey marls.	

Stormy Down, Glamorgan, SS 846806, Francis (1959, p.163)

Sandstone, brown fine-grained, clay partings, vertebrate remains.	2.4
Shale, green and brown with fish remains.	1.47
Pebble bed with abundant fish remains.	0.1
Sandstone, hard, massive, white and yellow with vertebrate fragments and galena.	5.28
Keuper green marls.	

Aust, Avon, ST 564895

Second limestone (upper *Pectin*), dark grey, shelly.	0.12
Shale, black, fissile.	2.28
First limestone (lower *Pectin*), dark grey, shelly.	0.18
Shale, black, fissile.	1.22

A part of this bed, 0.6 m above the base contains pellets and patches of calcareous sandstone. These are up to 150 mm long and 6 mm thick and the coarser-grained ones have rare vertebrate fragments. At the base, fissile black shale is laid upon Tea Green Marl without a trace of sandiness or fossils. There are some rolled pellets of Tea Green Marl.

Remarks

The basal bone-bed at Aust Cliff is probably the best known in the country. *In situ* it is found high up in the cliff so it has been studied largely from pieces which have fallen on to the beach. The bed was excavated in July 1961 during the construction of the River Severn Suspension Bridge (M.4). It is a part primary bed being a well cemented, grey, calcareous matrix with many coarse clasts of quartzite and limestone; there is also an unsorted, well preserved, comprehensive vertebrate fauna.

Also from the beach, a second, highly fossiliferous bone-bed is described (Reynolds, 1945, p.32) as slabs of arenaceous limestone derived from the top and bottom of the lower *Pecten* bed. Short (1904, p.173) describes this bed as containing numerous quartz pebbles up to 12 mm across.

Over a distance of approximately 80 m to the South West the 150 mm bone-bed passes laterally into black shale with no bone-bed content. Similarly the highly fossiliferous lower *Pectin* bed passes into a shelly limestone. This shows that the currents which deposited the coarse breccia material must have had local effect only, probably scouring in the vicinity. It also shows that the absence of bone-bed is consistent with the lack of coarse deposits even when the presence of rolled Tea Green Marl indicates a certain amount of redistribution at the base.

Trace bone-beds are found with traces of the coarser-sand within the lower shales.

Barnhill Quarry, Avon, ST 725830, Macfayden (1970, p.204)

	metres
Limestone, grey, argillaceous.	0.15
Shale, black with impersistent ferruginous layer full of vertebrate remains.	1.00
Limestone, *Pectin* bed with layers of fibrous calcium carbonate.	0.3
Shale, black.	2.43
Bone-bed with fish, reptiles and quartz pebbles.	0.3
Carboniferous limestone.	

Redland, Avon, ST 585753, Rendle-Short (1904, p.173)

Limestone, dark, shelly.	0.15
Shale and clay, black. Siliceous band with bone-bed fossils.	0.6
Shale and clay, ferruginous.	0.92
Shale, black.	0.53
Sandstone, gritty, calcareous with vertebrates, coprolites and pebbles.	0.025
Carboniferous limestone.	0.025

Cotham Rd, Avon, ST 586739, Rendle-Short (1904, p.177)

Marl, yellow.	0.45
Limestone, thin bands, very shelly containing fish remains and coprolites.	0.92
Limestone, shelly, black with fish scales.	0.12
Shale, black, siliceous bands with fish scales.	4.5
Bone-bed absent.	
Below base of Westbury beds not recorded.	

Brislington, Avon, ST 635704, Kelloway (1933, p.566)

Upper Rhaetic marl, brown.	0.76
Limestone with fish remains.	0.23
Marl.	0.75
Limestone with bivalves and fish remains.	0.3
Shale, variable.	2.5
Arenaceous, calcareous layer with fish, reptiles, coprolites.	0.05

	metres
Pylle Hill, Avon, ST 598718, Wilson (1891, p.546)	
Limestone, light blue, bedded (Upper Rhaetic).	
Limestone with fish remains (Upper Rhaetic).	0.3
Lower Rhaetic	
Shales with fish scales.	0.25
Limestone.	0.075
Shale, black with pyritic seams having bone-bed fossils.	0.86
Shale, black.	0.7
Shale, black, firm with scattered coprolites and scales.	0.45
Shale, black with seams and pockets of pyritic grit with fish, reptiles, coprolites and pebbles.	0.12
Tea Green Marl.	
Uphill, Somerset, ST 317589, Kellaway & Oakley (1933, p.476)	
Shale, black.	2.00
Bone-bed, sandy shale and saccaroidal limestone.	0.15
Shale, grey and black.	0.9
Tea Green Marl.	
Chilcompton, Somerset, ST 652522	
Marl, light grey, weathering buff.	0.12
Marls and limestone, grey, clayey marl weathering buff with shelly layers and thin limestones.	0.5
The limestones show ripple marks and the under surface of the lowest one is covered with vertebrate fossils, associated with the shelly layer immediately below it.	
The shelly layers are in the lower part of the bed, they consist of numerous fragments of shells with vertebrate fossils, chamosite grains a little quartz and rolled fragments of shell, many of which have accumulated calcite and some become oolitic (table 11).	
Shale, black with thick layers of buff coloured material dominated by shelly remains.	0.075
The shale is crumbly and contains bivalves, many of which are unbroken; it is without bone-bed content.	
The shelly layers occur in the lower part of the bed and are similar to those in the bed above except that there is some finer-grained material that does not contain bone-bed fossils (table 12).	
Shale, black, fissile and crumbly, with many bivalves.	2.00
Limestone, a series of variable limestones with muddy partings: Five parts, 'a' to 'e' (top).	0.105
e 6 mm thick	
Limestone with occasional complete shell valves.	

Chilcompton Tables 11 to 14

Table 11, marls and limestone, lower part

	850-500 microns	Fraction percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz			0.00	0.0	0.000	0.02	0.12	0.000	0.05	0.49	0.001	0.00	0.00	0.07	0.44
Phosphatic			0.87	3.2	0.016	0.65	3.09	0.038	1.24	11.35	0.092	0.16	3.76	2.92	10.52
Calcite			1.02	3.8	0.028	0.00	0.00	0.006	0.00	0.00	0.000	0.00	0.00	1.02	1.60
Rest			25.16	93.0	0.606	20.23	96.79		9.63	88.16	0.707	3.96	96.24	58.98	87.44
Totals in gms			27.05			20.90			10.92			4.12		62.99	

Table 12, black shale with shelly layers

	850-500 microns	Fraction percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz			0.004	0.08	0.000	0.02	5.24	0.001	0.10	2.8	0.011	0.03	1.5	0.154	0.85
Phosphatic			0.28	4.66	0.054	0.29	89.51	0.001	0.58	15.5	0.091	0.19	8.9	1.34	7.65
Calcite			0.166	3.01	0.028	0.31	4.91	0.083	0.50	13.5	0.130	0.25	11.6	1.226	6.91
Rest			5.430	92.25	11.887	5.29	0.34	1.915	2.55	68.2	0.939	1.66	78.0	14.93	84.59
Totals in gms			5.88			5.91			3.73			2.13		17.65	

Table 13, shelly mudstone

	850-500 microns	Fraction percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz			0.01	0.08		0.01	0.05	0.000	0.00	0.00		0.00	0.00	0.02	0.05
Phosphatic			0.02	0.11		0.10	0.6	0.002	0.20	1.79		0.05	0.85	0.37	0.85
Rest			11.86	99.81		15.03	99.35	0.324	11.10	98.21		5.21	99.15	43.20	99.10
Totals in gms			11.89			15.14			11.30			5.26		43.59	

Table 14, basal bone-bed

	850-500 microns	Fraction percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz	6.79	40.50	9.06	47.45		9.73	54.60		2.50	51.8		1.96	59.4	30.04	48.70
Phosphatic	4.65	27.75	5.99	31.37		7.48	40.02		1.55	35.9		1.12	34.1	20.79	33.70
Pyrite	4.42	26.38	3.40	18.81		0.98	5.38		0.27	6.3		0.22	6.5	9.29	15.06
Shale	0.92	5.37	0.64	2.37		0.00	0.00		0.00	0.0		0.00	0.0	1.56	2.54
Totals in gms	16.78		19.09			18.19			4.32			3.30			

For explanation see text. pp. 204, 221-225.

metres

d 17 mm thick

Below a mudstone parting is a limestone with a small amount of shell debris which has associated minute vertebrate fossils. The lower surface is ripple marked.

c 20 mm thick

Below another mudstone parting is a limestone with thinly scattered shell debris. It contains vertebrate fossils corresponding to the density of shell material. (Plate 16, fig. 1).

b 18 mm thick

Another mudstone parting, then a limestone with disseminated shell fragments and vertebrate fossils in the upper and lower layers (Plate 16, fig. 2).

a 44 mm thick

Beneath the last mudstone parting is a limestone with masses of shelly fragments, vertebrate fossils and a little quartz. There is slight evidence of current bedding and, at the top, an abrupt change to a 5 mm layer of argillaceous limestone.

Shelly mudstone. 0.025

Similar to the shelly beds above the limestones though with less rolled fragments and fewer vertebrate fossils (table 13).

In the lower part, the fragmentation is finer and without vertebrate fossils.

Shale, black, part fissile and part crumbly. 0.7

Mudstone, black with thinly scattered vertebrate fossils and quartz grains, especially in the upper part. 0.3

Bone-bed.

At the base, discontinuous over distances of less than 1 m, leaving black shale resting directly upon Tea Green Marl. The bed is only a few mm thick and generally consists of cemented sand and vertebrate fossils though one specimen has a bone-bed layer 2 mm thick and on top a smooth limestone layer 4 mm thick.

Further along the cutting the bone-bed is still discontinuous though up to 25 mm thick. It is friable consisting of sand and fossils in a mudstone matrix (table 14).

Remarks

The basal bone-bed at Chilcompton illustrates its changing nature when traced laterally. At the section under review it is a few mm thick, cemented and associated with limestone. Approximately 80 metres to the north-east along the cutting it is up to 25 mm thick and is a friable mudstone with a large quartz and fossil content (table 14).

The higher bone-beds at Chilcompton are an exception which helps to prove the rule that vertebrate fossils are associated with coarse deposits laid in current action. There are only small amounts of fine sand present though there are masses of shell fragments, many of which have been rolled by current action and accumulated secondary calcite (tables 11, 12 & 13). Where this action is less evident and the deposits are of finer-grade the phosphatic remains are rare (table 13).

Within the bone-bed limestones the shell fragments do not have secondary calcite deposition. The vertebrate remains are minute and sorted in sizes comparable with the shell

Explanation of Plate 16

Fig. 1. Chilcompton, 'limestones', part 'c'

This calcareous matrix contains silt, shell fragments, minute bone-bed fossils and some very fine sand. There are also extremely minute, pyritised shell fragments scattered through the rock. It is layered with bands having greater concentrations of shelly remains which contain the boney fossils. In the layers where sand and shell fragments are not concentrated the vertebrate remains are lacking; a well sorted and bedded secondary bone-bed.

Fig. 2. Chilcompton, 'limestones', part 'b'

This bedded rock has a similar matrix to part c, fig. 1. The shell fragments are scarce and phosphatic remains almost absent except for a thin, concentrated layer near the top which also contains some very fine sand. A well sorted, 'secondary' rock with the shell fragments orientated along the bedding and a thin trace bone-bed near the top.

Fig. 3. Blue Anchor Bay. 'Main bone-bed' part 'b'

This is a trace bone-bed in a bed of fibrous calcite. It has a layer of silt with some grains of medium sand, pyrite and bone-bed fossile.

Fig. 4. Blue Anchor Bay. 'Main bone-bed', part 'a'

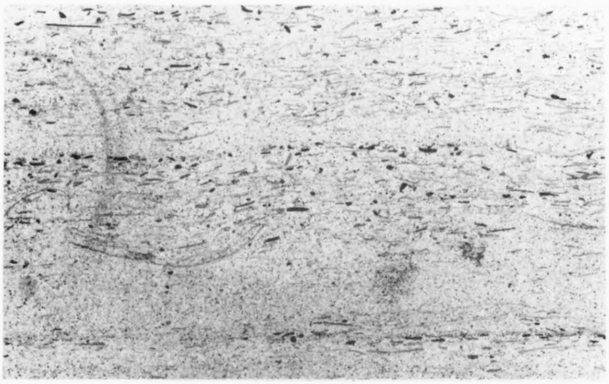
The lower part consists of quartz, phosphatic fossils and shells in a muddy limestone. The bone-bed content is poorly sorted within a fairly narrow range. It is not bedded but with the fossils generally orientated horizontally. Many of the shells are pyritised. There is an abrupt change to a fine-grained, well-sorted rock containing a mass of minute shell fragments, many of which are pyritised. There is some fine sand and occasional phosphatic fossils present. A well orientated, secondary bone-bed.

Fig. 5. Blue Anchor Bay. 'Main bone-bed', part 'a'

Approximately 1 metre laterally from the locality for the sample shown as fig. 4, this second sample from the same bed shows changes. There is a greater development of silty, shelly material which tends to lack bone bed content. The upper part is less shelly, more silty and better bedded; a secondary bone-bed.

Fig. 6. Blue Anchor Bay. 'Richardson's Clough'

The rock contains a mass of quartz grains and phosphatic fossils with some shell remains, in a calcareous matrix. The material is not bedded or sorted; ranging from very fine to coarse sand with minute and large fossils. Coprolites are present and the shells are not very fragmented. At the base there is an abrupt break from a limestone without bone-bed content - a part primary bone-bed.



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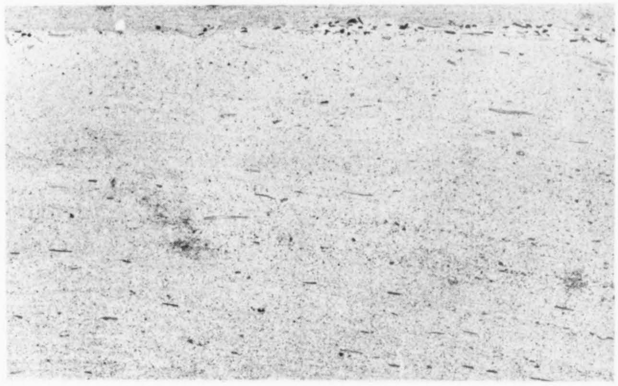

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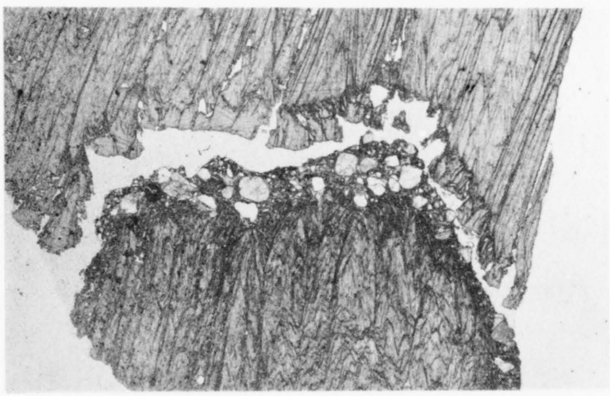

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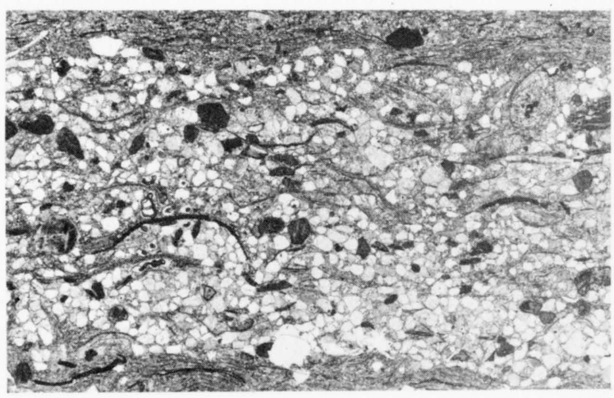

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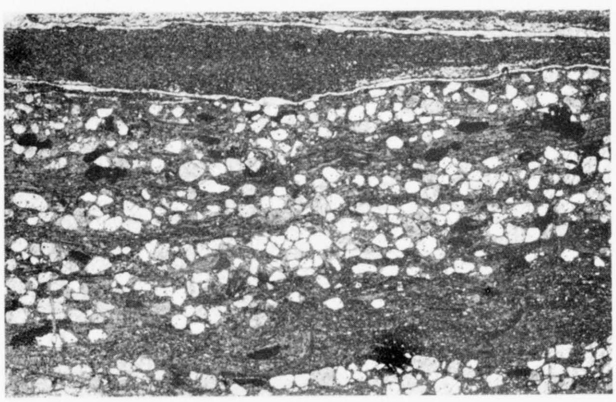

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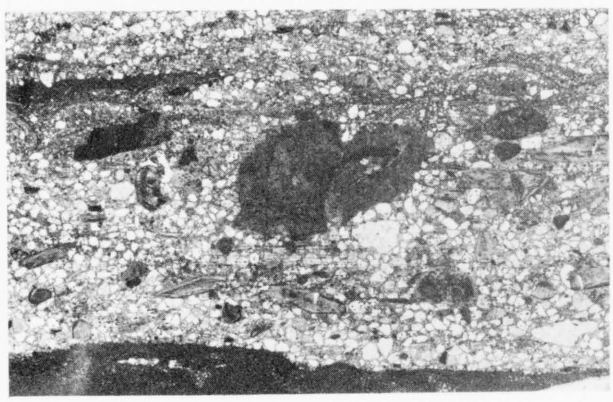

6

fragments. They are chiefly associated with the denser shell fragments and with the quartz present (Plates 16, figs. 1 & 2).

All the bone-beds above the base are dominantly secondary.

The control of shells on vertebrate deposition is seen to play a minor role at Penarth (Plate 15, figs. 4 & 5) though at Chilcompton fragments of valves, rather than quartz grains, are found in association with well-sorted vertebrate fossils. (Lyell 1875, p. 558) in his pursuit of the principle that the processes of the present are the key to the past, made a search for bone-beds which are forming at the present time. He recorded two occurrences of recent bone-beds, one on the Rockall Bank, which extends for two miles along the bottom of the sea, and the other just east of the Faroe Islands which covers a distance of twenty miles at a depth of 45 fathoms. In both cases the bones are associated with an abundance of broken valves. It is therefore possible, given the right conditions, for shell fragments to play the same role as quartz in occurrence of and preserving bone-bed fossils.

Richardson reported a section examined earlier by H. B. Woodward (In Richardson, 1911, p. 66) at this railway cutting. It gives the following comparative description of the bone-beds.

Woodward	Metres	Present author	Metres
Marl, pale greenish yellow.	0.76	Marl, grey weathering buff.	0.12
Limestone, argillaceous with a thin, gritty bone-bed at the top.	0.1	Marl and limestone.	0.56
Shales, marly.	0.3	Shale with buff, shelly layers.	0.075
Shales, black.	0.6		
Sandstone, thin layers.	0.05	Shale, black.	1.98
Shale, black.	0.3		
Limestone, grey, arenaceous	0.075	Limestone, variable.	0.075
Shale, black. fissile.	0.6	Shale, black, shelly at the top.	0.6
Shale, black, unbedded.	0.3	Mudstone.	0.3
		Shale, black, fissile	0.3
Bone-bed, fish, coprolites, pebbles.	0.075	Bone-bed.	0.025
	3.16		4.035

Woodward found unbedded shale immediately above the basal bone-bed whereas there is 0.3 metres of fissile shale intervening in the present section. This contains pellets of Tea Green Marl which were gathered from the underlying beds elsewhere. Within the mudstone of the present section there is a thin scatter bone-bed which could still be derived from disturbed bone-bed material elsewhere and laid in a typical scatter bed medium.

The lowest limestone Woodward found to be arenaceous, which gives a lateral sandy association to this bone-bed (Plate 16, figs. 1 & 2).

In the argillaceous limestone near the top of the section, he found a bone-bed coincident with a gritty, arenaceous layer; this was not found in the present section. He places this horizon in the Upper Rhaetic though doubt has been thrown upon this conclusion (C. Duffin in personal correspondence). It is interesting to note that bone-beds may form high in the succession when the coarse deposits are present.

	metres
Emborough, Somerset, ST 612514, Richardson (1911, p.68)	
Shale, grey.	0.2
Sandstone, bone-bed with layers of 'beef' on top.	0.075
Shale, black with thin sandstones.	0.05
Sandstone, laminated and conglomeratic bone-bed.	0.3
Sandstone, false bedded.	0.43
Coarse, conglomeratic bone-bed.	0.12
Tea Green Marl.	

Wells, Somerset, ST 545455, Brodie (1886, p.95)

"One piece of bone-bed was found out of *situ*. — A mass of conglomeratic limestone and sandstone with bone-bed fossils."

Bagley, Somerset, ST 457462, Richardson (1911, p.53)	
Shales, black.	0.45
Sandstone bone-bed, pale grey, calcareous, 3-6 layers shell debris.	0.36
Shales, black.	1.2
Limestone passing into sandstone bone-bed.	0.025
Marl, yellowish, sandy.	0.12
Limestone passing into sandstone bone-bed.	0.025
Sandstone bone-bed and yellowish, sandy shale.	0.15
Limestone, massive, grey and shelly with occasional fish remains.	1.2
Shale, black, clayey with occasional fish remains.	1.2
Shale, black with thin, brown sandstones.	2.00

Lilstock, Somerset, ST 167456, Richardson 1911, p.28.	
Shale, black, fissile.	0.45
Sandstone bone-bed, hard, grey with pebbles, coprolites and fish remains; becoming a limestone upwards.	0.15
Shale, black.	0.75
Limestone and shale.	1.5
Shale, black with gritty layers.	0.5
Sully beds.	

Saint Audries Bay, Somerset, ST 101434 (Tables 15-22, pp.228-229).	
Shale, black.	0.075
Sandstones and shales, calcareous, divided into three parts, 'a' to 'c'.	0.53

c 230 mm thick

Light grey, calcareous siltstones and thin, calcareous shales.

metres

b 240 mm thick

Light grey, calcareous, fine sandstone and siltstone with some black shale. There are scattered grains of chamosite, pyrite and rolled shell fragments. Thinly bedded parts have ripple marks; thicker bedded parts have some vertebrate fossils and occasional coarse quartz grains.

a 60 mm thick

Light grey, fine sandstone with shell fragments, ostracods and some bone-bed fossils and quartz. There are inclusions of dark limestone. (Plate 14, fig. 6).

Limestone and shales; at the top there is a dark grey, shelly limestone, nodular in places. Below this are layers of hard, calcareous, shelly shale. At the base is a thin layer of limestone.	0.12
Shale, black, fissile and part crumbly.	1.45
Shale, black, bedded and lumpy, with variable coarse deposits.	0.36

They are divided into seven parts, 'a' to 'g' at the top.

g 25 mm thick

Mainly bedded with scattered quartz and vertebrate fossils also some thin layers and patches which are cemented and contain chamosite and crystaline quartz grains (table 15).

f 25 mm thick

This has a large amount of unbedded quartz grains and bone-bed fossils; the base shows channel fillings (table 16).

e 75 mm thick

Well bedded black shale with small patches of bone-bed material. There are scattered quartz and fossils also occasional grains of the underlying Sully marl (table 17).

d 75 mm thick

Layers of black shale and medium to fine sand, the coarser type containing fossils (table 18).

c 50 mm thick

Less well-bedded black shale with medium and coarse and also fossils spread throughout. There are some patches of bone-bed content and also some marl fragments as in 'e' (table 19).

b 75 mm thick

Black shale with layers and patches of quartz and fossils (table 20).

a 25 mm thick

Poorly bedded shale with concentrations of medium and coarse quartz. Bone-bed fossils are spread sparsely throughout. These lowest shales are laid directly upon Sully Beds where the basal bone-bed is not present. (table 21).

Bone-bed with quartz and fossils.	0.025

St. Audries Bay, Tables 15-22

Table 15, part 'g'

	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	205-125 microns	Fraction percentage	125-63 microns	Fraction percentage	Fraction totals and % of 100 gms	Percentage of residue
Quartz	2.43	10.50		3.39	15.34		6.32	36.85	0.58	10.83	12.72	18.78
Phosphatic	0.54	2.33		0.48	2.16		0.34	1.98	0.12	2.17	1.48	2.19
Shale	20.19	87.17		18.21	82.50		10.49	61.17	4.64	87.00	53.53	79.03
Totals in gms	23.16			22.08			17.15		5.34		67.73	

Table 16, part 'f'

Quartz	7.29	70.37		17.61	66.13		1.74	70.03	6.44	63.00	33.08	66.55
Phosphatic	1.14	11.00		2.79	10.50		0.20	8.24	0.63	6.13	4.76	9.58
Shale	1.93	18.63		6.24	23.37		0.54	21.73	3.16	30.87	11.87	23.87
Totals in gms	10.36						2.48		10.23		49.71	

Table 17, part 'e'

Quartz	0.12	4	0.032	1.00	12.0	0.450	7.42	51.0	2.72	30.0	11.26	18.78
Phosphatic	0.06	2	0.009	0.13	1.5	0.017	0.51	3.5	0.18	2.5	0.88	2.19
Shale	2.76	94	0.975	7.21	86.5	3.466	6.63	45.5	2.46	67.5	19.06	79.03
Totals in gms	2.94			8.34			14.56		5.36		31.20	

Table 18, part 'd'

Quartz	0.51	60.0	0.606	1.14	47.17	0.568	11.22	74.12	6.43	78.00	19.30	35.96
Phosphatic	0.06	6.5	0.010	0.14	5.88	0.017	1.78	11.75	1.04	12.65	3.02	2.84
Shale	0.32	33.5	0.145	1.13	47.05	0.634	2.14	14.13	0.78	9.35	4.37	61.20
Totals in gms	0.95			2.41			15.14		8.25		26.69	

Table 19, part 'c'

Quartz Phosphatic Shale	0.73 0.10 1.82	27 4 69	0.305 0.010 1.013	2.19 0.28 2.31	45 6 49	1.683 0.035 0.738	15.48 2.22 3.26	74.00 10.62 15.38	10.25 1.18 1.28	80.25 9.25 10.50	28.65 3.78 8.67	69.70 9.20 21.10
Totals in gms	2.65			4.78			20.96		12.71		41.10	

Table 20, part 'b'

Quartz Phosphatic Shale	0.78 0.06 11.16	6.0 0.5 93.5	0.067 0.002 1.883	5.37 0.32 15.79	25.2 1.5 73.3	1.574 0.013 4.976	17.06 1.81 6.98	66 7 27	6.68 0.77 2.75	65.5 7.5 27.0	29.88 2.97 36.68	43.0 4.3 52.7
Totals in gms	12.00			21.48			25.85		10.20		69.53	

Table 21, part 'a'

Quartz Phosphatic Shale	0.60 0.26 3.14	15.0 6.5 78.5	0.054 0.008 0.452	29.24 1.23 2.87	87.7 3.7 8.6	3.953 0.080 0.274	21.41 1.90 2.96	81.5 7.25 11.25	5.69 1.21 1.06	72.0 15.5 12.5	56.94 4.60 9.97	79.63 6.43 13.94
Totals in gms	4.00			33.34			26.27		7.90		71.51	

Table 22, Comparative amount of quartz and phosphatic content in tables 15-20

Table number & horizon letter	21 a	20 b	19 c	18 d	17 e	16 f	15 g
Quartz Phosphatic	56.94 4.00	29.88 2.97	28.65 3.78	19.36 3.02	11.26 .88	33.08 4.76	12.72 1.48
Totals in gms and percentage of 100 gms	6.094	32.85	32.43	22.38	12.14	37.84	14.20

For explanation see text. pp. 204, 226-230.

Remarks

At the base there is a thin, discontinuous bone-bed up to 20 mm thick. It is poorly cemented with a dominant, poorly sorted quartz content; an intermediate part primary bed.

The lowest 0.36 m of the deposits which appear as black shale are an excellent example of scatter and trace bone-beds with quartz and fossils scattered through the rock or in small patches and thin layers. The fluctuating fossil content is linked to the sandy content. This is shown in table no. 22 which is a compilation of tables nos. 15-21. The presence of Sully marl in these beds (tables 17 and 19) would help to indicate that they are a redeposition of disturbed basal bone-bed.

The lower part of the Westbury Beds at St Audries was first measured before 1871 by R. Etheridge (in Richardson, 1911, p. 21), before the publication of his paper in which he stated that the section was then obscured. Richardson also reported that the section was obscured but he gave Etheridge's measurements.

Etheridge (in Richardson)	metres	Present author	metres
Shale, black.	0.46	Shale, black	0.075+
Bone-bed, siliceous rock with rolled pieces of limestone, fossils, coprolites & quartz pebbles.	0.12	Sandstone and siltstone.	0.53
Shale, black.	0.38	Top Light grey calc. siltstone and black, calc. shale.	
Sandstone layers, greenish yellow, and black shale.	0.075	Middle Transitional from lower to upper.	
Shale, black.	0.46	Lower Bone-bed with quartz, shell fragments & limestone pieces.	
Limestone, hard, grey with fibrous calcite.	0.13	Limestone, partly nodular, shaley at the base.	0.12
Shale, black.	0.46	Shale, black, fissile.	1.45
Limestone.	0.025		
Shale, black.	0.46	Shale, bedded and lumpy with coarse deposits.	0.36
Earthy shale with lumps of marl and basal bone-bed.	0.075	Bone-bed.	0.020
	2.645		2.555+

These measurements must have been taken a short distance from each other and up to the bone-bed they compare fairly well. The sandstones which contain the bone-bed in the right-hand column above do not have the coarse, pebbly deposits or the thick bands of shale. The bone-bed is of much finer-grade and is found at the base rather than at the top as in the earlier measurements. The bone-bed in the present exposure is secondary being fairly well sorted and containing shell debris. It is possible that the limestone inclusions link it with Etheridges report of rolled pieces of limestone, coprolites and other part primary indications in the vicinity. (Plate 14, fig. 6).

Blue Anchor Bay, Somerset, ST 042432	metres
Limestone (*Pleurophorus*), medium grey, shelly with fibrous calcite.	0.23
Shale, black, fissile with bivalves	0.2
Bone-bed, a composite bed with five parts 'a' to 'e' at the top.	0.28

e Up to 120 mm thick

A massive, calcareous gritstone containing numerous vertebrate fossils which are generally small fish remains or fragments of larger fossils; coprolites are rare. Thin scrins of calcite pass through the bed which may cut across fossils. Many of the quartz grains have a unipyramidal crystaline development (table 23).

d 50 mm thick

This is transitional to the part below. It has layers of calcareous bone-bed sandstone, thin layers of black shale and some limestone. There is less quartz development. The bone-bed content grades smaller downwards.

c 70 mm thick

This part consists of alternating layers of non-calcareous, fissile black shale and thin layers of calcareous bone-bed sandstones. A feature, is distinct ripple formation throughout. The shale contains bivalves which may be laid immediately upon a sandstone. The thin sandstones vary from extremely thin wedges up to 11 mm thick. The grade is fine to medium sand and the fossils are scarce but scattered generally throughout the sandstone.

b Up to 30 mm thick

A fibrous calcite bed, variable in thickness. One sample (Plate 16, fig. 3), has a trace bone-bed layer of quartz fossils and pyrite.

a 18 mm thick

A calcareous, sandy bone-bed laid on black shale. It has a shelly lower part and is silty at the top (Plate 16, figs. 4 & 5). One sample contrasts in being packed with coprolites in a thin sandy bed.

Shale, black, fissile with many bivalves.	0.15
Limestone, grey, massive with limestone shales at the top.	0.6
Shale and limestone, black with limestone shale and limestone at the base. Thickness was not determinable.	
Shale, black.	0.12
Limestone, fibrous calcite at the top and nodular at the base.	0.15
Shale, black.	0.6
Shales and limestones, poorly exposed though plentiful loose.	0.91

Richardson's Clough bone-bed must be from this horizon though not found *in situ*. In the samples on the beach, the bone-bed is found as part of a massive limestone. With the bone-bed there is an abrupt change to a coarse gritstone with a calcareous matrix. (Plate 16, fig. 6).

	metres
Limestone, limestone shale and shale.	0.9
The limestone is dark grey unbedded. The 1st shales are bedded and unfossiliferous. Part of the black shale is bedded and some unbedded. It has much silty deposit which can be seen as thin alternating layers with black shale. There are occasional bone-bed fossils.	
Limestone, dark grey with bivalves, thickness was not determinable.	
Shale, black, fissile.	0.9+
Limestone, thin, sandy with scattered, well preserved vertebrate fossils.	0.025
Shelly mudstone.	0.12
Numerous shelly fragments in a mudstone matrix. The upper part is much more shelly (table 24). Quartz and bone-bed fossils are present scattered through the rock. There are fragments of Sully marl, especially near the base (table 25).	

Remarks

The bone-beds illustrate the varying kinds of bone-bed deposition. The lowest beds are examples of scatter bone-beds. The upper part has a greater amount of broken shells and rather more quartz and fossils though the proportions are similar in both samples (tables 24 & 25). On top of these beds the lithology changes to a sandy limestone though the scatter bone-bed content is retained.

In the shales above the second limestone there are thin trace bone-beds. A random 100 gms sample was broken down which proved to contain approximately 50% black shale, a substantial fraction of very fine sand and the rest silt. No fossils were noted.

The horizon known as 'The Clough' (Richardson, 1911, p.18) is an example of a part primary bone-bed (Plate 16, fig. 6).

Part 'a' of the main bone-bed, which is near the top of the exposure, shows changing conditions both vertically and laterally. In the lower typical bone-bed part of two adjacent samples (Plate 16, figs. 4 & 5), one, (fig. 5) is thinner and has a much stronger development of fine-grained, unfossiliferous matrix. In the upper part there is a change from an almost unfossiliferous siltstone (Plate 16, fig. 5) to a shelly, calcareous matrix with some scattered quartz and fossils (Plate 16, fig. 4). Traced laterally a short way, it is dominated by coprolites, a part-primary feature.

Part 'b' provides an example of a trace bone-bed (Plate 16, fig. 3) in a generally unfossiliferous calcium carbonate rock which has become fibrous, presumably by subsequent diagenetic pressure.

Part 'c', by its rippled nature, shows that current action was affecting the deposition. It again demonstrates that the bone-bed fossils are only found associated with the coarser deposits. The distinct break from bone-bed sand to black shale with bivalves and vice versa, occurs several times in this part of the bed.

Part 'e' has a mixture of primary and secondary features. It is unbedded, poorly sorted with a mixture of worn and unworn fossils deposited with random orientation. The minute fossils are well integrated with the larger ones and there are very few coprolites. Table no. 23 shows the high proportion of coarse sand present. With such a coarse and originally porous rock it is probable that the crystaline development was caused by silica rich fluid passing through the rock laterally or being squeezed upwards during compaction. The pyrite could be of similar origin. Scrins of calcite which cut across the consolidated rock must have been a later development.

Blue Anchor Bay, Tables 23, 24 and 25

Table 23, 'Massive grit'

	850+ microns	Fraction percentage	Deviation ± percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Deviation ± percentage	Totals in gms and percentage of 100 gms.	Percentage of residue
Quartz	19.00	77.30	0.943	28.29	88	1.171	29.05	88.0	3.353	3.87	70.13		1.84	74.12		82.03	83.96
Phosphatic	4.35	17.70	0.078	3.21	10	0.103	3.46	10.5	0.382	1.39	25.25		0.49	19.75		12.90	13.20
Pyrite	1.24	5.00	0.014	0.64	2	0.015	0.49	1.5	0.007	0.25	4.62		0.15	6.13		2.77	2.84
Totals in gms	24.59									5.51			2.46				

Table 24, Shelly base

	850+ microns	Fraction percentage	Deviation ± percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Deviation ± percentage	Totals in gms and percentage of 100 gms.	Percentage of residue
Quartz				0.10	0.7	0.023	0.76	5.1	0.044	10.34	45.5	2.901	0.86	12.9	0.364	12.06	20.6
Phosphatic				0.46	2.9	0.016	1.18	7.9	0.060	1.45	6.4	0.087	0.42	6.4	0.065	3.47	5.9
Rest				14.05	96.4	0.674	12.98	87.0	3.361	10.93	48.1	3.682	5.33	80.7	2.279	43.29	73.5
Totals in gms				14.57			14.92			22.72			6.61			58.82	

Table 25, Lowest base

	850+ microns	Fraction percentage	Deviation ± percentage	850-500 microns	Fraction percentage	Deviation ± percentage	500-250 microns	Fraction percentage	Deviation ± percentage	250-125 microns	Fraction percentage	Deviation ± percentage	125-63 microns	Fraction percentage	Deviation ± percentage	Totals in gms and percentage of 100 gms.	Percentage of residue
Quartz	0.15	0.93		0.02	1.12	0.004	0.39	9.16	0.454	5.22	83.28	3.481	0.12	8.48	0.071	5.95	19.46
Phosphatic	0.48	2.98		0.12	4.89	0.028	0.28	6.57	0.101	0.42	6.73	0.108	0.12	8.88	0.086	1.45	4.74
Rest	15.47	96.09		2.30	94.38	0.612	3.59	84.27	5.042	0.63	9.99	0.441	1.16	82.64	2.388	23.09	75.78
Totals in gms	16.10			2.44			4.26			6.27			1.40			30.47	

For explanation see text pp.204, 231-2.

Charlton Mackrell, Somerset, ST 417212, Richardson (1911, p.42)	metres
Shale, black.	0.1
Limestone, black, earthy, mixed with shale, slightly arenaceous with bivalves and fish remains.	0.1
Shale and similar limestone.	0.1
Limestone, dark grey, very shelly with fish remains.	0.075
Shale, black, fissile.	0.9
Limestone.	0.18
Shale, black.	2.1
Shale, black, arenaceous, micaceous, with numerous coprolites and fish remains.	0.2
Limestone, sandy, micaceous.	0.12
Sandstone bone-bed, hard, grey with fish, reptiles, coprolites and pebbles.	0.15
Shale, black and greenish with a nodular limestone.	1.2
Shale, sandy with pebbles and many fish remains.	0.075
Shale, black, non-laminated, streaked with white, sandstone layers.	0.45
Tea Green Marl.	

Langport, Somerset, SY 417272, Richardson (1911, p.50)	
Shale, black with a few gritty seams.	3.0
Sandstone, earthy with fish remains.	0.075
Shale, black and yellow.	0.18
Sandstone, grey, fine-grained with pebbles, coprolites and fish remains.	0.6
Shale, black.	0.012
Shale, black, fissile.	0.22
Shale, black with green marl and fish remains.	0.012
Tea Green Marl.	

Culverhole Point, Devon, SY 275893, Richardson (1906, p.40)	
Shale, black, earthy.	0.33
Limestone, dark grey, pyritic with bivalves and fish remains.	0.2
Bone-bed black shales, indurated, gritty, fills cracks in the Tea Green Marl. It contains fish remains and coprolites.	0.05

Discussion

The commonly held opinion on the origin of the Rhaetic throughout England and Wales is that the sea encroached rapidly across a low lying plain of continental deposits and salt lakes; and that the Rhaetian deposits were laid generally in shallow waters (Wells and Kirkaldy, 1956, p.332, Wills, 1950, p.92).

Black shale is the dominant deposit of the lower Rhaetic beds. It is accompanied by sand and siltstone and especially in the south-west by more calcareous deposits and limestones.

After the deposition of the black shales there was a general shallowing of the sea for the Upper Rhaetic deposits, accompanied by a decline in the marine fauna, its absence in many places, and elsewhere a reversion to the Keuper type of deposition (Kent, 1970, p.361).

During the period of the Lower Rhaetic a number of bone-beds and incipient bone-beds formed at certain horizons. In the sections examined it has been found that bone-bed formation coincides with the presence of sandy deposits. This fact has been generally confirmed by descriptions in the relevent literature.

There appears to be a direct comparison between the grade of the coarse sediment and the size of the bone-bed fossils. The fossils range from many cm long, down to the extremely minute. The largest are nearly always found in the pebbly part primary bone-beds.

In the secondary beds the range of fossil sizes is usually larger than the quartz grains present but finer particles contain finer fossils eventually down to the silt grade which, as a rule, is unfossiliferous. The conclusion is made that in the secondary beds the fossils are graded along with the rest of sediments.

Scales, fin rays and larger fossils are occasionally found in the black shales though their occurrence is rare and isolated. It is necessary to explain why the fossils should be preserved only in the coarser deposits. Ager (1963, p.197) pointed out that the number of organic remains found within a bone-bed is not the significant factor that it was once considered to be by theories based on catastrophic events, because, at any given interval, a whole generation has time to die before an appreciable amount of sediment has been deposited. This is also true during the deposition of the black mud, but in those conditions the vertebrate fossils were only rarely preserved. It is likely that the coarse sediments were not only coincidental with the gathering and sorting of the fossils but they also provided a medium for their protection after deposition. This has been previously suggested by Swinnerton and Kent (1949, p.36).

Denison (1956, p.389) describes the formation of a bone-bed by a process of the winnowing away of the finer material and the slow accumulation of a residual material over a lengthy period of time. This leaves the problem that some of the thickest bone-beds are found in the areas of greatest deposition such as at Blue Anchor Bay. If we can accept that it was possible for a supply of boney material to be available and incorporated contemparaneously, and preserved with the coarse content; then the problem of slow, condensed deposition does not necessarily arise. We can then explain the puzzling mixture of worn and unworn fossils in the part primary bed and the presence of both these primary and secondary features within the same bed.

Bennison and Wright (1970, p.282) outline the possible land areas at the time of the Rhaetic. They extended over the greater part of Wales and the London Brabant Massif in the east, with a few small islands in the Mendips and Bristol Channel districts. There are exceptional thick deposits of sandstone in the Bridgend district of South Wales (Francis, 1959, p.163) and some littoral, basal deposition around that region. However, the land areas are considered by Audley-Charles (1970, p.65) to have been only gentle uplands and he remarks on the absence of important sources of arenaceous deposits in the Bristol region and the diminished source of clastic element from the east. With the incoming of the sea over a peneplaned area there would be little deposition from the surrounding upland areas. It is likely that the Lower Rhaetic deposits will have been derived largely from the thick strata of previously deposited Keuper Marls. The change of colour from grey-green to black is considered to be due to the prescence of carbonaceous matter, anaerobic bacterial activity and reducing conditions leading to the formation of iron sulphides.

Samples of Tea Green Marl from immediately below the base of the Westbury Beds consist of clay grade material with small fractions of silt and sand. Rhaetic deposition, which is predominantly composed of fine sediments, could well be a resorting of the Keuper Marls into fine paper shales with layers of silt and some sandstones. Undisturbed black shales infer quiet depositional conditions but with the occurrence of bone-beds there are signs of current activity. The current caused by the incoming sea could remove the low lying areas of marl (Kent, 1970, p.361) and in doing so sort out the finer material leaving concentrations of coarser material including fossils. Thus the incursion of the Rhaetic sea could provide the current action responsible for the creation of a widespread bone-bed. Whilst erosion was occurring in some places, there is evidence in others, that small amounts of coarse sediment were being left in hollows and dried out cracks in the underlying marl. In some areas bone-bed sediments would be banked up comparatively thickly thus creating a widespread, but discontinuous bed.

Considering that there are bone-beds above the base, of the Rhaetic with a suggestion that there are two other peaks of bone-bed forming activity (text-fig. 1); it is possible that there will have been two other periods of disturbance and current activity, though not necessarily simultaneously, over the whole area. These may have been due to eustatic movements or crustal warping causing changing in sea level before the return to the shallower conditions of the Upper Rhaetic. The increased number of secondary bone-beds at these higher levels (text-fig. 1) indicates a greater tendency for the sorting and reworking of the deposits than at the initial marine invasion.

Hecker (1965, p.38) states that 'in shallow, agitated waters, changes in local conditions of life and concomitant sedimentation may occur very quickly and as a result strata formed under these changing conditions may be very thin.' A striking feature of many bone-bed exposures is that, in spite of their being thin, they display abrupt changes in their type of deposition. This can occur vertically as for example in the basal bed at Barrow-on-Soar or horizontally as is strikingly displayed at Penarth.

Part Primary bone-beds

The mixing of primary and secondary depositional features creates wide variation in the nature of bone-beds. One type are extremely fossiliferous, having very coarse deposits and large well-preserved vertebrate remains. Perhaps the best example being the well known bone-bed at Aust Cliff.

In others, the primary aspects of deposition are more concerned with the nature of limestones and their invertebrate faunas such as at Penarth (Plate 15, figs.4 & 5).

The boundaries between the different bone-bed categories are not clearly drawn and in some cases the secondary influences are stronger and the primary features less determinate. These, such as at Blue Anchor Bay (Plate 16, fig.5) and Barrow-on-Soar (Plate 14, fig.1) can only be classed intermediate part primary bone-beds.

Secondary bone-beds

All the bone-beds observed have shown some aspects of secondary deposition in the forms of fragmentation, abrasion and integration of the contents. In many of them, secondary features are almost excusively present and in examples from Wainlode Cliff (Plate 14, fig.3) and Chilcompton (Plate 16, fig.1) they are completely dominant.

Amongst the bone-beds noted (text-fig.1), in the three major bone-bed horizons the number of part primary beds declines upwards from 17 to 14 to 2 whereas the secondary bone-beds have the opposite trend upwards from 6 to 19 to 16. This shows that secondary features are more apt to occur at higher horizons which reflects the changing nature of subsequent current activity after the first marine invasion.

Scatter bone-beds

These could be aptly named fossiliferous shale. They are not obvious as such until a close inspection is made of the rock when the isolated fossils and sand grains are found scattered widely within them. At St Audrie's Bay there is thick scatter bone-bed of varied concentration though the amounts of quartz and boney fossils, which constitues the bone-bed content, are linked together as is shown in table no. 22.

In considering their origins it is significant that these scatter bone-beds are always found near above a part primary or secondary bone-bed horizon, especially where the bone-bed is thin or missing at that locality. Scatter bone beds are typically unbedded or poorly bedded which would suggest that they have not travelled far or that they have been rapidly deposited, preventing the grains from settling and orientating to develop fissility. In part primary and secondary bone-beds the quartz and vertebrate fossils are found in close association in a thick layer and if scatter bone-beds are a diseminated redistribution of this material before its cementation, it is likely that the current action also swept away a considerable amount of finer material which was re-deposited before there could be a resorting of the sediments.

Pellets and flakes of marl can often be found in the basal bond-bed, showing the association of these beds with the basal shales and underlying marls. An example occurs 3 cms above the base in the scatter beds at St. Audries Bay.

Trace bone-beds

These are confined to the finer grades of material. Much of the black shale contains layers of clean silt and, associated with them are thin layers and patches, even pellets of fine of medium grade sand. In most cases when the latter deposits are present, minute bone-bed fossils can be found with them. At Barnstone they occur only below and immediately above the bone-bed. The restriction of the trace bone-bed to the 25 mm above the bone-bed suggests that the fragments in the 25 mm have been derived from the underlying bone-bed, being resorted and redeposited. Traces of bone-bed which are found at the base of the Rhaetic could be directly associated with the wide-spread basal bone-bed as incidental material trapped in mudcracks, or left by currents which were piling up thicker bone-beds elsewhere. At other localities their presence is much more at random and not distinctly associated with a major bone-bed, an example is at Barrow-on-Soar. If these trace beds developed independently of a major bone-bed it is feasible that the current action which sorted the sand also sorted the fossils and these are incipient secondary bone-beds.

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Secretary's Report for 1975-76

1975 was an important year in the history of the Society. It had been intended from the earliest days that charity status should be sought, and now at last, during the twelfth year, this had been achieved, and the Society had become a registered charity.

Fourteen meetings were held during the year, comprising six field excursions, five lectures, an Annual General Meeting together with a Collectors' Meeting, an Extra-Ordinary General Meeting and an Annual Dinner.

There was a record attendance of over 100 at the Annual General Meeting in March. Business was quickly dispatched; the serving Officers were re-elected for a further term, and Mr. H. Key was elected to Council to replace Mr. E. T. Winks who had resigned upon removal from the Midlands. A vote of thanks was proposed to Mr. Winks for his services to Council.

Before the commencement of the meeting, exhibitions had been arranged, and when the business was completed, members were free to circulate and enjoy the many interesting collections. Throughout the evening there was a continual inflow of new arrivals, and Mrs. M. Taylor and her efficient company of assistants were busily occupied in serving tea.

Again, Mr. J.H. Sykes held a rock sale, his stall concealed by a dense throng. His profit on this occasion was £27.20, and this he later donated to the Society's Trust Fund.

A list of exhibits follows:

1.	A.E.G. Allsop	Northumbrian holiday.
2.	P.G. Baker	Microscope slides of micromorphic brachiopods from Westington Hill Quarry, Gloucs.
3.	M. Beaumont & J. Allen.	The Geology of the Colne Valley.
4.	M. Boneham	"Housekeeping on the Wilder Shores of Geology" - How did they live? What did they eat?
5.	H. B. Briggs	"Looking Back." Mammalian tooth, large ammonite, calcite crystals, drilling bore section, Jurassic crinoid, agate boulder, cave pearls.
6.	B. & J. Cantrill	Selection of rocks from the Isle of Mull.
7.	C. Champion	Collection of orthid brachiopods.
8.	E. & J.R. Clough	Miscellany - echinoids, granite, mica schist.
9.	R.E. Elliott	Borehole core of volcanic ash from Coal Measures near Epperstone.
10.	N. & J. Ellor	Limestone fossils and plaster casts.
11.	H.G. Fryer	Rock specimens from Charnwood Forest.
12.	D. & E. Hanford	Collection of flints from the beach near Sheringham, Norfolk.
13.	P.M. Hanford	*Teleosaurus* from the Alum Shales.
14.	R.C. Gratton	Mixed fossils and Blue John slices.
15.	P.F. Jones	Authigenic gypsum from Pleistocene till, Boulton Moor, Derby.
16.	N. Leiter	Some common gemstones.
17.	R.W. Morrell	Recent and fossil mollusca.
18.	D.M. Morrow	Lava from Lanzaroti, Canary Isles.
19.	G.A. Naylor	Collection of quartz, calcite and fluorspar in variety.
20.	H.R. Potter	Sediment sampler used to measure sediment content of small rivers.
21.	E. Ramsell	Mineral specimens from Cannington Park Quarry, Somerset.
22.	G.S. Robson	Holiday in Scotland, Graptolites, haematite, metamorphics.
23.	M. Stanley	Ipswichian mammalian fauna from the Beeston Terrace, Boulton Moor, near Derby (Derby Museum)

24.	J.H. Sykes	Geological quiz.
25.	Dept. of Geology Univ. of Nottingham.	Examples of fossil preservation. Assortment of geological books from the Dept. library.
26.	The Editor	Back issues of the Mercian Geologist.

In April, the last indoor meeting of the session was held. Mr. J. G. Ford, (Department of Liberal Studies in Science, University of Manchester), described his study of Palaeotides. His paper on this unusual subject was shortly to be published in the Mercian Geologist, and the introductory lecture was welcomed.

The weekend excursion early in May was centred in the Ingleton area and the party of 40 were for the most part accommodated in hotels in Ingleton. The leader, Dr. A. C. Walton of the Department of Geology, Trent Polytechnic, provided transport for the bulk of the Derby and Nottingham members, and also drove the minibus. Before retiring for the first night, he fixed up his screen, gave an introductory talk on the geology of the area, and illustrated it with superb slides. With this energetic start he set the pace for a most delightful and impressive two days in sunny karst country, dramatic caves and waterfalls on the one hand and spectacular limestone pavements on the other, and a second showing of geological slides on Saturday evening. Indeed the enthusiasm of this indefatigable leader was so infectious that the minibus party extended the excursion by visiting Malham Cove on the homeward journey.

In June, Dr. F. Broadhurst of the Department of Geology, University of Manchester, met the party at Buxton to lead an excursion to the Goyt Valley and the Macclesfield area. After visiting Goyts Moss to examine exposures of Coal Measures, the party travelled to Kerridge to see a fine bed of bivalve escape shafts among the sediments. The final locality of the day was Axe Edge which brought to an end a most interesting and informative excursion.

Also in June, Dr. F. M. Taylor (Nottingham University) conducted one of his popular geological coach tours, this time to the Peak District. The outward journey ran northwards up the eastern side of the Pennines, and the return journey southwards down the western side. Coach excursions such as this are welcomed by members unwilling to commit themselves to a day's walking.

The July excursion to the Nuneaton area was led by Dr. W. A. Cummins, also from Nottingham University. The emphasis was laid on Cambrian sediments and ample time was allowed for a detailed study of these.

In September an Extra-Ordinary General Meeting was called. During the previous eighteen months, Council had held communication with the Charity Commissioners on the question of charity status for the Society. At last an agreement had been reached that charity status would be accorded when certain amendments had been made to the wording of the Society's Constitution. Council decided that the amendments were acceptable and called a meeting to obtain the approval of the Society. On 20th. September 1975 this approval was given and from that date the Society was recognised as a charitable institution. All the lengthy negotiations were carried out by Mr. R. C. Gratton, to whom the Society is extremely grateful.

Next day, Mr. D. N. Robinson, M.Sc., Resident Tutor, Nottingham University Department of Adult Education, met the coach at Tattershall, Lincs., and conducted a large party on a tour of the Fen area of Lincolnshire, culminating in a visit to Gibraltar Point. After hearing an account of the development of this most interesting strip of coast, members examined shingle deposits until it was time to leave for the return journey which was made through the undulating country north of the Fen. Most of the party found time to call into the new Visitors' Centre, which had much to offer.

The October excursion to Crich and Kilburn was led by Dr. D. V. Frost and Mr. G. J. O. Smart, both of the Institute of Geological Sciences. The imagination was captured at the first exposure, when the party was introduced to "Morley Muck", a material which did not belie its name but which was rich in well-preserved fossils. Later in the day there was a pleasant visit to Crich Hill.

The first indoor meeting was held in November when Professor C. Downie of the Department of Geology, University of Sheffield, lectured on "The use of Plankton in Stratigraphical Studies". There was a large audience present who received the lecture with great interest.

Early in December, Dr. M. A. Khan, Dean of the Faculty of Science, Leicester University, gave an excellent lecture on the subject of Magnetism and Geology. Again there was a large audience and a deal of discussion.

In January, a meeting was held in Matlock jointly with the Matlock Field Club. The speaker, Dr. F. M. Taylor, took as his title "Fossils of Derbyshire excluding Corals - well, almost! ", and dealt energetically with them to the delight of his enormous audience.

The eleventh Annual Dinner was held in February in the Wollaton Park Golf Clubhouse, where a large party enjoyed a pleasant evening arranged by Dr. R. B. Elliott.

The President gave his third Presidential Address in February. He took for his subject Sediments of the Kingston Brook Catchment, and gave an interesting description of the investigations carried out on sediments derived from varied soils.

There was great attendance at both lectures and excursions, and the Society is very grateful to the speakers, Mr. Ford, Professor Downie, Dr. Khan, Dr. Taylor, and to the President for an excellent session of lectures, to Dr. Waltham, Dr. Broadhurst, Dr. Cummins, Mr. Robinson, Dr. Frost and Mr. Smart for their splendid excursions, and to Dr. Taylor for his geological tour.

Eleven circulars were sent out in 1975, although during that time postage costs almost doubled and became a considerable drain on the Society's resources. It is a very great help that so many members are willing to distribute circulars and journals by hand, a very much appreciated service.

Membership remained reassuringly steady and there was a regular inflow of new members to offset the loss through removal from the area. The state of membership at the end of the year was as follows:

Honorary	Ordinary	Joint	Junior	Institutional	Total
2	257	120	20	107	506

Editorial affairs flourished during 1975 and the Editor succeeded in publishing Volume 5, No. 3 in September and Volume 5, No. 4 in December. At the Annual General Meeting he acknowledged the support which he received from the Society in his work, from manuscript readers, proof readers and from his efficient band of collators who reduced his costs by some £60 per issue.

Acknowledgement must also be given to Miss Susan and Miss Marian Taylor who kindly typed members' addresses for computerisation. The adhesive labels so produced greatly reduced time and labour in despatching circulars and journals, and earned the gratitude of both Secretary and Editor.

A valuable addition to the Society's resources was made during the year in the portable display unit designed and produced by Mr. M. F. Stanley, and intended for exhibition in libraries, museums and other public places throughout the East Midlands. The Society appreciates this means of publicising its activities. Mr. Stanley has kindly taken charge of its movements.

It remains only now to record the gratitude of the Society to Professor Lord Energlyn, our very good friend, and to the University body who provide us with our spiritual home.

D. M. Morrow,
Secretary.

THE MERCIAN GEOLOGIST

Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time 22 parts, comprising 5 volumes have been issued; the last, vol. 6, no. 2, in March 1977. The Mercian Geologist published articles especially on the geology of the Midlands of England, but other articles have been published which relate to Midlands geology or are of current interest to geology generally. Contents include original papers, review articles, biography, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

For Contributors:

Authors intending to submit manuscripts of papers for publication in the Mercian Geologist are asked to follow the format of papers included in a recent number of the journal, and if possible to provide two copies. As the journal is read by Members with a wide spectrum of geological interest and ability, authors are asked to ensure adequate introductions for their papers, particularly, if the subject has not been reviewed in the journal over the last few years. The paper should be complete in itself, without the need of the reader to refer to specialist journals not easily available to the average Member of this Society. It follows that the length of the paper may be greater than that published by some other journals but authors are asked to be as lucid and concise as possible and to avoid repetition.

Text-figs. normally occupy a full page of the journal, but part page diagrams can be fitted into the typed page. Double page diagrams have been published with a single fold but each printed page has to be folded by hand. The standard reduction by our present printing process is approximately × 0.75. Thus the optimum size for the original diagram, including space for caption, index and explanation if required on the diagram, should be 285 × 190 mm. (285 × 380 mm with a single fold). Greater reduction is possible but care must be taken with the original to ensure that at the final reduced size (230 × 155 mm; or 230 × 310 mm) the smallest letters are no smaller than 1 mm and that there is a similar minimum spacing between letters and lines. Bar scales (metric) should be provided as the exact reduction cannot be guaranteed.

Half-tone plates are reproduced at the original size, and should not exceed 230 × 155 mm. The quality of the published photograph depends initially on the quality of the original and it follows that the photographs submitted should be exactly as the author would wish them to appear in the journal - good contrast, in focus, adequate magnification and without distortion.

If there are any points of difficulty, please do not hesitate to contact the editor during the production of the manuscript. The Editor's sole concern is to produce excellent quality papers to be enjoyed by all readers. Please send completed manuscripts to the editor.

For Readers:

All parts of the journal are available for purchase and a detailed contents list will be sent on request. Current numbers of the journal are usually obtained by subscription: [22 parts issued in 13 years].

Ordinary Members	£4.00	Joint Members	£4.25
Institutional Members	£4.00		

Single Copies £2.25 (£2.00 Institutional Members; Other Members £1.50)

Complete volumes, 4 parts: £9.00 (£8.00 Institutions; Other Members £6.00).

Librarians in overseas libraries and geological institutions may take part in an exchange scheme organised by the Science Library of the University of Nottingham. About 200 institutions throughout the world receive the Mercian Geologist by sending in exchange, original geological periodicals.

Address: Editorial matters, manuscripts, exchanges, orders for back numbers:

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