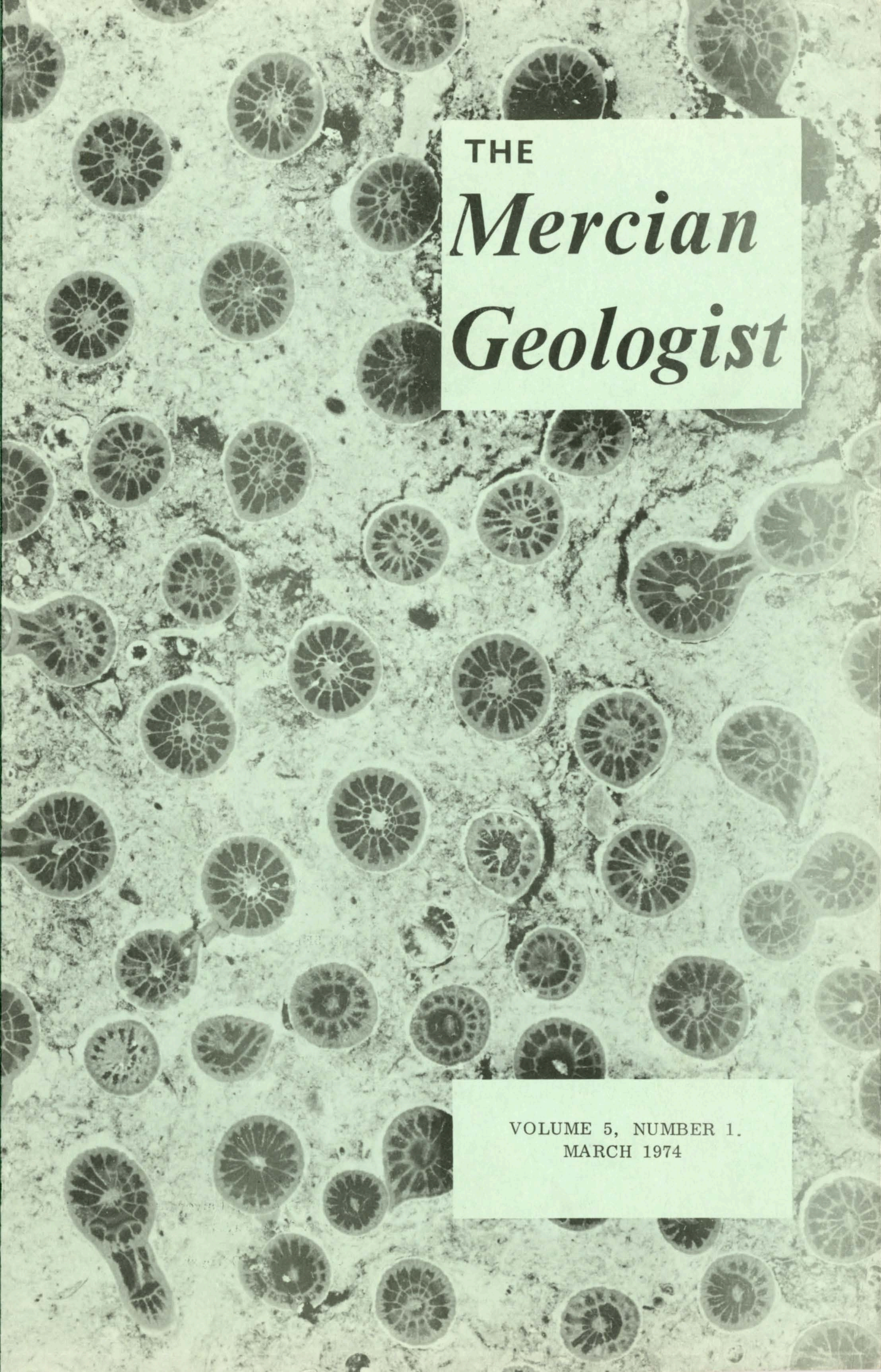

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Transverse section, X 7. Thin section prepared by T. Foster,

Photograph by D. Jones, Department of Geology, University of Nottingham.
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Carboniferous Limestone, D. zone, Coombsdale, Derbyshire.

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SKELETAL VARIATION IN COLONIAL RUGOSE CORALS

7th Presidential Address to the East Midlands Geological Society

5th February 1972

by

F.M. Taylor

Summary

Skeletal variation in a number of colonial Rugose corals from the Carboniferous Limestone of Derbyshire is described. The variation is attributed to the presence of corallites representing different stages of ontogenetic development, to genetic variation and the consequent appearance of phylogenetic trends, and to the effects of external environmental controls. Some types of extreme variation may be caused by pathological factors.

Introduction

A brief glance at any thin section cut from a colony of Rugose corals, (Plate 1, figs. 2, 4; cover of vol. 1, no. 1; vol. 3, no. 2; or vol. 5, no. 1 of the Mercian Geologist) may suggest that in any one colony, there is little variation to be seen between the morphology of one corallite and that of another, but with closer observation, differences become apparent. All the examples quoted above show variations of corallite size, usually indicated by differences of diameter of the corallites and small differences in the arrangement of the skeletal components. These include the epitheca or outer wall, the inner wall, if present, septa, tabulae, dissepiments and axial structures (text-fig. 1).

The first variation, that of size, is due to the development of new corallites within the colony. The life-history, or ontogeny, as recorded by the developing skeletal structures, is very rapid, and can only be examined satisfactorily by preparing serial sections cut at 0.5 mm. intervals or less, at the start of development. The second variation, which affects the adult corallites, may be due to evolutionary changes, which Lang (1923) referred to as coral trends and which could be controlled by genetic variation. Similar skeletal variation may be the result of external environmental factors. The morphology of certain rare corallites differs so markedly from that of their neighbours that other reasons must be advanced to account for this extreme variation.

It is proposed in this Presidential Address to illustrate these three types of skeletal variation and to conclude with comments on their taxonomic significance. The text-figs. 4 - 11, which illustrate the variations, are drawn from either thin coral sections or acetate peel sections cut transversely across, or longitudinally through, the coral tubes.

Mercian Geol. Vol. 5, No.1.
1974, pp. 1-18, 12 text-figs.
Plate 1, Cover.

EXPLANATION OF TEXT-FIGURES

Text-fig. 1

Terminology used in this address to describe the Rugose corals. The progression from fig. 1 to fig. 6 also illustrates the colonial trend, see text-fig. 10. p.13.

No particular species are illustrated. Figs. 4, 5 and 6 are transverse sections only.

T.S. = transverse section. L.S. = longitudinal section.

Text-fig. 2

Insertion of septa in solitary corals illustrating the zaphrentoid, or delayed method of insertion of minor septa. No particular species is shown and all figs. are transverse sections.

c = cardinal septum o = counter septum = counter lateral septum

a = alar septum m = minor septa

nos. 1, 2, 3, 4, and 5 are successive major septa.

Text-fig. 3

Insertion of all skeletal elements, including the simultaneous development of minor septa (cyathaxonid method). No particular species is illustrated and all figs. are transverse sections.

Letters and numbers as in text-fig. 2.

Figs. 5 and 6 are numbered on the right-hand side only.

Text-fig. 4
(p. 5)

Ontogeny of *Lithostrotion junceum.* Immature corallites (y) illustrating development from an early stage, (figs. 1, 2) to an early adult stage, about half the adult diameter, (fig. 11). The skeletal details of the parent corallite (P) has not been completely illustrated.

fig. 1 Initial bulge is illustrated with incomplete epitheca.

fig. 2 Epitheca is developing from opposite sides and one septum is present.

fig. 3 Epitheca developing mainly from one side and a single septum is present.

fig. 4 Incomplete epitheca.

fig. 5 Epitheca is complete and one septum is present.

fig. 6 Three septa shown and advanced separation of the young corallite from the parent.

fig. 7 A rare example of two young corallites developing almost simultaneously from the same parent corallite. A developing epitheca can be seen in one corallite and in the more advanced corallite there are seven septa and tabulae present.

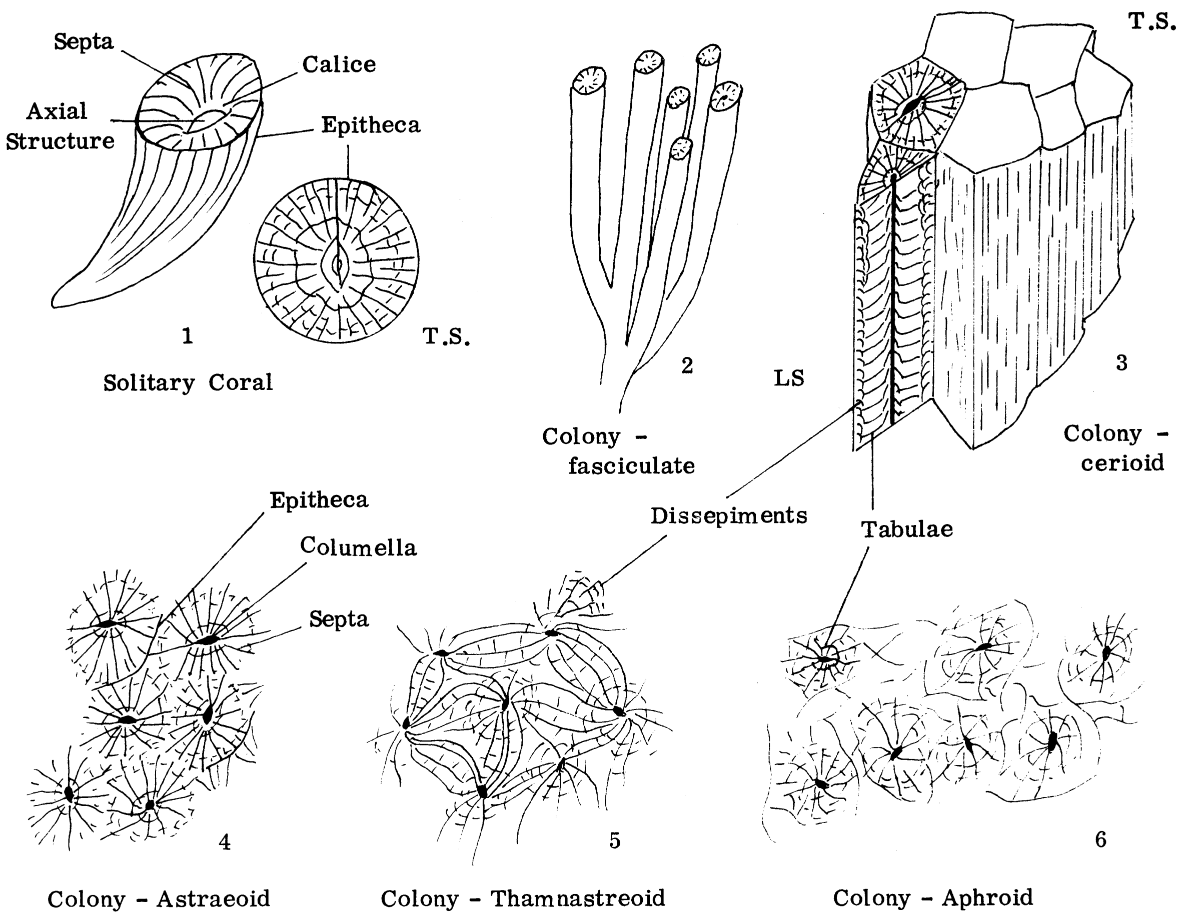
fig. 8 Seven septa are present.

fig. 9 In this corallite there are twelve septa, one of which is elongated with two short septa adjacent.

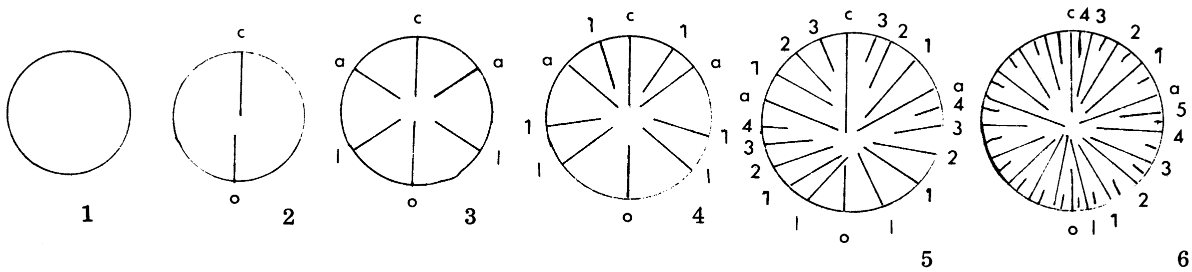
fig. 10 Separation of the young corallite has now been achieved. There are nine septa present, one elongated and tabulae can be seen.

fig. 11 In this young adult there are thirteen septa, one long and the columella is formed. Dissepiments are not formed in this species.

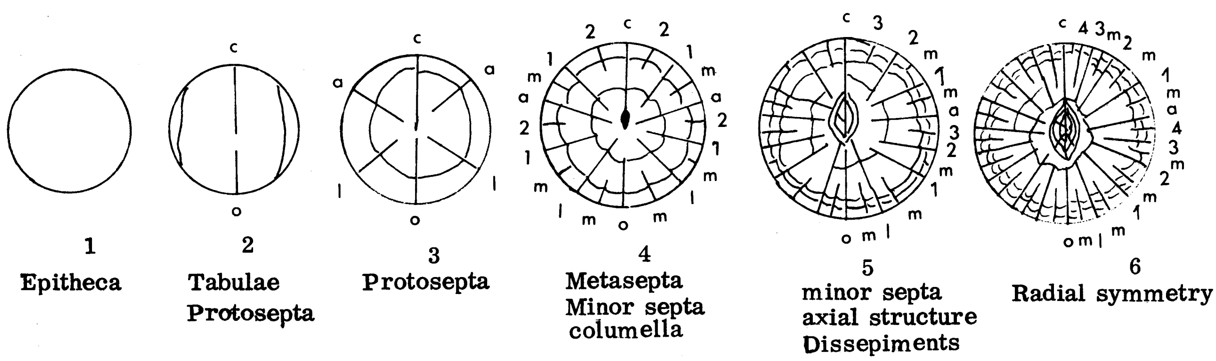
fig. 12 The longitudinal section shows the incomplete epitheca at the point of origin of the young corallite.



<u>Text-fig. 1</u>
Coral form and main skeletal elements of Rugose Corals.



<u>Text-fig. 2</u>
Transverse section of corallite, showing septal insertion with delayed minor septa.



<u>Text-fig. 3</u>
Transverse section of corallite - development of all skeletal elements, with simultaneous minor septa.

Ontogeny of Colonial Rugose Corals

(Text-fig. 4-9, Plate 1).

Almost all books on palaeontology, including treatises (Hill 1956, Dobrolyubova 1962, 197b) and popular works (Pinna 1972), faithfully reproduce diagrams (text-fig.2) to illustrate the insertion of septa in solitary corals. Little has been added to the pioneer work of Kunth (1869), Carruthers (1906) or Thompson (1883) or the later detailed work in various papers by Lewis, Ryder and Hudson. There was little information available about the development of the other skeletal elements (compare text-fig.3, with text-fig.2) or the growth of corallites in colonies when I commenced work on corals in 1953. Smith (1916, 1917) had described the ontogeny of *Lonsdaleia* and *Aulina*. Dobrolyubova published her work on colonial Rugosa from Russia in 1958 (English transl. 1964) reprinted with some additions in the Russian Handbook on Palaeontology (1962, English transl. 1971); Jull (1965, 1967) has made further contributions on *Lithostrotion* and *Lonsdaleia* from Australian and Canadian Rugosa. It is proposed to illustrate this review of the ontogeny of colonial rugose corals with special reference to the following species from Derbyshire. (Taylor 1957).

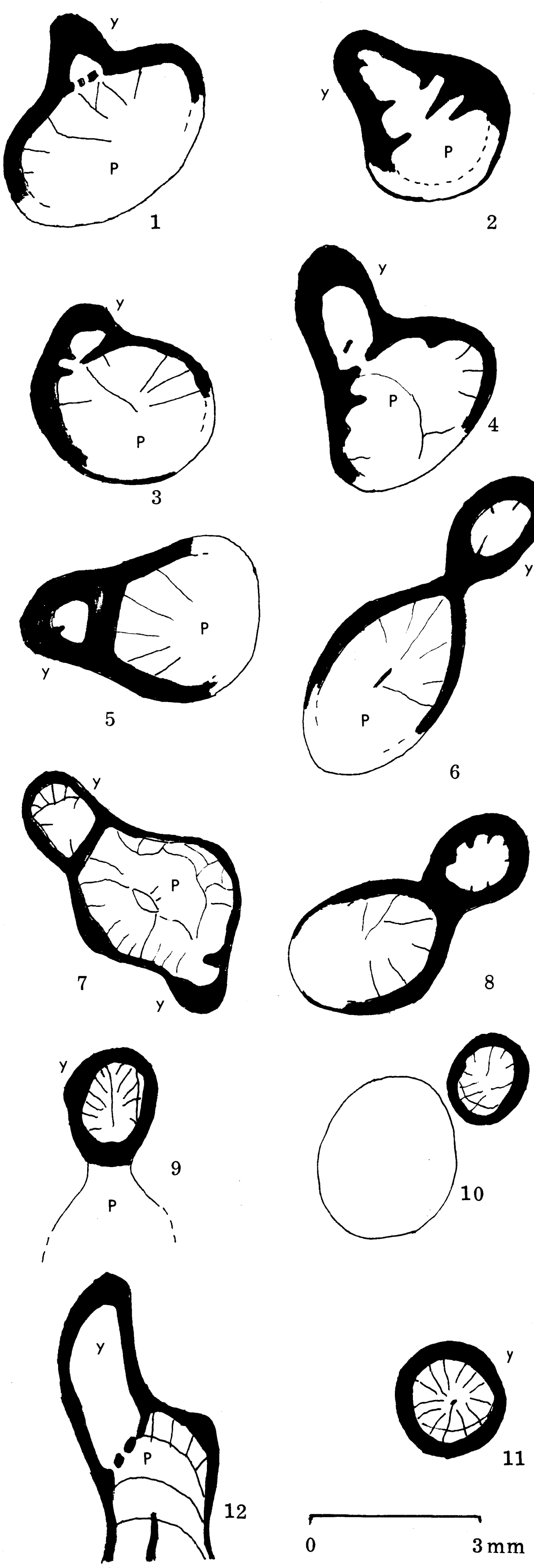
Lithostrotion junceum (Fleming) *Diphyphyllum lateseptatum* (McCoy) *Lonsdaleia duplicata* (Martin)	}	Branching or fasciculate colonies
Lithostrotion decipiens (McCoy) *Lonsdaleia floriformis* (Martin) *Thysanophyllum minus* (Thomson)	}	Massive, cerioid colonies
Palaeosmilia regia (Phillips)	-	Aphroid colony

Initial development of corallites

The appearance of some irregularity in skeletal structure usually precedes the development of the skeleton of a new corallite. In *L. junceum* (text-fig. 4, figs. 1, 2, 3) and in some colonies of *L. duplicata* (text-fig. 5, figs. 1, 2, 3) the corallite epitheca begins to bulge outwards. The regular septal plan of the other corals and most colonies of *L. duplicata* becomes disrupted by the appearance of an open area, devoid of septa or dissepiments, close to the epitheca. The same type of open structure occurs in an angle of the epitheca of the cerioid *L. decipiens* (text-fig. 6, fig. 1) and within the extracalicular structures of the aphroid *P. regia* (text-fig. 9, fig. 1). In some specimens of *L. duplicata*, the skeletal thickening of the inner wall extends towards the periphery of the corallite (text-fig. 6, figs. 9 and 10) forming the initial platform for the new polyp. One or two skeletal elements, basal tabulae, may cross the newly designated area. As the new polyp begins to secrete its own skeletal structures they replace those of the parent in this area and it can be considered that the soft body of the new polyp has displaced that of the parent.

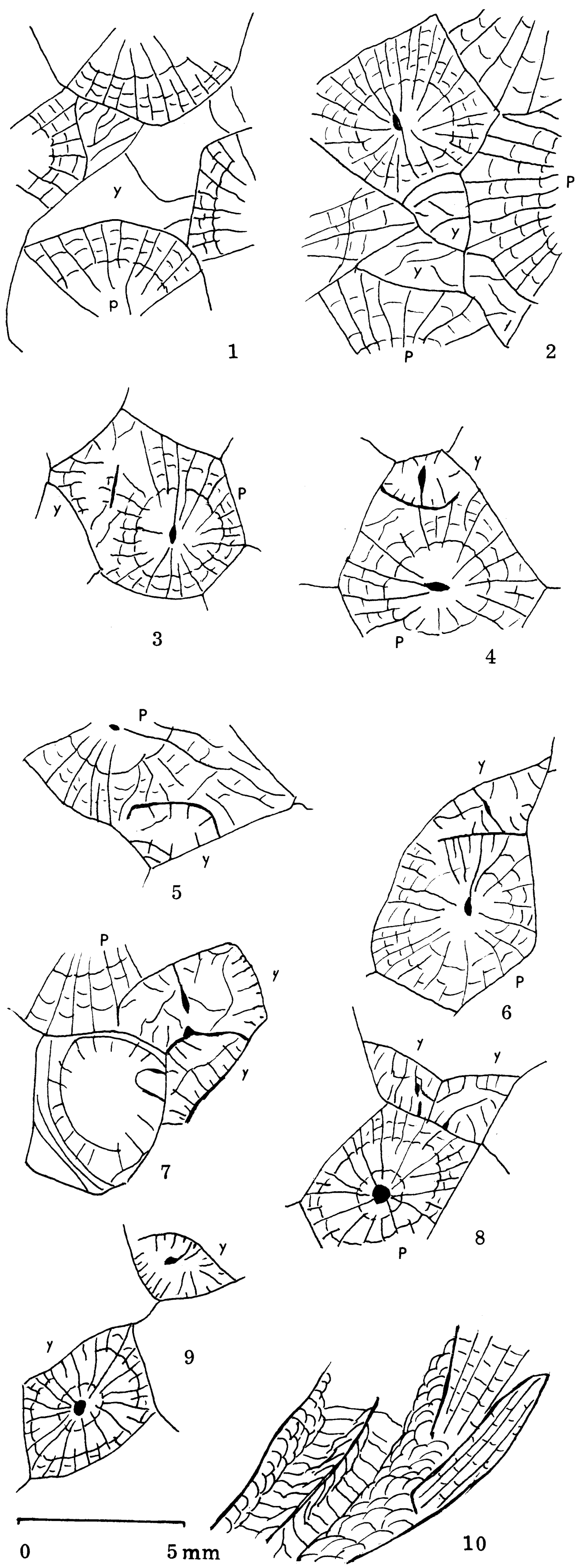
Tabulae

Although not always the first new element to appear, the tabulae are amongst the first to be secreted in all the colonies, preceding the epitheca and the septa. The initial tabulae are often irregular in shape, making distinction between septa and tabulae difficult in the early stage. Regular shaped tabulae are a feature of *Diphyphyllum* (text-fig. 8, fig. 2) from an early stage, new tabulae being small replicas of the previous ones. In the other corals the tabulae eventually attain the adult characteristics, gradually increasing in diameter. If two or more series of tabulae are formed, as in *L. decipiens*, *L. decipiens*, or *D. lateseptatum*, the inner set appear before the outer set(s).



Text-fig. 4

Young corallites of *L. junceum*.
See p.2.



Text-fig. 5

Young corallites of *L. decipiens*.
See p.8.

The epitheca

The epitheca of the new corallite is developed in two parts. First of all there is the continuous upward growth of the original epitheca. As there is no break in the growth of the structure close to the developing new polyp, it must continue secreting the epitheca, after it has replaced the parent polyp, in exactly the same position as before. The second stage is for a new epitheca to be secreted around the remaining periphery of the new polyp separating the new polyp completely from the parent. In *L. junceum* the old epitheca bulges outwards (text-fig. 4, figs. 1, 2, 3) whilst the new structure crosses from one side of the bulge to the other, or commences from both sides of the bulge, meeting on the centre (text-fig. 4, fig. 4). Growth is initially fastest on the outside wall and the result is a cup-shaped depression for the new corallite (text-fig. 4, fig. 5). As growth continues at a more uniform rate, a cylinder is formed which gradually becomes separated from the parent corallite (text-fig. 4, figs. 7, 8, 9, 10). This method of increase applies to other fasciculate species including *L. duplicata*. The new wall in the cerioid species may commence from a point along the straight section of the parent epitheca and grow across the angle of the parent corallite to join up with the epitheca on the opposite side, producing a polygonal tube. (text-fig. 5, figs. 3, 4, 5, text-fig. 7, fig. 2.) It is not uncommon for the new epitheca to appear within the parent dissepimentarium and then extend outwards (peripherally) towards the parent epitheca, again enclosing a small polygonal tube. The resulting enclosure is now occupied by the new polyp developing its own skeletal structures. The wall separating the two individuals is maintained by both at an equal rate of growth and contact is maintained throughout the length of the corallite, producing the massive coral structure. The new epitheca commences fractionally after the first tabula has been laid down, so that there is always skeletal continuity between the parent and the new corallite at its apex (text-fig. 5, fig. 10). In *Diphyphyllum* new walls commence from the centre of the old calice and grow outwards towards the old epitheca. If two new polyps are formed, the new wall will bisect the old calice. As many as four (three and the original?) new polyps may appear together, resulting in the simultaneous development of four new tubes (text-fig. 8, fig. 1). An epitheca is not developed in the aphroid colony of *P. regia*.

The septa

The first septa frequently appear before the epitheca is compete. In *L. junceum* and in some other fasciculate species, the new septa appear first of all on the outside wall, as this structure develops more quickly and is of greater length than the new epitheca. A single long septum has been seen in a corallite, but usually the first group, made up of 5, 6, 7 or 8 septa, appear together. Text-fig. 4 illustrates the development of septa in *L. junceum*. Within 5 mm. of growth, up to two-thirds of the adult number of septa may be present. Initial growth of septa in corallites which eventually attain large diameters may be relatively slow, there being less than half the adult number in *P. regia* at the 10 mm. stage. If the minor septa are strongly developed in the adult, they will alternate with the major septa at an early stage (text-fig. 5, fig. 7), but frequently the appearance of the minor septa is delayed. As the adult number of septa is approached in *L. junceum* or *L. decipiens*, the rate of septal development slows, allowing one to see the appearance of two septa on either side of an elongated septum (text-fig. 4, fig. 4, fig. 9, (text-fig. 5, fig. 9). Through further successive serial sections the two short septa are seen to develop to normal septum length, with two further small septa taking their place on the cardinal side. In *L. junceum*, where the minor septa develop very late, if at all, one may conclude that the small septa are short major septa and that the cardinal septum lies between them. *In L. duplicata* (Text-fig. 6, fig. 5) and *P. regia* (text-fig. 9, fig. 2) the cardinal septum may be diagnosed when there are about 15 major septa present. The identification of the alar septa is more difficult, but once the cardinal septum has been identified, two other positions of septal insertion can be recognised in the septal plan. (text-fig. 6, fig. 7, text-fig. 9, fig. 2).

The late appearance of minor septa is characteristic of *L. junceum* and *D. lateseptatum*, where the minor septa are seen only in the corallites with the largest diameters. Again, only the normal adult corallites of *L. duplicata* and *Thysanophyllum minus* possess minor septa. The small *L. decipiens* may well develop minor septa before all the major septa are present or the epitheca complete. Minor septa are developed simultaneously with the major septa in

P. regia, which eventually attains the largest diameter and possesses the largest number of septa of any of the colonies studied. This difference in the time of appearance of the minor septa is also a feature of some solitary corals. (Hill, 1938)

Thus the insertion of major septa in colonial corallites follows the same tetrameral pattern that has been described for solitary corals (text-fig. 2) but in the colonial corallites septa are initially developed at a far faster rate.

The inner wall (text-fig. 6)

Of the genera referred to in this address, *Lonsdaleia* and *Diphyphyllum* develop an inner wall. In *Diphyphyllum*, the structure appears with the formation of an inner series of tabulae with vertical edges, separated from the epitheca by an outer series. In longitudinal section, the appearance of the inner tabulae is rectangular or box-like and it is the vertical continuity of the sides of the box which produces the inner wall. The special mode of division of this genus ensures that the inner wall develops within a few mm. of corallite growth. In *Lonsdaleia*, the inner wall develops in a different way. The junction of the tabulae, dissepiments and septa is thickened and as growth continues, the rate of increase of diameter of this thickened area is less than that of the epitheca. Text-fig. 6, fig. 8 - 12, show the commencement and development of an area of thickening which will result in a new set of corallites. The continued development of these corallites would follow a course similar to that portrayed in figs. 4 - 7 (text-fig. 6). The space between the epitheca and the inner wall, the dissepimentarium, thus enlarges, as upward growth continues, with the formation of large blister-like dissepiments. In the cerioid species, *L. floriformis*, the diameter of the corallite increases more slowly and the inner wall is really only well developed in the oldest corallites.

The columella (text-figs. 4 & 5).

A columella is developed by *L. junceum* and *L. decipiens* and is one of the last structures to form in the corallite. In colonies where the columella is strongly developed in the adult corallites, the cardinal septum becomes elongated across the centre of the corallite within the first few mm. of growth but may appear later in corallites of other colonies. The cardinal septum may be permanently attached to the columella and at a later stage be joined by the counter septum and some of the other major septa. The typical septal plan of the genus *Lithostrotion* is now evident. At a later stage, and in those colonies with a weakly developed columella, the major septa, including the cardinal septum, become detached leaving the columella as a rod-like axial structure.

If the columella fails to grow for any reason after it has been formed, it is doubtful if a subsequent columella is an extension of the cardinal septum. Colonies with an incipiently developed columella in the corallites show that the structure develops from the centre of the inner set of tabulae and is not in contact with the cardinal septum, which is withdrawn towards the periphery of the corallite. Such structures usually continue through a few tabulae before ending at the under-surface of another. A similar 'columella' may begin at a higher level. There are therefore two possible methods of formation of the columella.

In *Diphyphyllum*, no true columella or axial structures are formed. An incipient columella, formed from the centres of the tabulae, may be present in occasional corallites of a colony. A dividing wall, indicating the early stages of division of the corallites of *Diphyphyllum* may be mistaken for a columella.

The axial complex (text-figs. 6 & 7)

More complicated than the columella, the axial structure is made up of median plate, conical tabellae and the septal lamellae. Of the corals reviewed here, an axial structure is a feature of *L. duplicata*, *L. floriformis* and *Thysanophyllum*. As with the columella, the first element to appear is the elongated cardinal septum (text-fig. 6, fig. 5) and

Explanation of text-figs. continued.

<u>Text-fig. 5</u> Ontogeny of *Lithostrotion decipiens*. Immature corallites (y) illustrating development from an early stage, (figs. 1, 2,) to an early adult stage, (fig. 9). Parent corallites are marked with the letter, P.

fig. 1 An open space exists between corallites, one or two basal tabulae are already present.

fig. 2 A rare example of three young corallites grouped together, with complete epitheca and a few tabulae.

fig. 3 More usually an incomplete epitheca can be detected and new septa are already present.

fig. 4 Epitheca is now almost complete, new septa are present including 1 long septum with swollen axial end (columella) and two short adjacent septa.

fig. 5 The epitheca is incomplete but seven septa and tabulae are present.

fig. 6 The epitheca is incomplete. 12 - 13 septa are present including joined cardinal and counter septa with columella in the centre.

fig. 7 Two young corallites are illustrated with complete epitheca. Minor septa are evident in the youngest corallite and a columella is present in the oldest.

fig. 8 Two young corallites with complete epitheca.

fig. 9 Two young corallites, the oldest has a dissepimentarium and is about $\frac{3}{4}$ adult size.

fig. 10 The longitudinal section shows the incomplete epitheca at the point of origin of young corallites.

<u>Text-fig. 6</u> The ontogeny of *Lonsdaleia duplicata*. Immature corallites (y) illustrating development; extracalicular gemmation figs. 1 - 7. Development within the dissepimentarium to an advanced stage, figs. 8 to 12. Figs. 1 - 7 from the same colony; figs. 8 - 12 from the same corallite.

fig. 1 Epitheca is incomplete but their are five or six septa present.

fig. 2 Epitheca is complete and an outward bulge is evident. Approximately 7 septa are present.

fig. 3 Outward bulge has commenced although the epitheca is incomplete. 6 septa can be seen.

fig. 4 Isolation is now imminent, 13 septa, one of which is elongated, tabulae and the first dissepiment can be seen.

fig. 5 The inner wall is now complete separating the tabularium from the dissepimentarium. Tabellae attached to the long septum indicates the start of the axial complex.

fig. 6 Same corallite as fig. 5, with additional tabellae.

fig. 7 Same corallite as fig. 5, separation is now complete and a small axial complex has formed. Note the small septa adjacent to the long septum.

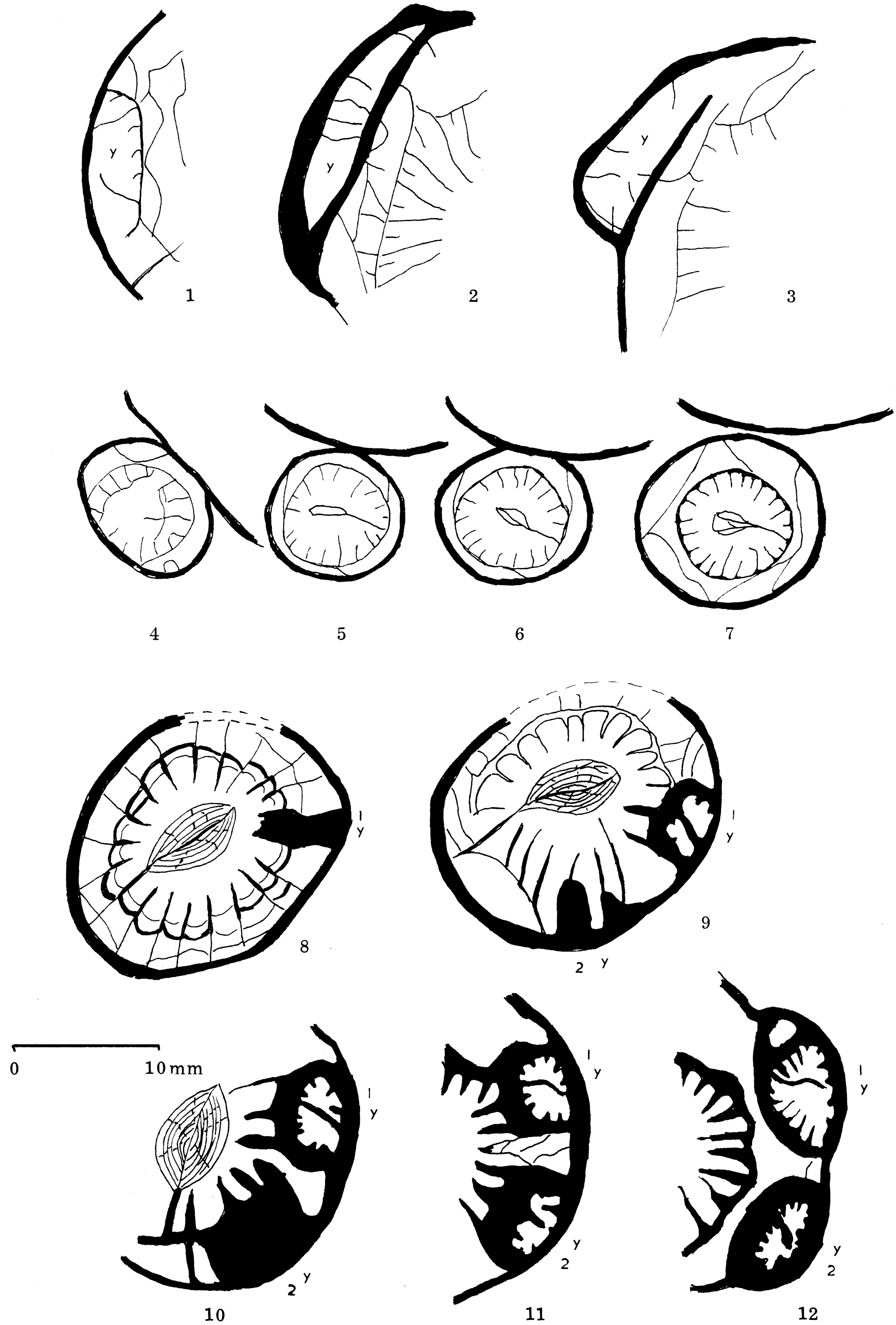
fig. 8 Corallite 1 - A thickened basal tabula is formed between two septa.

fig. 9 Corallite 1 - Epitheca is complete and the first few septa are present.
Corallite 2 - Basal tabula develops as thickening around a group of septa.

fig. 10 Corallite 1 - There are now 11 septa including a joined cardinal-counter septum.

Corallite 2 - First few septa formed.

/contd. p. 10.



Text-fig. 6

Young corallites of *Londsaleia duplicata*

Text-fig. 6 Contd.

fig. 12 Corallite 1 - 16 septa are present including a long septum with short septa adjacent.

Corallite 2 - 15 or 16 septa present.

Further development as figs. 4 to 7.

Text-fig. 7 Ontogeny of *Thysanophyllum minus.*

fig. 1 New epitheca appears.

fig. 2 Epitheca is still incomplete but 12 septa are present.

fig. 3 Epitheca is now complete with 16 septa one of which is elongated with short septa on either side.

fig. 4 Epitheca is complete at an earlier stage than fig. 3. 6 septa are present one of which is long.

fig. 5 Further septa are added and the inner wall develops.

fig. 6 Development of the axial tabellae.

fig. 7 Loss of the axial tabellae.

figs. 4-7 from the same corallite.

Text-fig. 8 Development of new corallites in *Diphyphyllum lateseptatum.*
fig. 1. Group of 3 corallites, showing the epitheca best developed in the centre. Separation of the corallites is imminent.

fig. 2. Longitudinal section to show the origin of the epitheca from the centre of the tabularium.

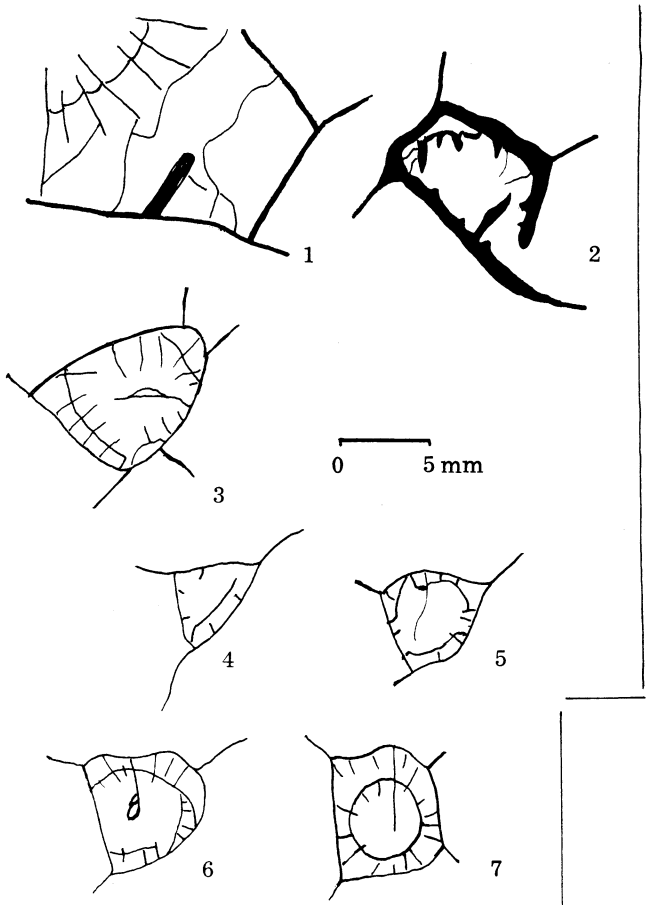
Text-fig. 9 The ontogeny of *Palaeosmilia regia.*
figs. 1 - 4 are ontogenetic stages of the same corallite.
c = cardinal septum in the cardinal fossula.
a = alar septum in the alar fossula
o = counter septum.

Explanation for Plate 1

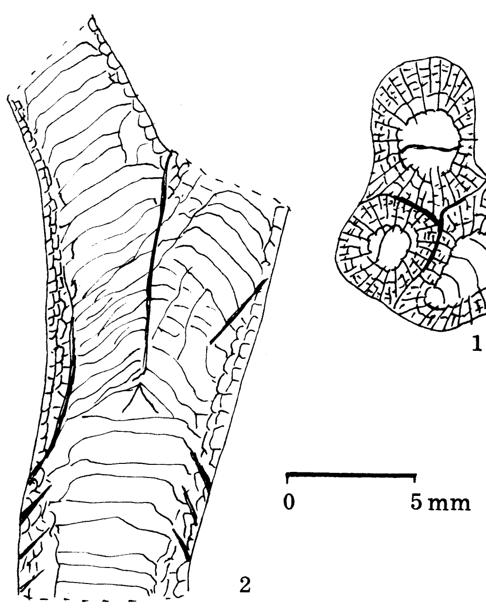
Transverse and longitudinal sections of *Lithostrotion decipiens.* Figs. 1, L.S., fig. 2, T.S., of a variety with conical inner series and wide flat outer series of tabulae.

Fig. 3, L.S., fig. 4, T.S., of a variety with flat, wide inner series and poorly developed outer series of tabulae.

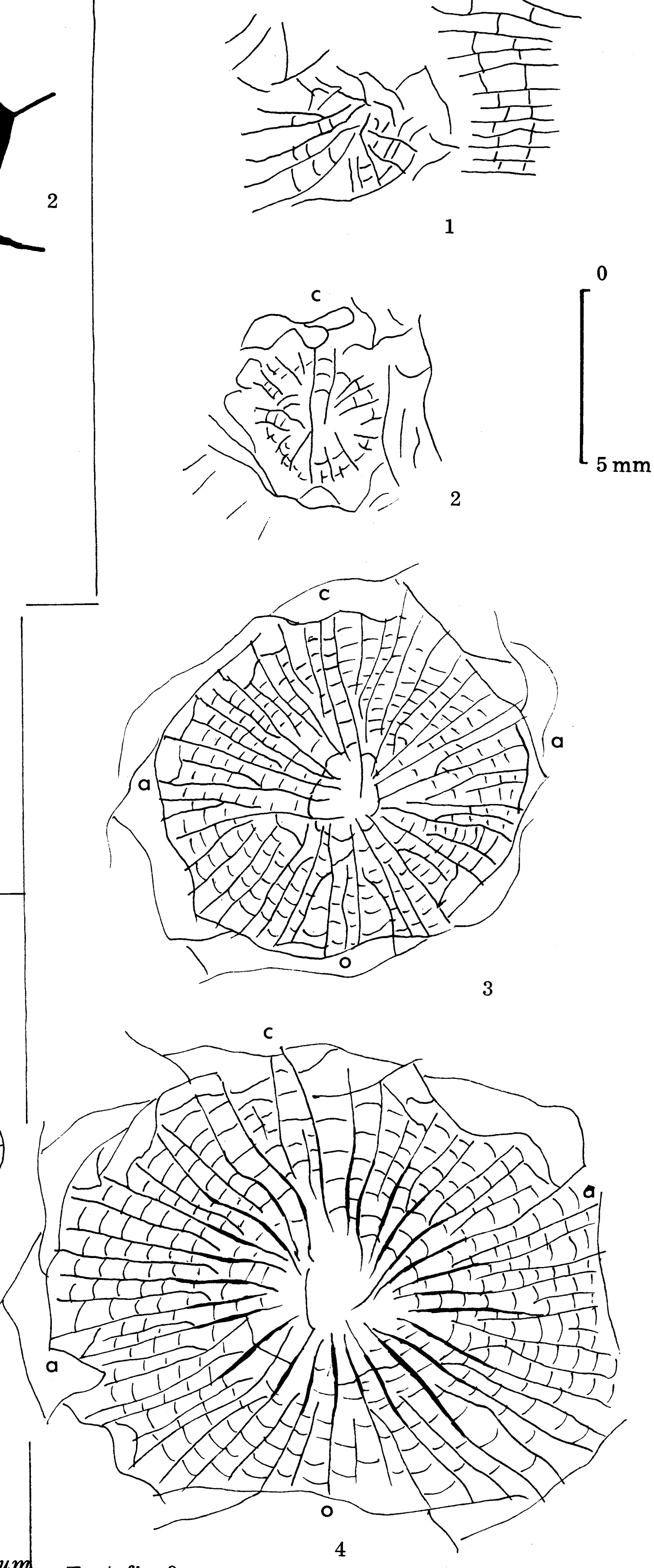
Fig. 2 shows the incipient development of the astreaoid trend. The white patches on the photograph is the mineral ankerite.



Text-fig. 7
Young corallites of *Thysanophyllum minus*



Text-fig. 8
Development of the epitheca in *Diphyphyllum lateseptatum*.



Text-fig. 9
Young corallites of *Palaeosmilia regia*.

not the counter septum, as stated by Smith (1916). A single tabella is often located at the axial end of the long septum. In *L. duplicata*, this stage is reached at about the time the new corallite separates from the parent. In the cerioid species, the same stage is reached after the appearance of the 12th major septum and before the formation of the dissepiments. The median plate eventually becomes separated from the cardinal septum and further tabellae and the septal lamellae are added. The development of the axial structure is very slow in most colonies of *L. duplicata*, despite the increase in diameter, compared with the faster development of the structure in the cerioid species, *L. floriformis*. Specimens of the genus *Thysanophyllum* follow the same type of development as indicated for *L. floriformis*, but before the corallite is halfgrown (as indicated by the diameter) the axial structure becomes less well developed and in the adult it will compare with the early stages of *Lonsdaleia*.

Dissepiments

The last elements to appear in the corallite are usually the dissepiments. Initially one row will be present but others are added as the diameter of the corallite increases. In *L. junceum*, the diameter of the adult corallite is rarely greater than 6 mm. and dissepiments are not formed. Specimens of *L. decipiens* display an increase in the number of dissepiments in the angles of the corallites. Corallites of *Lonsdaleia*, develop small elements close to the inner wall and large blister-like structures against the epitheca. The maximum development of dissepiments is seen in *P. regia*, where they comprise the extracalicular tissue of this aphroid colony. It is in the area of the dissepiments that most new corallites of the colonial Rugosa are formed.

Rate of development of new corallites

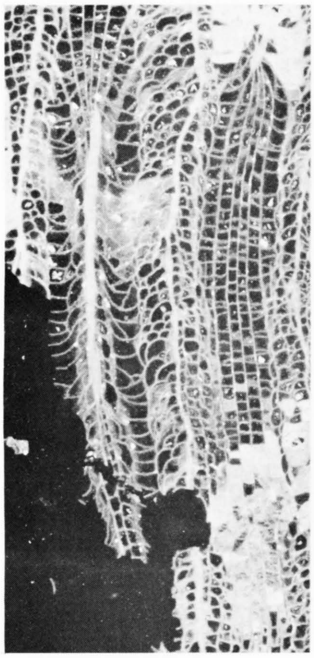
Initial development of the skeletal structures is rapid in all the species studied. This would be followed in some species, for example *L. decipiens* and *L. junceum*, y an almost complete cessation of septal insertion or increase in diameter, growth being restricted to increase in length of the corallite and the addition of new tabulae at regular intervals. The diameter and number of septa in such corallites is relatively constant within the colony. Other species continue to insert new septa into the corallite and increase its diameter as upward growth continues, but the addition of septa and the increase in diameter occurs at a much slower rate than in the initial stage. This is the mode of skeletal development in *L. duplicata* or *P. regia*. Text-fig. 11 illustrates these two rates of development. It follows that there will be maximum variation of diameter and number of septa in the corallites of colonies where there is continued slow increase of size.

Certain colonies, for example *L. junceum*, produce new corallites at specific levels within the colony, resulting in the long parallel tubes of a phacelloid colony. New corallites are formed continuously in other species, for example *L. duplicata*, two corallites often being produced simultaneously, resulting in the formation of a dendroid colony.

It may be possible to define the attainment of the adult stage by stating the minimum diameter above which the initial period of rapid growth has ceased. The diameters calculated for some of the species referred to in this paper are indicated on text-fig. 11.

Variation in the morphology of the adult corallites

Having determined variation which results from the growth of immature corallites, attention can now be concentrated on variations which occur in the mature corallites of the colony. New polyps are produced by budding, an asexual means of reproduction, which should result in the development of identical adult corallites. In the colonies studied, this was seen to be far from the truth. Lang (1923, 1938) described adult variation as the result of evolutionary trends and those relevant to the colonial species studied are summarised as follows and illustrated in text-fig. 10.



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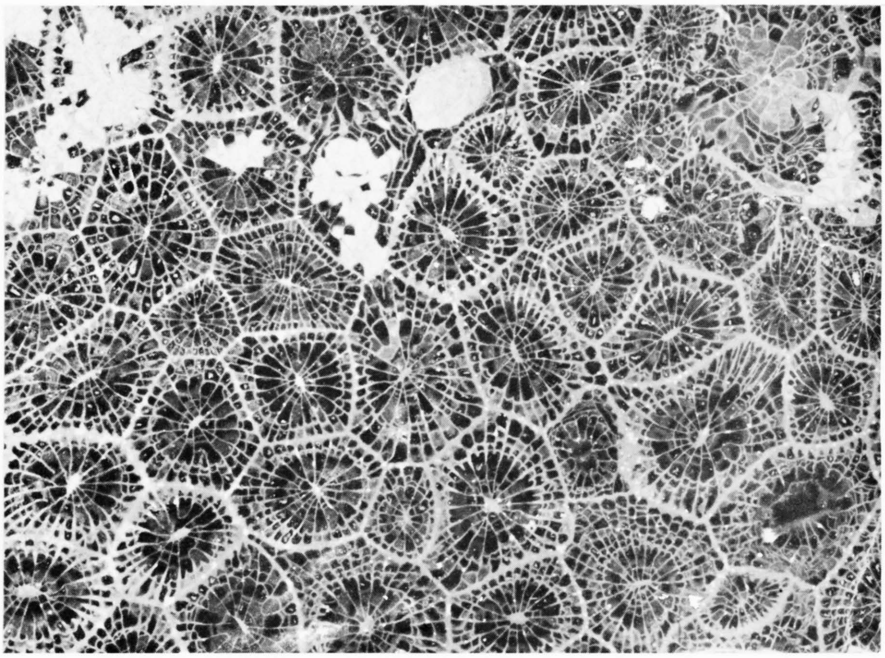

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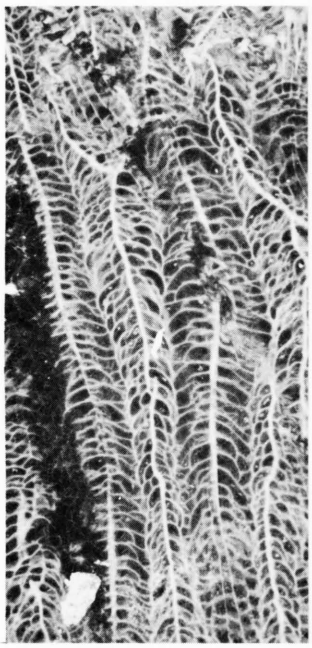

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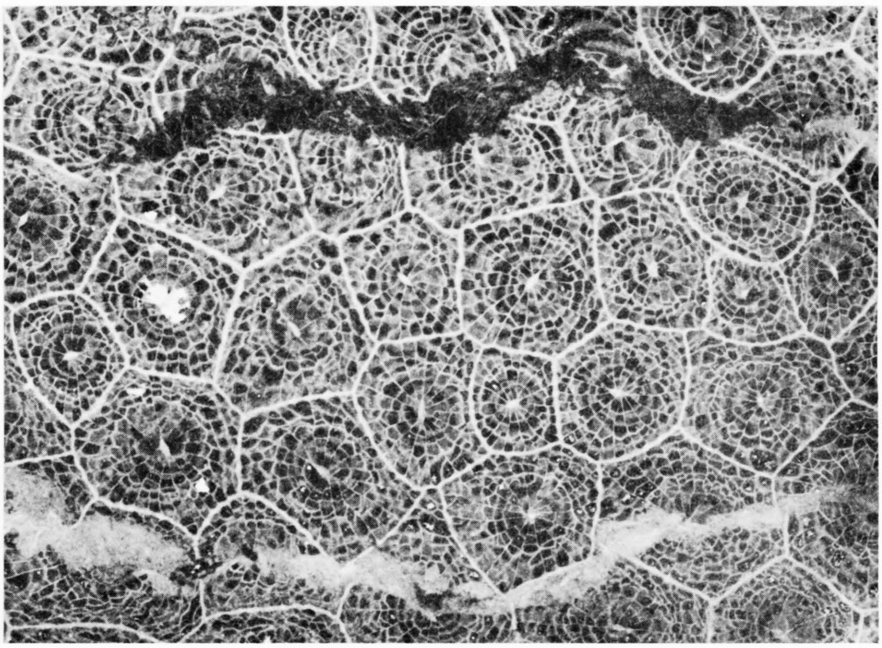
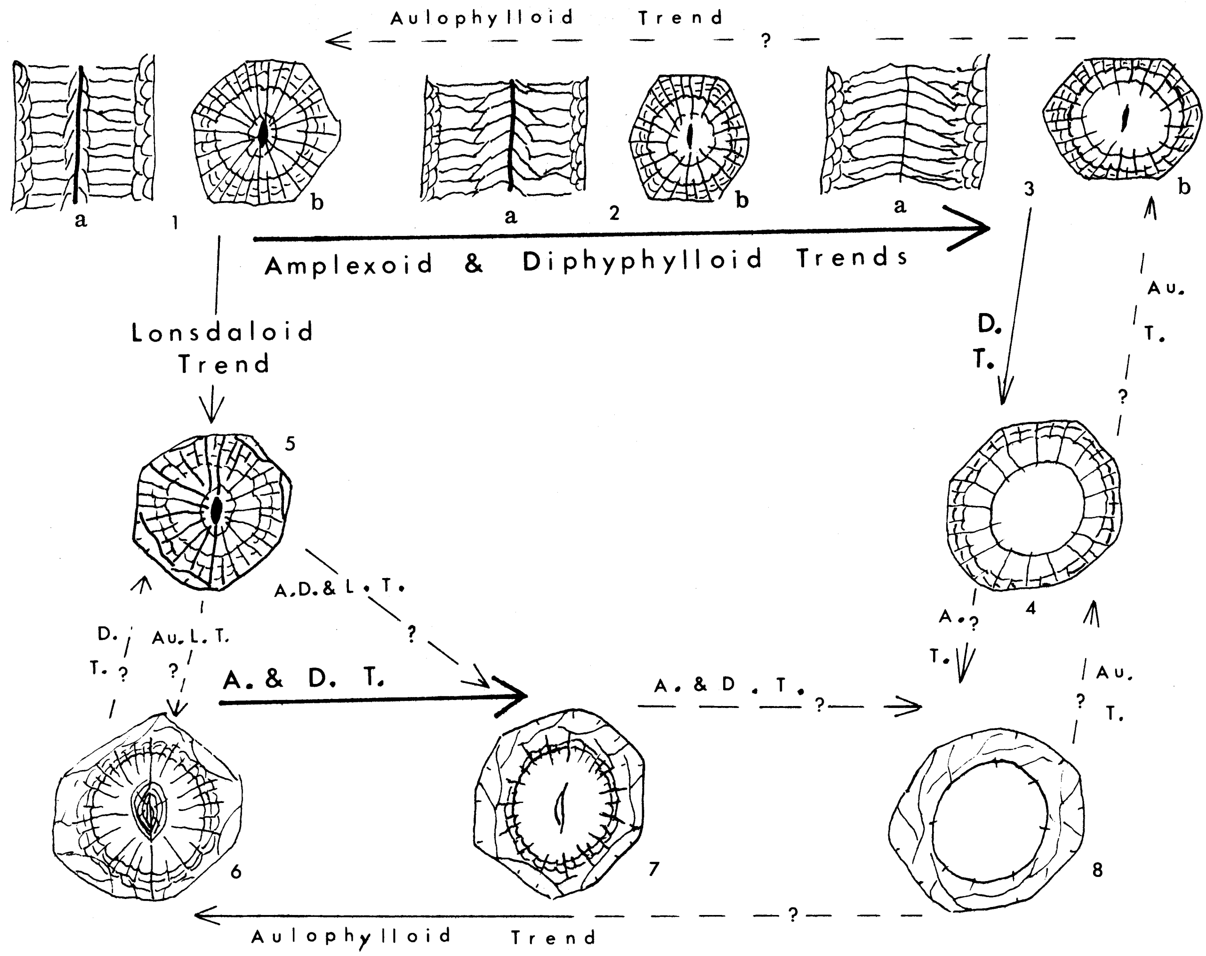


4

Transverse and Longitudinal sections of *Lithostrotion decipiens*



Text-fig. 10. Evolutionary trends noted in the colonies studied.

Explanation

A = Amplexoid Trend — Au = Aulophylloid Trend

D = Diphyphylloid Trend — L = Lonsdaloid Trend

——► indicates, with large lettering, the **main routes** of morphological change.

figs. 1 to 2 to 3. Loss of columella and the septa fail to reach the axis of the corallite.

figs. 6 to 7 Loss of axial structure and the septa fail to reach the axis of the corallite.

——► indicates, with large lettering, the **minor routes** of morphological change.

figs. 1 to 5 (direct) Acquisition of dissepiments.

figs. 3 to 4 The end member 4 is very rare in colonies mainly composed of corallites similar in morphology to figs. 1 and 2.

figs. 7 to 6 It is often difficult to be certain of the direction of the trend, compare with 6 to 7.

— — ► indicates, with small lettering, the reverse, **theoretical routes**, but with the exception of the route from figs. 4 to 1, **said to be possible by Smith and Lang,** the routes have not been proved.

Axial length of the septa

In the standard corallite, (text-fig.10, fig.1a, b) the major septa extend from the epitheca to the centre (axis) of the corallite, joining with, or ending adjacent to, the columella or axial structure if present. In many corallites, the major septa fail to reach the centre and the columella or axial structure is isolated in the centre (text-fig.10, fig. 2, 3). This is the amplexoid trend.

Peripheral length of the septa

If the major septa are not in contact with the epithéca, but are separated from it by the presence of large blister-like dissepiments, the corallites are said to be affected by the lonsdaleoid trend (text-fig.10, fig. 5).

The axial structure

Lang considered that the genus *Diphyphyllum* differed from *Lithostrotion* in the absence of an axial structure and any weakening in the development of the columella or axial complex is referred to as the diphyphylloid trend. The columella can vary, from a cylindrical shaped structure extending throughout the corallite to a thin discontinuous plate. If the axial complex is affected by the same trend, the median plate is weakly developed and sinuous when seen in cross-section, becoming indistinguishable from the irregularly shaped tabellae. The tabellae and septal lamellae decrease in number (text-fig.10, figs. 2, 3, 4; 5, 6, 7).

Conversely, the acquisition of an axial structure occurs in a few corallites of *Diphyphyllum*, where the upturned central section of a tabula continue upwards for a few centimetres and in *Thysanophyllum*, where the axial structure persists in mature corallites.

The tabulae

In the genus *Lithostrotion* the presence of a strong columella is usually associated with an inner series of conical tabulae. Those of the outer series are broad flat discs. Corallites with a weak columella usually possess a wide flat inner series and a narrow flat outer series of tabulae, often incompletely developed. (Compare text-fig. 10, figs. 1a, 2a, 3a; Plate 1, figs. 1-4).

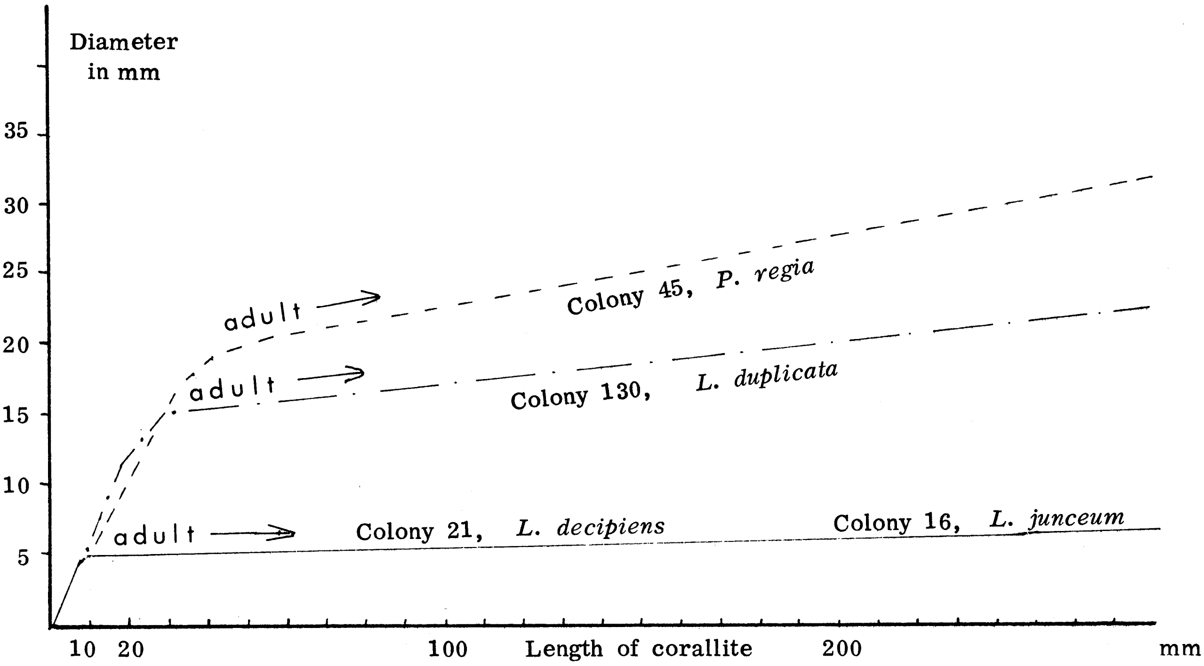
The epitheca

According to Lang, colonies originated by means of a trend which initially produced branching or fasciculate colonies from related solitary species. The next stage (text-fig.1, fig.3) is the production of the massive cerioid colony and then, by disappearance of the epitheca, the more complex astraeoid, thamnastreoid and aphroid colonies evolved (text.fig.1, figs. 4, 5, 6). There is some doubt that this series can be demonstrated, but the only variation of the mature corallites which is attributed to this trend is the breakdown of the epitheca in some corallites of *L. decipiens*, and the presence of confluent septa. This change results in the development of the thamnastreoid colony. In most areas of the colony where this variation occured, there was also deposition of ankerite, but it has not been ascertained which came first, the mineral or the extraordinary skeletal structure.

Certain colonies situated in isolated positions often showed different colonial forms, usually cerioid in the centre and fasciculate at the outer edge.

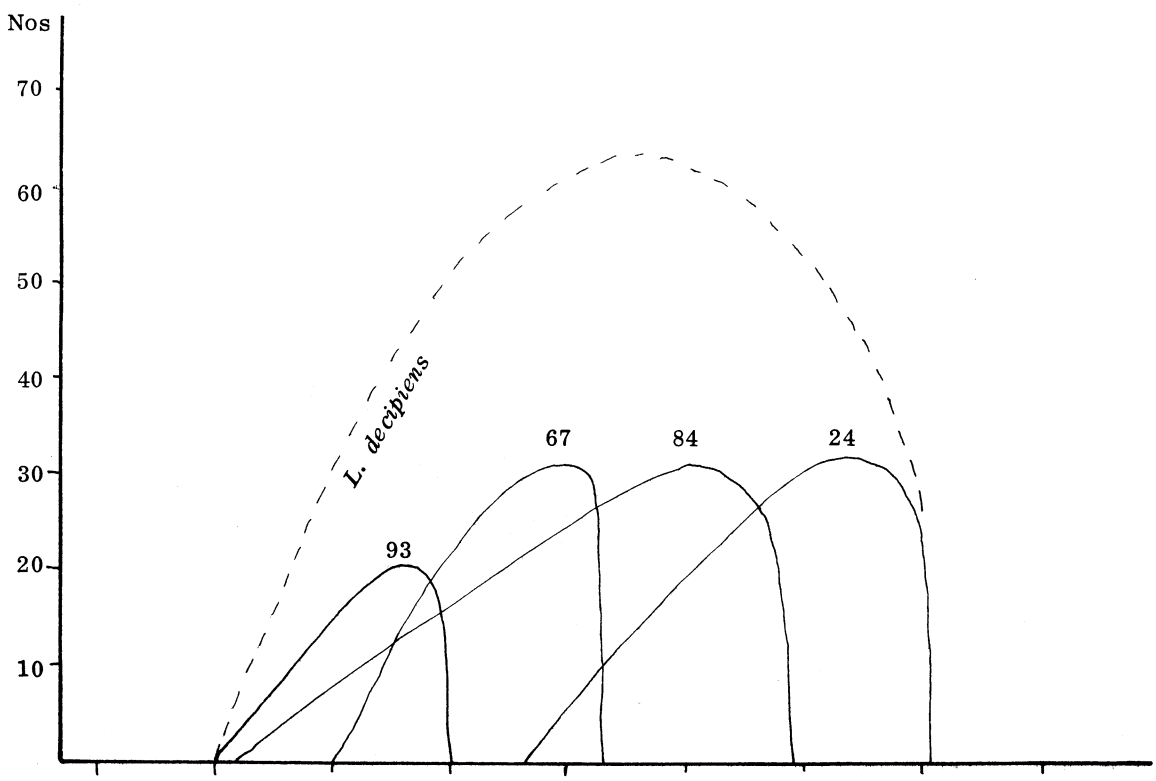
Other possible variations, which might affect colonies but which were not particularly apparent in those studied, would be concerned with the shape of the corallites, the development of fibrous skeletal tissue and the production of more complex microstructures of the skeletal elements (Hill 1956).

The main variations affecting the adult corallites in *Lithostrotion* were those concerned with the septa (amplexoid) the columella and the tabulae (diphyphylloid). The development of



Text-fig. 11

A comparison of increase of corallite diameter and length, showing initial rapid development. Graphs for *L. junceum* and *L. decipiens* are so similar that one line represents both species. Colony numbers refer to specimens in the author's collection.



Text-fig. 12

Frequency distribution curves of diameters of corallites of colonies of *L. decipiens*. Young corallites are excluded. Skew is due to most corallites having maximum diameter (See fig. 11). No single colony has maximum variation indicated by graph for the species as a whole.

lonsdaleoid dissepiments was a minor variation. The main skeletal differences seen in *Lonsdaleia* and *Thysanophyllum* affected the axial structure. The morphology of *Palaeosmilia regia* was remarkably constant.

The effect of the environment

In a previous presidential address, (Taylor 1972), the coral environments of Derbyshire were examined in detail. The main form of coral reef during the Lower Carboniferous Period was considered to be the patch reef. Colonies on the fringe of the patch, or located in an isolated position, are the ones that show the most variation within the colony. Those in the centre of the patch reef, the usual position for colonies of *Palaeosmilia regia*, exhibit the least amount of variation. So far no objective testing of this observation has been attempted and the possible effects of erosion on the edges of the patch reefs prior to fossilisation, removing the more variable colonies, has not been considered.

Extreme skeletal variation

So far, the morphological variation described from a single colony has been shown to be within certain limits and could be considered to be the result of a trend causing increase change away from a norm. In a number of colonies of *L. decipiens*, one or two corallites showed extreme variation (text-fig. 10, fig. 8). The incipient development of thamnastreoid corallites associated with ankerite may be an extreme example of variation. This type of variation is not characteristic of the species and there is no sign of the intermediate type of colonial development, the astreoid colonial form. The development of confluent septa is characteristic of the genus *Orionastraea*.

Elsewhere in the colony can be seen the extreme development of the amplexoid and diphyphylloid trends affecting the septa, columella and tabulae (text-fig. 10, fig. 8). The result is a corallite composed essentially of an epitheca, dissepiments and flat tabulae. Such corallites are far outside the expected variation of the species, let alone the colony. There is no circumstantial evidence available to blame the environment for this extreme variation. Instead one must consider the possibility of peculiar gene mutation which has emphasised the trend producing the diphyphylloid corallites. It is possible that this extreme variation could be the result of pathological factors affecting the polyp.

Comparison of variation in different colonies of the same species

From the examination of a number of corallites of different colonies of the same species, it can be seen that the morphology of the skeletal elements may be relatively constant in one colony, whilst another may display considerable variation. The point is best illustrated by taking one variable, for example the diameter of the adult corallite and producing a frequency distribution curve. The curves for a number of colonies of *L. decipiens* have been plotted on text-fig. 12. A comparison of the curves showing the distribution of the diameter of adult corallites for colonies 67 and 84 illustrates the greater variation of this character in colony 84 compared with 67. Similar graphs have been produced for other variables, including the number of septa and the spacing of the tabulae.

Many colonial Rugose coral species have been named with reference to specimens composed of a small number of corallites. This is particularly true of McCoy's species described from specimens from the Carboniferous Limestone of Derbyshire, Ireland and the north of England. (McCoy, 1849). It is clear from the above discussion that, with only a few corallites on which to base the description, insufficient information may have been available for the complete variation of the species to be appreciated. Many colonies should be studied before the description of a species is attempted.

Summary of Conclusions

Increase in the size of a colony, by the production of new corallites, can take place in more than one way in a species, although one method may be dominant. *L. junceum* demonstrates epithecal budding, the polyp developing a bud outside the ring of tentacles (extratentacular gemmation). *L. duplicata* may produce buds in the same way but more usually the bud or buds develop within the tentacle ring and within the dissepimentarium (intracalicular gemmation). Development in this marginal (peripheral) area is standard for the massive colonies of *L. decipiens*, *Lonsdaleia floriformis* and *Thysanophyllum minus* which rarely produce more than one new individual at a time from a single parent. *Diphyphyllum* is exceptional in that division takes place in the axial position, resulting in the production of multiple corallites. The generic separation of *Diphyphyllum* from *Lithostrotion* would be justified on this evidence alone.

The skeletal tissue of new corallites is not completely separated from that of the parent, there being approximately 1 mm. of common skeletal tissue at the base of the new corallite.

The study of the ontogeny of a number of colonial Rugose coral species indicates that, after initial rapid insertion of septa, the typical tetrameral pattern of septal insertion becomes established and the counter, alar and cardinal septa may be identified. Insertion of minor septa may be delayed until a late stage of the ontogeny, or may occur simultaneously with the major septa.

The orientation and initial development of the columella and the median plate of the axial complex is controlled by the cardinal septum.

The rate of development of the skeletal elements is very variable. In some species, (*Lithostrotion* sp.) the adult characteristics are present after only a few mm. of corallite growth, followed by many cm. of constant adult morphology. In others, (*Lonsdaleia* sp., *Palaeosmilia* sp.), after initial rapid development there is a continued but decelerated increase in the complexity of the skeletal structure, usually associated with an increase in diameter. Such colonies appear to be more varied in their morphology than those where increase in diameter ceases at an early stage.

Variation of adult morphology, although partly attributed to ontogeny of the corallites, may also be accounted for by phylogenetic trends. The relative importance of genetic and environmental factors cannot be ascertained, as both seem to produce a similar morphological result. Variation within the colonies is most marked at the fringes of patch reefs and in single isolated colonies.

Acknowledgements

Much of the original work forming the basis of this address was undertaken during the tenue of a Ph.D., grant by the (then) Ministry of Education from 1954 to 1957, under the supervision of Professor L.R. Moore at the University of Sheffield. Although research on the subject has continued since that time, I would still like to thank Professor Moore for encouragement during the early years and since that time, for his continued support.

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REVISION OF THE CRACOEIAN STAGE (Lower Carboniferous) IN THE BOWLAND-CRAVEN BASIN (U.K.) OF SEDIMENTATION

by

Donald Parkinson

Summary

Much geological research has been conducted by various workers in different parts of the Clitheroe-Slaidburn-Skipton region of Northeast Lancashire and the West Riding of Yorkshire. An attempt is made here to compare the results of these investigations, so far as they are concerned with the strata of *Beyrichoceras* (B_1 B_2) age and their relation to the older and younger beds. Among the matters discussed is the position of the boundary between B_1 and B_2 and also that between Lower and Upper B_2. It is argued that the available evidence necessitates unconformities, both below and above the Upper B_2 sub-zone. The latter break results from the Sudetian I earth movement of post early P_{1a} and pre-P_{1b} age. The break below Upper B_2 is of later date than the Cravenian movement (S_2/S_2D_1) which has not been proved south of Skipton and precedes Sudetian I. It follows a simple uplift, to denote which the name "Bowlandian" is suggested.

Introduction

The Cracoeian Stage of the Lower Carboniferous comprises the former *Beyrichoceras* (B) zone, which spans the interval from the *Bollandoceras hodderense* Beds (base of B_1) to the *Goniatites crenistria* (P_{1a}) zone at the base of the Bollandian. It approximates to the S_2 and D_1 zones (Middle Viséan). The Beds of B_1 and B_2 age have not proved amenable to subdivision into a sequence of goniatite zones which have the precision of those of the overlying Bowland Shales. Goniatites, though everywhere rare, are (except in the *hodderense* Beds) commoner in B_2 than in B_1, and, within B_2, more abundant in the upper than in the lower part. Attempts have been made with only partial success to subdivide the B_2 zone into Lower, and Upper B_2. sub-zones. In the Geological Survey Memoir, "Geology of the country around Clitheroe and Nelson" (Earp et al, 1961) the B_2 zone was treated as a single unit.

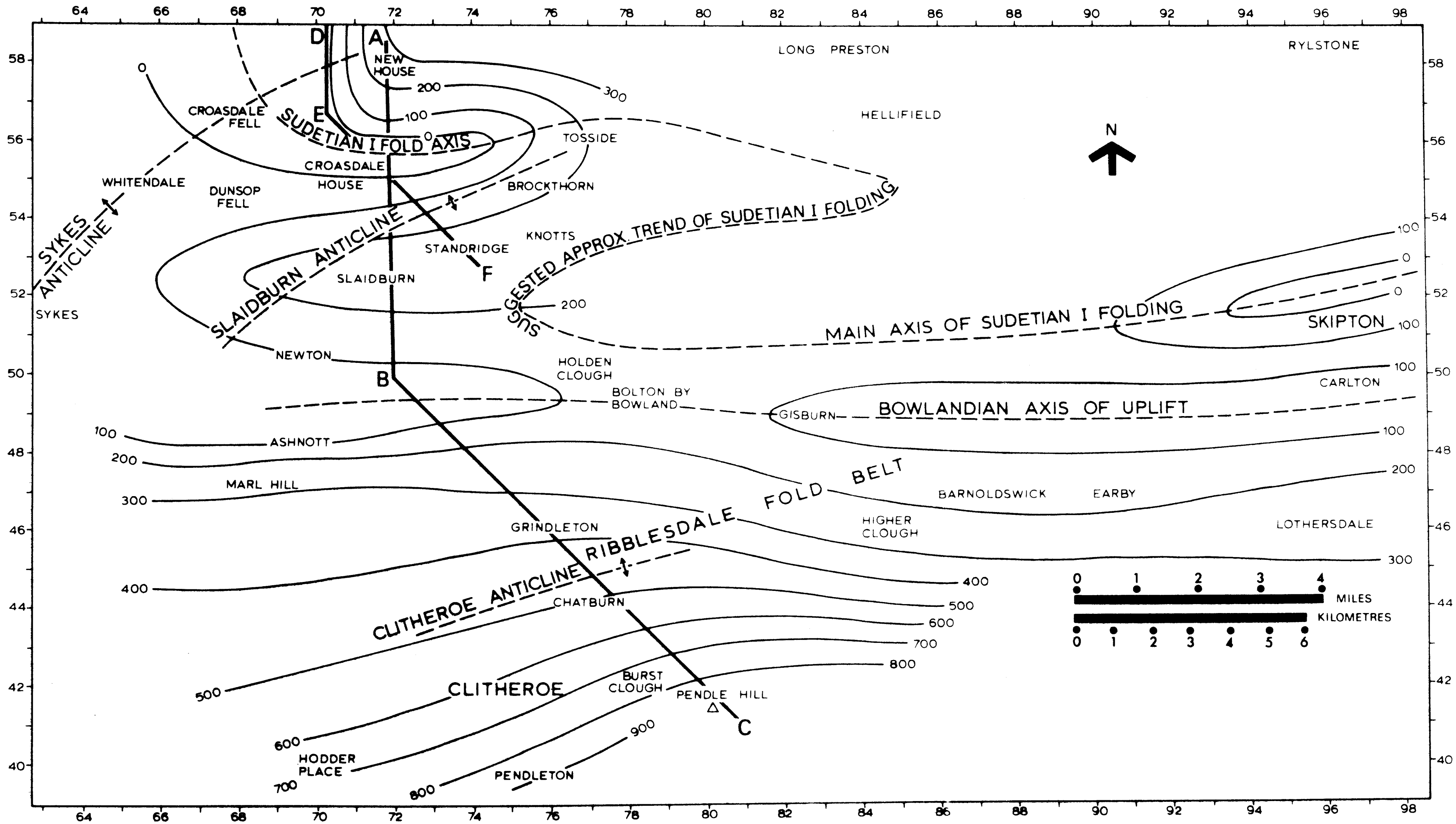
The present communication discusses the more important features of the Cracoeian Stage in the area covered by Sheet 68 (Clitheroe) and districts to the north and west of it (text-fig. 1).

The *Bollandoceras hodderense* Beds (lower B_1)

The basal 15 to 30 feet of the B_1 beds, where typically developed, are readily recognized in the field. They consist of very hard cementstone bands interbedded with calcareous shales. The lithology, which has been fully described in various papers, is unusual, the cement-stones in some of the bands displaying blotches of various colours. The goniatite species include *Bollandoceras hodderense* (Bisat), *Merocanites applanatus* (Frech) and at least one species of *Nomismoceras* (Bisat, 1924, 1934; Parkinson, 1926, 1936; Earp et al., (1961). *Merocanites henslowi* (J. Sowerby) has been collected from this horizon (J. Miller *in litt.*). and Earp et al. (1961, p. 180) record it from "shales at the top of the (*hodderense*) band in Porter's Brook, Grindleton.".

North of a line from Croasdale House near the southern end of the Stocks Reservoir through Barnoldswick to the south of Lothersdale the *hodderense* Beds are not typically

Mercian Geol. Vol. 5, No.1. 1974, pp. 19-32, 3 text-figs.



Text-fig. 1. Isopachyte map of the Bowland-Craven basin of sedimentation. The isopachs, which are drawn at 100 ft. intervals on the beds of Cracoeian age, although only approximately placed, are indicative of the relationship between the Bowlandian and Sudetian earth movements and the post-Millstone Grit folding.

developed, but the horizon has been recognised in an exposure between Carlton and Earby (Earp et al, p. 74). In the Skipton Anticline (Hudson and Mitchell, 1937, p. 14) beds in the Upper Skibeden Shales-with-Limestone, displaying green chloritic patches and yellow weathering, are probably of *hodderense* age.

The *Merocanites henslowi* Beds (Upper B_1)

In a zonal table, Hudson (1938, p. 308) placed *M. henslowi* as the index fossil for Upper B_1 and equivalent to higher S_2. As noted above, this species also occurs in Lower B_1 and it has been found in beds higher than B_1 on Buttershaw Knoll, Cracoe, Yorkshire (Bisat, 1934, p. 306). The location is a little north of the northeastern corner of the map (text-fig.1) and the horizon according to Bond (1950, p.167) is middle D_1. Nevertheless, *M. henslowi*, though not common, is the dominant and most widespread goniatite in the higher parts of B_1, notably in the Isle of Man. Within the area under consideration it is best known at the northeastern corner near Rylstone. The associated fauna consists largely of corals of *Cyathaxonia*-zaphrentid phase, whilst the goniatites recorded (apart from some species which Hudson and Cotton, (1945, pp. 280-1) suggested should be renamed) are *Beyrichoceras mutabile* (Phillips) *Beyrichoceratoides* aff. *implicatus* (Phillips) and *Nomismoceras* sp.. The type locality of *B. implicatus* is Black Hall Quarry, near Chipping, Lancashire, eight miles west of Clitheroe (just outside the limits of the map, (text-fig.1). This quarry is certainly higher than S_2 and the Rylstone form is apparently an early variety.

M. henslowi, identified by Bisat (1934, p. 306) was collected from an exposure near New House in the north-eastern part of the Sykes Anticline, 3½ miles north of Slaidburn (Parkinson, 1936, p. 308) which yielded an extensive fauna, including *Lithostrotion sociale* (Phillips) and *Stroboceras sulcatum* (J. de C. Sowerby).

In Burst Clough, northeast of Little Mearley, on the lower scarp of Pendle Hill, shale specimens of a form recorded as *Prolecanites compressus* (J. Sowerby) (Parkinson, 1926, p.214) were found at intervals from 10 feet above the *hodderense* limestone to the *Lithostrotion arachnoideum* Beds 400 feet higher in the sequence. *Merocanites compressus* is a C_2 (or C_2S_1) form and it is probable that the Pendle specimens should be referred to *M. henslowi*.

The Pendleside Limestone and the boundary between B_1 and B_2

In the type area of Pendle Hill the Pendleside Limestone proper is about 250 feet thick between Hookcliffe and Little Mearley, with its base some 400 feet above the *Bollandoceras hodderense* Beds. To the southwest it is largely replaced by shales and mudstones; to the northeast and northwest it thins out, partly by shale replacement and partly by reduced sedimentation. In some localities it loses its identity; in others it lies directly on the *hodderense* Beds. Thus in the Marl Hill Tunnel (Earp et al., p.68 and Pl. VI) 294 feet of limestone rest, apparently conformably, on 21 ft. 4 ins. of the *hodderense* Beds, and in Clough Wood, Holden, the Pendleside Limestone, 84 feet thick, lies on 27 ft. 10 ins. *hodderense* Beds (*op. cit.*, pp. 72-73).

Among the fossils collected from the lower beds of the Pendleside Limestone (*Lithostrotion arachnoideum* Beds) in and near Burst Clough (Parkinson, 1926, p.215), *Stroboceras sulcatum*, *Lithostrotion sociale* (recorded as *L. affine*) and *M. henslowi* (recorded as *P. compressus* ?) were later found, as noted above, in the New House Bed.

Some species, not known on Pendle, were collected by the Rev. G. Waddington (1927) from the section in the River Hodder at Hodder Place, 3½ miles southwest of Clitheroe. Hudson and Cotton (1945, p.298) referred this assemblage, which includes *Rylstonia benecompacta* Hudson and Platt and *Rhopalolasma bradbournense* (Vaughan) - and elsewhere *M. henslowi* - to passage beds between S_2 and D_1. The re-survey did not add to existing knowledge and no opinion was expressed in the memoir (Earp et al., 1961) as to age, but the comment was made (p.180) that "the beds in the Hodder are of a faunal phase distinct from that of the true Pendleside Limestone, and a considerable fauna has been found there, including *Lithostrotion* (Waddington, 1927, p.40)". It is further stated (Memoir, p.180) that "owing to the rarity of goniatites the position of the boundary between B_1 and B_2 is not known".

A single goniatite from a few feet below the base of the Pendleside Limestone in Burst Clough, Pendle, was referred by Bisat (Parkinson, 1926, p.215) to *Beyrichoceras micronotum* (Phillips). This was a poor specimen, which according to a revised opinion of Bisat (in litt. to Earp et al, p.180) may have affinities with *Girtyoceras*. This solitary specimen and *M. henslowi* are the only goniatites which are known in that part of the sequence where the boundary between B_1 and B_2 might be expected to be found. The numerous species of *Girtyoceras* described by E.W.J. Moore (1946) were all collected from beds above the Pendleside Limestone, so it is possible that the Burst Clough specimen is a B_2 rather than a B_1 species. The evidence, such as it is, suggests that the junction between B_1 and B_2 is a little below the base of the massive Pendleside Limestone. In the Hodder Place section, assuming the usually accepted view of the equivalence of the goniatite B_1B_2 and the coral - brachiopod, S_2D_1 stages, the junction can be taken at the level of the *Rylstonia* fauna, the position of which is shown in text-fig. 3. (See Waddington, 1927, p.37 and Earp et al, 1961, p.69).

In the Skipton Anticline, although the rocks of Cracoeian age are much thinner than those in the Pendle area, many more fossils are recorded from them. The fauna is a coral-brachiopod phase. The species listed by Hudson and Mitchell (1937, pp.19-21) from the Draughton Limestone indicate a D_1 age, though some forms from the lower beds suggest S_2. Among these, according to the authors, many specimens are probably derived from the underlying Intake Limestone, a local deposit in the Upper Skibeden Shales-with-Limestone. No goniatites are named. The most probable horizon of the B_1-B_2 boundary is the base of the Draughton Limestone. This limestone is a greatly condensed equivalent of the Pendleside Limestone and displays two horizons of breccia-conglomerate, the higher of which, up to six feet thick, is known as Tiddeman's Breccia (*op. cit.* p.17).

Strata of Lower B_2 age

The B_2 beds were subdivided by Hudson (1938, pp.312-3) into Lower B_2 and Upper B_2. In his 1945 paper with Cotton (p.257), Hudson proposed as index fossil for the whole of B_2 *Goniatites maximus* Bisat, whilst for Lower B_2 he suggested *Beyrichoceras vesiculiferum* (de Koninck) and for Upper B_2 *B. delicatum* Bisat. Within the area of text-fig.1 the only goniatite which can with some confidence be assigned to Lower B_2 is *Bollandoceras* cf. *phillipsi* (Bisat) which was recorded by Earp et al. (p.180) from the Pendleside Limestone of Pendleton Brook, a quarter of a mile southeast of Pendleton Church. This horizon is at least 200 feet above the *Girtyoceras* bed in Burst Clough (Parkinson, 1964).

Strata of Upper B_2 age

Along the Pendle Range there are many stream sections and some of them have yielded Upper B_2 goniatites. The sudden increase in the number of goniatite species is coincident with the widespread occurrence of the trilobite *Phillibole* aff. *aprathensis* R. and E. Richter (Earp et al., pp. 89, 180), and the entry of this species seemed the obvious horizon to place the base of Upper B_2 (Parkinson, 1964). The Upper B_2 beds, which consist largely of shales and mudstones, with occasional bullions, overlying the Pendleside Limestone, thin out towards the northeast from 150-175 feet at Little Mearley Clough to 54 feet at Higher (Cowdale) Clough southwest of Barnoldswick. The combined records of these and other localities by Moore (1936, 1941, 1946), Bisat (1952), Earp et al., (1961) and Miller and Grayson (unpublished work) suggest the existence of the following sequence, in descending order, below the *Goniatites crenistria* - *Beyrichoceratoides truncatus* beds of P_{1a}.

Dimorphoceras gilbertsoni (Phillips)

Bollandites castletonenis (Bisat),
Beyrichoceras delicatum Bisat.

Goniatites crenistria Phillips, *Girtyoceras platiforme* Moore, *Girtyoceras deani* Moore, *Bollandoceras globosum* Bisat

Goniatites maximus-wedberensis group, *Bollandoceras* cf. *excavatum* *Beyrichoceras* aff. *vesiculiferum* (de Koninck), *Beyrichoceras* cf. *micronotoides* Bisat, *Prolecanites hesteri* Moore, *Epicanites* aff. *bowlandensis* Moore, *Nomismoceras* sp.

Bollandites castletonensis (Bisat).

Goniatites hudsoni Bisat, *Girtyoceras simplex* Moore *Cowdaleoceras difficile* Bisat, *Prolecanites hesteri* Moore

Bollandites castletonensis (Bisat), *Nomismoceras rotiforme* (Phillips)

The lowest of these three levels of *Bollandites castletonensis* was found in Limekiln Clough, Pendle, southwest of Little Mearley Clough, by Miller and Grayson. Mr. Miller has kindly provided me with details of this section which was earlier studied by Moore (1936) and Earp et al (1961, pp. 89, 181). The Upper B_2 beds here are about 150 ft. thick and consist mainly of shales and mudstones. The upper leaf of the Pendleside Limestone, 8 ft. thick, is 80-90 ft. below the bullion bed containing the highest horizon of *B. castletonensis*. The new horizon of this species is near the base of the measured section and some 110 ft. below the bullion bed. It thus appears to be much lower than the *B.* aff. *castletonensis* horizon in Little Mearley Clough (Earp et al, Fig. 8, p. 90) which is about 20 ft. below the bullion bed (*op cit*, p. 181). Messrs Grayson and Miller collected a varied fauna from Limekiln Clough, including *Phillibole aprathensis*, which here ranges through the lower 80 ft. of the sequence.

Below the Bowland Shales in the Slaidburn and Sykes Anticlines, the Slaidburn Breccia (Parkinson, 1935, 1936, 1964; Moseley, 1962) is widespread. It thins out towards the south from about 100 ft. to zero. In the northeastern part of the Sykes Anticline, where it is thickest, it approximates to a reef facies with both brecciated and unbrecciated limestone which has yielded many species of brachiopods, together with a fair number of corals and a few goniatites. It has been argued (Parkinson, 1964) that these beds could be as old as Lower B_2. Among the goniatites recorded, (Parkinson, 1936, p. 312), *Girtyoceras discus* (Roemer), *Prolecanites serpentinus* (Phillips) and *Beyrichoceras parkinsoni* Bisat do not differentiate between the lower and higher parts of B_2, but *Beyrichoceras* cf. *micronotum* (Phillips) suggests Upper B_2, since there is apparently no reliable record of this goniatite at lower horizons. The corals (*op. cit*, p. 311) include a number of D_1 forms, some of which survive into D_2. The most important of these is *Lithostrotion maccoyanum* Edwards & Haime, which is dominant in lower D_2 (P_1) and apparently does not appear below the middle of D_1. It was found (*op. cit*, p. 315) on the northern slopes of Knotts Hill, associated with the D_2 coral *Lonsdaleia floriformis* and other fossils. In the Clitheroe Memoir the only occurrence noted (p. 83) of *L. maccoyanum* is in the P_{1a} beds of Grindleton Back Brook. In Derbyshire this species ranges, with varieties, from the upper part of the Chee Tor Rock to the top of the

Lower Monsal Dale Beds (middle D_1 to Lower D_2), the typical form being characteristic of the higher horizons (Chapel-en-le-Frith Memoir, 1971. Note in particular the table on p.129).

This evidence appears to justify the assignment of the Slaidburn Breccia to Upper B_2 (higher D_1). The earlier suggestion of Lower B_2 (Parkinson, 1964, p.163) was based largely on the relation of the breccia to the *Michelinia* cf. *tenuisepta* - *Emmonsia parasitica* fauna which is characteristic of Upper B_2-P_{1a} in the Pendle and Cracoe areas. The *Michelinia-Emmonsia* Beds of Bond (1950) were assigned to Upper D_{1-2}. This fauna is apparently absent from the Slaidburn Breccia, though occurring in the beds above it. However, this does not necessarily mean, as will be shown, that the breccia predates Upper B_2.

In the Skipton Anticline the limits of Upper B_2 are problematical owing to lack of goniatite evidence. The lower limit might be as low as Tiddeman's Breccia, which, like the Slaidburn Breccia, is below the beds containing the *Michelinia* - *Emmonsia* fauna. The Slaidburn Breccia has erosive effects on the beds below, whilst, as stated by Hudson and Mitchell (1937, p.19), the irregular base of Tiddeman's Breccia cuts down locally into the lower beds by as much as one foot in six feet. But, as further noted by these authors, the higher beds of the Draughton Limestone display several erosional surfaces, and the base of Upper B_2 could well be higher than Tiddeman's Breccia, though not in my view so high as the base of the Draughton Shales. This opinion is based on the suggestion of Hudson and Mitchell (1937, p.23) that the Draughton Shales (which did not yield any diagnostic fossils) are possibly of P_{1a} age. However, it is also possible that Upper B_2 might range into the Draughton Shales. The top of B_2 therefore would appear to be either at the base of, or within, the Draughton Shales.

North of the Skipton Anticline in the Craven Reef Belt the base of Upper B_2 is usually taken at the level of an oolitic conglomerate, which is a deposit also recognized in the Castleton area of Derbyshire (Hudson and Cotton, 1945, pp.302-5; Parkinson, 1947, pp.103-4, 108).

Earth Movements

The name "Cravenian" was proposed by Hudson and Mitchell (1937, p.30) for a crustal movement in the Skipton Anticline of $S_2/S_2/D_1$ age. This may be equivalent to the Selkian phase of the early Variscan folding. These authors (p. 31 and Figs. 3 and 6) adduced evidence of a stratal break at the base of the Draughton Limestone with some transgression of the underlying Skibeden Shales. The Draughton Limestone with its two breccia-conglomerate horizons is a "condensed sequence deposited over an area relatively uplifted or stable when compared with the belts of Craven Reef Limestone and Pendleside Limestone deposition to the north and south of it". The authors agree with Tiddeman that the upper and lower breccias were formed of material denuded by wave action on adjoining deposits.

The Cravenian break may have existed, locally at least, in the Craven Reef Belt where Bond (1950, p.164) suggested a possible non-sequence between S_2 and D_1 in Swindon Quarry near Cracoe.

No evidence of unconformity of this age has been reported from the Pendle area, but work as yet unpublished by Miller and Grayson has disclosed the existence of mudstone conglomerates below the Pendleside Limestone.

Within the Draughton Limestone, as noted above, there is evidence of a minor unconformity at the base of Tiddeman's Breccia. A major unconformity (Sudetian I) was demonstrated in the Skipton Anticline by Hudson and Mitchell (1937, p. 32) and attributed to an earth movement of D_1/P_{1b} age. Later movements caused minor unconformities of P_{1c}/P_{2a} (Sudetian II) and E_{1a}/E_{1b} (Sudetian III) age.

In the Slaidburn paper (1936) I submitted evidence indicating an unconformity below the Bowland Shales in the Ashnott, Slaidburn and Sykes Anticlines. Earp et al (1961) disputed this conclusion, partly on their work near Ashnott (p. 67) where I had inexcusably misinterpreted an exposure. The Survey officers concluded (p. 19) that all the standard zones were present, the thickness changes being related to different rates of subsidence.

In my 1964 paper the stratal break was placed at the base of the beds with the *Phillibole* aff. *aprathensis* fauna, though no unconformity had been found on Pendle itself. In the Ashnott area Upper B_2 was interpreted as following Lower B_1, the equivalent of some 750 beds in the Pendle sequence being absent. I agree with the Survey officers that the subsidence rate was greatly reduced between Pendle and Ashnott, but still believe that this does not account for the apparent absence of Lower B_2 and most of B_1. North of Ashnott, above a thin development of Pendleside Limestone there is an exposure of the *P.* aff. *aprathensis* shales (Memoir, p. 68). These shales have not been seen north of Slaidburn. At Standridge and Knotts Hill the Pendleside Limestone is succeeded by the Slaidburn Breccia, which is in turn followed by the Bowland Shales. If, as argued above, the breccia is of Upper B_2 age it must postdate the Lower B_2/ Upper B_2 earth movement (which was at a maximum near Ashnott) instead of predating it as was formerly supposed (Parkinson, 1936, 1964). This involves the existence of two unconformities, since further north the Bowland Shales are transgressive over the breccia and lower beds. The higher unconformity followed the Sudetian I crustal movement. In the Carlton district the beds of *Beyrichoceras* age are a little more developed than those near Ashnott, but whereas P_{1a} is present around and north of Ashnott it has not been found near Carlton, unless 10 feet of sandy micaceous shales with two hard sandstone bands are of this age, a possibility suggested by Gill (1940, p. 259), who compared them with the Draughton Shales in the Skipton Anticline. Elsewhere in the area Gill found shales of P_{1b} age resting on the very thin Cat Gill (Pendleside) Limestone. He postulated an unconformity of Sudetian I age (Gill 1940, p. 262), but admitted that "wherever the junction can be seen the Bowland Shales rest on the limestone with no apparent disconformity." Earp et al (p. 78) discovered B_2 fossils above the Cat Gill Limestone in two localities. This evidence is consistent with a break below Upper B_2 and another one below P_{1b}.

On the north side of the Lothersdale Anticline the Pendleside Limestone is well developed, and a section (Earp et al., p. 74) shows it to be "abruptly overlain by dark grey shales containing *Goniatites maximus* of B_2 age, assigned to the Bowland Shale group." On page 99 of the memoir it is suggested that "the shales are possibly unconformable to the underlying Pendleside Limestone."

The post-Cravenian (pre-Sudetian I) earth movement is of sufficient importance to merit a distinctive name and I suggest "Bowlandian". Evidence of uplift about the same time has been found in Derbyshire and Staffordshire. (Parkinson, 1947, 1953, 1965, 1973; Parkinson and Ludford, 1964).

In text-fig. 1 isopachs at 100 ft. intervals are drawn for the beds of Cracoeian age. In the Sykes Anticline, where the *Bollandoceras hodderense* Beds have not been recognized, the base of the Cracoeian is placed immediately above the massive chert bed, presumed to be near the top of S_1 (Moseley, 1962; Parkinson, 1936, p. 306; 1964, Fig. 2, p. 160).

The isopachs illustrate the Bowlandian movement as a simple uplift along an east-west axis stretching from north of Ashnott to Carlton. It seems possible, however, that some incompetent small-scale folding in the southern part of the Slaidburn Anticline (Parkinson, 1936; Earp et al, 1961, p. 68) may be associated with the movement.

The influence of the Bowlandian uplift may have been small north of the Skipton Anticline, but there is some evidence of it in the Rylstone area where the Middle Visêan strata are very thin. At Clints (Rylstone Railway) Quarry, Booker and Hudson (1926) recorded, below beds with *Michelinia tenuisepta* and *Emmonsia parasitica* at the top of the quarry, 20 feet of finely brecciated limestone with an extensive fauna, including *Lithostrotion arachnoideum.* Below these beds are 10 feet of limestone with an abundant fauna of zaphrentid phase referred to on earlier pages as the *Rylstonia* fauna. The lowest 24 feet are the *Merocanites henslowi* (then recorded as *M. applanatus*) Beds of S_2 age. Although Bond (1950, p. 171) suggested that in this Quarry the whole of lower D_1 and perhaps the top of S_2 are missing, the faunal succession does not support such a view. There may be a non-sequence below the *Michelinia-Emmonsia* Beds corresponding to the higher part of the Pendleside Limestone, but the *L. arachnoideum* Beds are of Pendleside Limestone (Lower D_1) age and the *Rylstonia* fauna below them is paralleled in the Hodder Place section, which, as we have seen, can be regarded as passage beds from S_2 to D_1. In the discussion on Bond's paper (1950, p.185) Hudson stated that the suggestion of a mid-Viséan uplift at Rylstone was an error. My own suggestion is that around Rylstone the greatly condensed succession resulted primarily from a very slow rate of subsidence (accompanied possibly by small non-sequences) which was halted at the onset of the Bowlandian uplift, the effects of which extended northwards with diminishing intensity as far as Rylstone.

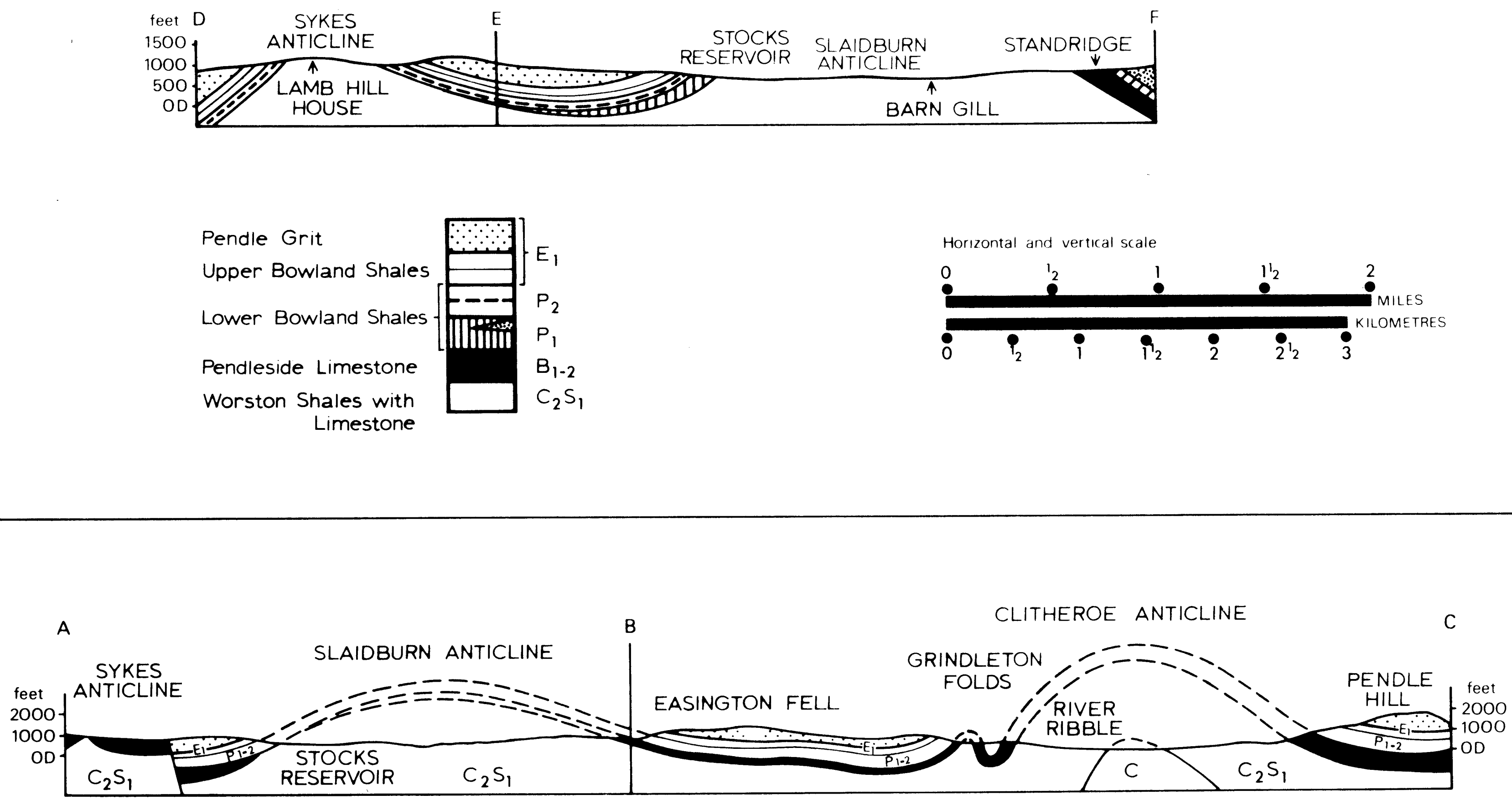
The Sudetian I movement was more powerful than the Bowlandian, and Hudson and Mitchell have made a good case that the Skipton Anticline itself was initiated by it. These authors state (1937, p. 32) that the Sudetian I folding gave rise to a "main axis to the south of which were numerous sharp folds of small amplitude arranged *en échelon*" They envisage a rock mass to the north "against which the rocks were pushed, buckled and packed from the south". The beds above the unconformity, beginning with P_{1b}, are much less severely folded than those below. The folding of the Draughton Shales conforms to that of the Draughton Limestone. Similarly, in the northeastern part of the Sykes Anticline, P_{1b} forms the base of the Bowland Shales (Parkinson, 1936, 1964). Westwards, P_{1b} is overlapped by higher beds almost to the base of E_1, and the shales are transgressive over the Slaidburn Breccia and Pendleside Limestone down to beds of S_1 age. (See generalized horizontal sections, text-fig. 2 and vertical sections, text-fig. 3). As in the Skipton Anticline the beds below the unconformity display many sharp small-scale folds, but the crustal movement as a whole does not appear to be related to the initiation of the Sykes Anticline unlike events in the Skipton Anticline.

In the Sykes, Brennand and Whitendale areas which constitute the southwestern part of the Sykes Anticline, the Slaidburn Breccia is followed by P_{1b} beds. If P_{1a} is present it is no more than 5 feet thick (Moseley, 1962, p. 295). The intense folding, unlike that of the Skipton Anticline, is not confined to the rocks below the Bowland Shales. Moseley (1962 p. 300) found no evidence of an angular unconformity below P_{1b}, and he notes that the lower beds of the Bowland Shales dip at the same angles as the limestones. Higher beds generally dip at lower angles in conformity with the overlying Pendle Grit. The southwestern part of the Sykes Anticline is interpreted by Moseley (p. 306) as a "concentric fold modified by disharmonic folding of the incompetent Bowland Shales."

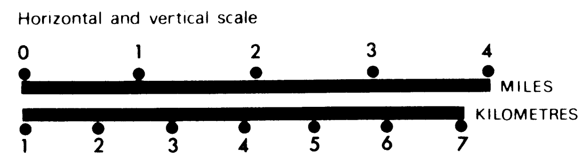
In the Bowland Forest Tunnel, beneath the grit of Dunsop Fell (Earp, 1955), where the succession was fully exposed, there is apparent conformity between the Bowland Shales and lower beds. The Pendleside Limestone with the *hodderense* Beds at its base is about 100 feet thick.

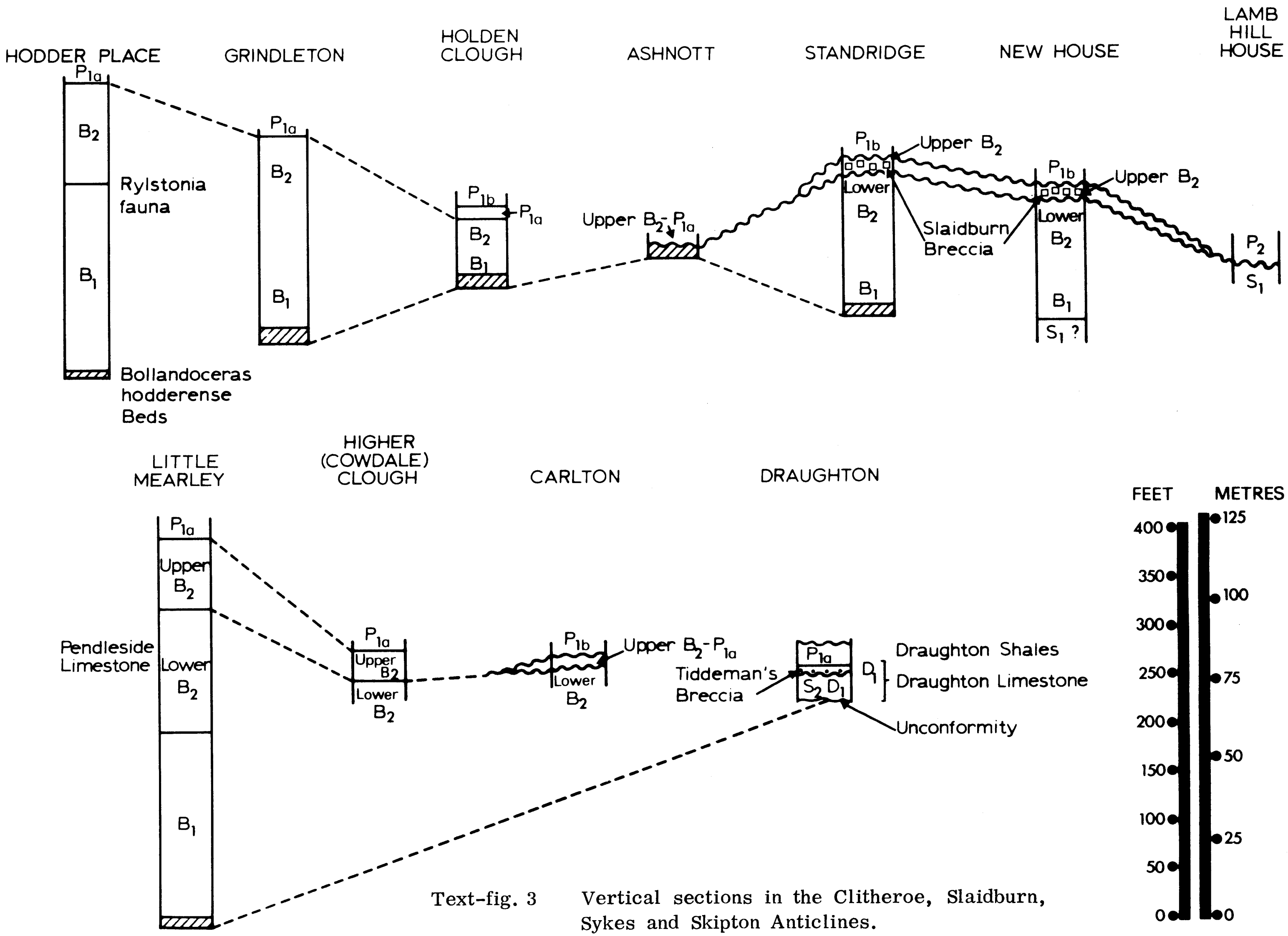
Along the northern limb of the Slaidburn Anticline, P_{1b} beds rest on sharply folded flaggy limestones, some beds being probably of pre-*hodderense* age. Many exposures are now buried in the Stocks Reservoir (Parkinson, 1936, Plate XXVI). The only section of proved P_{1a} beds is in Croasdale Brook, near Croasdale House (*op cit.*, pp. 314-5), where some 35 feet of shales and conglomeratic limestones underlie the *Nomismoceras* Band at the top of the zone. It is possible that the lower part of the succession may belong to Upper B_2, since southwards across the anticline both P_{1a} and Upper B_2 are very thin; otherwise the Upper B_2 beds may have been overlapped. Anyhow, the shales rest on a very thin development of Pendleside Limestone at the base of which are the *hodderense* Beds. About 20 feet above the *Nomismoceras* Band (Parkinson, 1936, p. 315) is a *Goniatites falcatus* Band, with another one 12 feet higher, within a P_{1b} sequence of shales and crinoidal limestones. Thus there is no evidence of a significant break below P_{1b}, as in the exposures northeastwards along the anticlinal limb. The Croasdale Brook section apparently lies just outside the influence of the Sudetian I unconformity.

It should now be re-iterated that in Moseley's view any earth movements prior to the post-Millstone Grit folding were of little significance. He suggested (Moseley 1962, pp. 308-9) that disharmonic folding had probably occurred in the northeastern part of the Sykes Anticline



Text-fig. 2 Generalized and simplified horizontal sections across the Slaidburn-Clitheroe area which are based primarily on the author's own work, but also, to some extent, on the one inch to one mile Geological Survey map of the Clitheroe district, Sheet 68.





Text-fig. 3 Vertical sections in the Clitheroe, Slaidburn, Sykes and Skipton Anticlines.

and in the Slaidburn Anticline, outside his mapped area. In the discussion of his paper he suggested similar disharmonic folding in the Skipton Anticline. Though he did not deny the possibility of minor unconformities or non-sequences, he thought a major unconformity below the Bowland Shales to be unlikely, and made the point that Hudson and Mitchell's map showed the Lower Bowland Shales to rest invariably on either the Draughton Shales or Draughton Limestone (together only about 250 feet thick). He thought that in an outcrop 12 miles long these formations should have been overstepped. But on Hudson and Mitchell's theory, any appreciable overstep would lie *across* the trend of the Skipton Anticline and not along it, and, in fact, these authors show, in their diagram (Fig. 6) illustrating the evolution of the anticline, that along its axis the Bowland Shales rest on beds well below the base of the Draughton Limestone. Because of recent denudation the full extent of overstep remains an assumption, but it need not have gone far below the Draughton Limestone to justify the authors' conclusions.

Along the Craven Reef Belt, as was demonstrated by Hudson (1930) and by later authors, Bowland Shales overlap on the reef limestones, the summit beds of which (in the Cracoe-Burnsall area) are of low $D_2(P_{1a})$ age (Bond, 1950; Black, 1958). The overlap extends from P_{1b} to E_1 and thus involves several goniatite zones, but the actual break below P_{1b} is small.

The Sudetian II movement in the Skipton Anticline (Hudson and Mitchell, 1937, p. 33) was preceded by the deposition of the Nettleber Sandstone "which suffered erosion in the final period of movement." (See also *op. cit.*, p. 24 and Hudson and Versey, 1935). Evidence of this uplift was noted along the north limb of the Slaidburn Anticline by the presence of boulder beds in P_{1c} (Parkinson, 1936, pp. 316-7; 1964, pp. 164-5).

The isopachs of text-fig. 1 indicate, as already noted, the position of the axis of Bowlandian uplift, which trends east-west from north of Ashnott to Carlton. They also illustrate, little more than a mile north of Carlton, the roughly parallel trend of the Sudetian I main axis of the Skipton Anticline. Westwards, pre-B_1 rocks are at outcrop over a wide area and the trend of the axis is lost. It is again shown following the northern limb of the Slaidburn Anticline in a more northerly position than near Skipton. The axis then swings round to the northwest to cross the axis of the Sykes Anticline. The suggested approximate trend of the folding is indicated in text-fig. 1, but alternative explanations are equally possible.

The Pendle area has produced no direct evidence of Bowlandian and Sudetian crustal movements, but it seems unlikely that sedimentation was continuous. It may be significant that on Pendle the D_1 Zone (i.e. the Pendleside Limestone and overlying Upper B_2 shales) is little more than 400 feet thick compared with some 1300 feet along the Derbyshire-Staffordshire border (Parkinson and Ludford, 1964). In North Wales the maximum thickness of the *Dibunophyllum* Zone may approach 3000 feet. This estimate (George, 1958, p. 281) includes D_2 (equivalent to the P_1P_2 beds of the basin areas.) In view of the 600+ feet of Lower Carboniferous shales and limestones in the Clitheroe-Pendle area, a mere 400 feet of D_1 is rather surprising if sedimentation was uninterrupted.

Conclusions

This analysis has clarified some important aspects of the stratigraphy of Middle Viséan age in an area which has claimed the attention of geologists and palaeontologists over many years.

It seems justifiable, mainly on structural evidence supported by lithology and fauna to separate the beds of *Beyrichoceras* age into four subdivisions, namely Lower B_1, Upper B_1, Lower B_2 and Upper B_2. Upper B_1 and Lower B_2 cannot satisfactorily be defined by goniatites alone. The junction of B_1 and B_2 on Pendle Hill is taken a little below the Pendleside Limestone and the corresponding horizon elsewhere can be recognized by a distinctive coral fauna.

The separation of B_2 into lower and upper sub-groups by means of the goniatite faunas, as these are at present understood, is of doubtful validity as was recognized by authors of the Chapel-en-le-Frith Memoir (Earp *et al.* 1971, p.141). The goniatites in themselves are inadequate to sustain such a subdivision in the Bowland-Craven region and the boundary between Lower and Upper B_2 is taken at the level of the Bowlandian unconformity.

Three periods of earth movement affecting the rocks of Cracoeian age are now, in my view, recognizable. Of these the Cravenian (S_2/S_2D_1) may not have extended far south of the Skipton Anticline. However, below the passage beds on Pendle Hill from B_1 to B_2 (S_2 to D_1) the undescribed mudstone conglomerates discovered by Miller and Grayson may be related to the Cravenian movement.

The Bowlandian uplift (Lower B_2/Upper B_2) which is at a maximum along a west-east line from near Ashnott to Carlton, extended northwards to the northeastern part of the Sykes Anticline where it is evidenced by the eroded base of the Slaidburn Breccia, though the break there may be small. The equivalent horizon in the Skipton Anticline may be the eroded base of Tiddeman's Breccia. South of the Ashnott-Carlton line the Bowlandian unconformity diminishes and there is no direct evidence of it on Pendle Hill, where its position is probably the base of the *Phillibole* aff. *aprathensis* beds.

The Sudetian I movement (P_{1a}/P_{1b}) was more intense and more complex than the Bowlandian, though its effects were only felt (southwards at least) over a smaller area. The southern limit of its influence apparently follows a line running southeast from north of Croasdale House and then east to south of Carlton.

Acknowledgment

It is a pleasure to acknowledge the help of Mr. John Miller who has kept me informed of the progress of his and Mr. Grayson's work on Pendle Hill and elsewhere. Their research has an important bearing on some of the problems discussed in the present paper.

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THE BERRY HILL - RAINWORTH TREMOR OF 26th JANUARY 1973

by

R.E. Elliott

Summary

A minor earth-tremor centred between Berry Hill at Mansfield and Rainworth, occurred at 05.07 hours on Friday, 26th January 1973. Evidence suggests that this originated on structures in sub-Carboniferous rocks; the Mansfield Anticline and its associated major fault being the near surface expressions of those structures.

Introduction

A small tremor was experienced for some 2 - 3 seconds by persons resident in the vicinity of Mansfield, Nottinghamshire, early on Friday, 26th January 1973. Verbal reports were collected by the author from an area of some 60-70 square miles ranging from Warsop to Bestwood on the northern outskirts of Nottingham City, and from the western side of Mansfield to Bilsthorpe (text-fig. 1). However, five miles further south on the Trent embankment at Nottingham, one observer noticed "a slight unmistakeable tremor", whilst sitting. The greatest concentration of reports was from the Forest Town and Berry Hill districts on the east side of Mansfield and from Rainworth. Reports of damage were rare and very slight. A second tremor was noticed by a few persons at about 11.15 or 11.20 a.m. on the same day, again east of Mansfield.

This tremor was one of the stronger ones of a series felt in the same general district over at least the last 20 years. These minor shocks have not, so far as the author is aware, been studied in detail and have usually been on a scale which does not readily allow investigation.

Scant information concerning earlier tremors was collected by Davison (1924). He reported earthquakes in the Mansfield district on three occasions; one in 1816 which caused slight damage to chimneys and other structures in Mansfield, Kirkby and Newstead and estimated to have attained intensity VI (Modified Mercalli, see appendix), 7 (Davison); a second in 1817 felt at Mansfield and neighbouring villages, and a third in 1825 reported from Mansfield and Newstead Abbey, reaching intensity III/IV (Modified Mercalli), 4 (Davison).

Details

Text-fig. 1 records the location of verbal reports, most known to be from reliable sources. Three zones are based on these reports; an outer 'dashed line' encloses all positive records of the tremor being felt and excludes localities where reports would have been likely to be forthcoming had the tremor been detectable by the inhabitants in general. A second line encloses most locations from which members of the public took trouble to report the incident voluntarily. The third, inner 'dashed line' encloses an area from which a large proportion of the residents noticed the tremor and from which a few reports (1 to 4) provided special evidence. Not all reports are plotted in this inner zone.

At location 1, a household pendulum clock was stopped and recorded 05.09 hours; the pendulum is about 16 inches long and swings in the directions indicated on text-fig. 1 by arrows. At point 2, a locked door was "burst open"; near 3, a few books and other articles fell to the ground and a greenhouse was said to have "dropped 6 inches"; at 4, miners at a depth of

Mercian Geologist, Vol. 5. No.1, 1974. pp. 33-37, 1 text-fig.

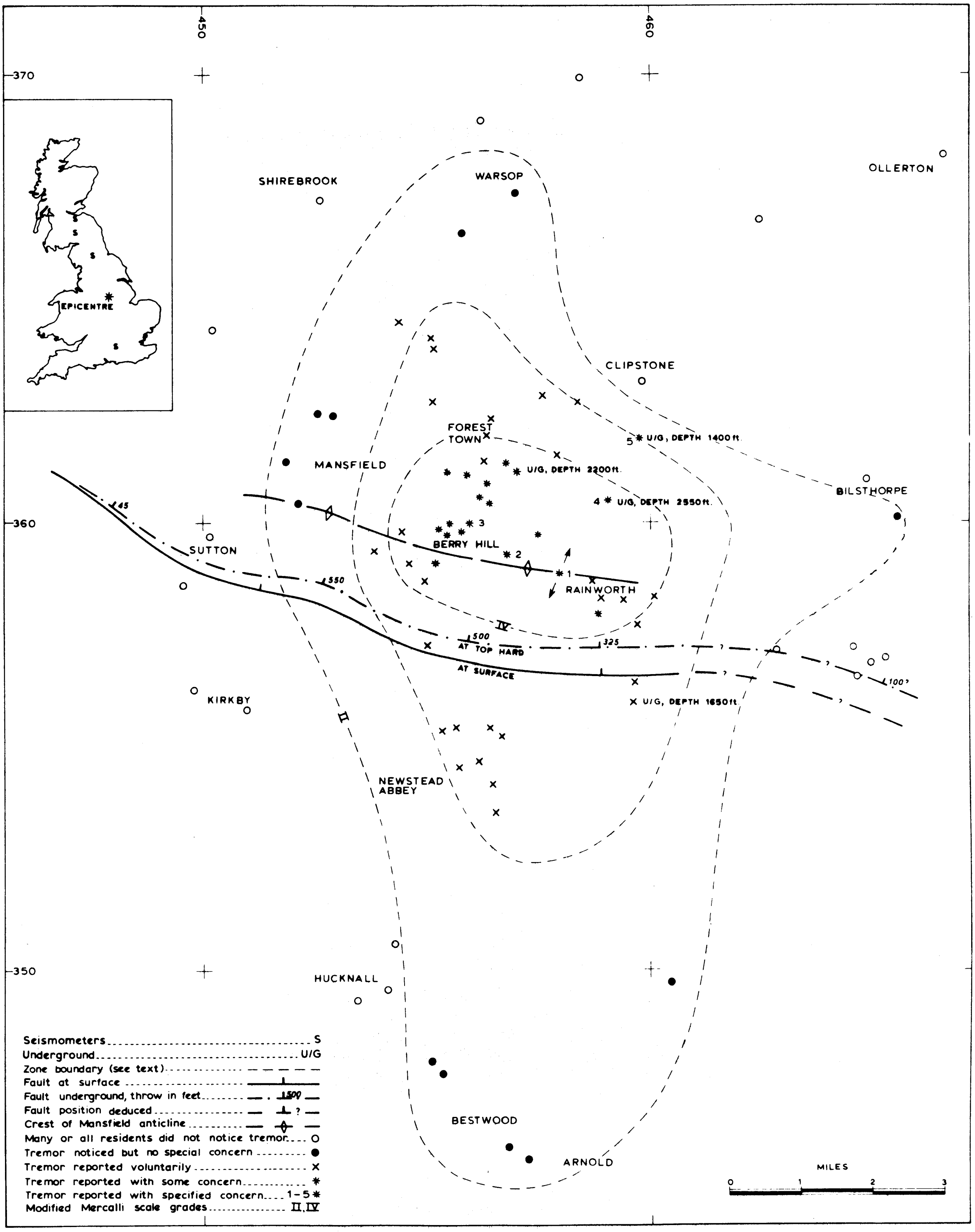

Fig. 1 Isoseismal Map of the Berry Hill - Rainworth Tremor.

2.550 ft. were concerned about the tremor, and at 5, miners at a depth of 1,400 ft. withdrew from an area of fragile roof strata. However, since at this latter locality there was special concern about the nature of the mining conditions independent of the tremor it is not enclosed by the inner line.

Many lights were turned on in the Berry Hill residential district as the inhabitants were awakened by the tremor; this evidence together with that from localities 1, 2 and 3, suggests that the surface epicenter from this tremor was within the Berry Hill - Rainworth district. A maximum intensity of V on the 12-degree Modified Mercalli scale is here interpreted from these reports. This may have been restricted to a narrow zone extending from Berry Hill to Rainworth (text-fig. 1), no more than one mile wide; moreover, because there are no habitations or other possible sources of evidence in parts of the area concerned, the Vth isoseismal is omitted from text-fig. 1. Also, since intensity III is difficult to define only the IInd and IVth isoseismals are labelled.

The tremor was clearly recorded on the Institute of Geological Sciences telemetered array of seven seisometers centred on Edinburgh. A magnitude of 3.5 on the body wave scale and 3.6 on the Richter local scale was registered and an origin at 05.07 hours was calculated. Signals recorded on the Atomic Energy Authority arrays of instruments at Eskdalemuir in Southern Scotland and Wolverton in Hampshire had arrival times of 05.07.36 and 05.07.27 respectively. These confirm that the time of origin was about 05.07 hours. They both gave an Estimated Richter magnitude (m_b) of about 3.0. Strain amplitude records produced by instruments set up in the Queensbury (SE 096300) and Woodhead (SE 137012) tunnels in Yorkshire by the Cambridge University Department of Geolesy and Geophysics did not show significant features; at both localities the strain amplitude was less than one part in 10^9. The seismic records of the University of Durham, Department of Geology, located at Rookhope, County Durham, show a disturbance at 05.07.30 hours.

Discussion

The local nature of the tremor, as felt by residents, and the maximum intensity of V suggests that its origin may be at a relatively shallow depth in seismological terms. This is given approximate quantification in the formula:

$$I_o - I_n = 4.5 \text{ Log}_{10}\ r_n/h$$ Karnik (1969, pp 29 and 32)

where I_o is maximum intensity, I_n is intensity at a well founded isoseismal, r_n is the average radius of that isoseismal and h, is the depth of origin. The calculated value of h is of the order of 7,000 to 10,000 ft.

A normal fault (text-fig. 1), trending east-south-east just south of the probable epicenter, is recorded at the surface and in coal workings at the Top Hard seam horizon. Its calculated hade at several points is about 45 degrees and it throws coal measures down on the north side about 500 ft. It faces the southern limb of the so-called Mansfield Anticline. This, the dominant limb, together with the 500 ft. fault, forms a "trap-door" like structure which is one of the major tectonic features of the East Pennine Coalfield. This faulted anticline is one of a number of major fault-fold combinations, which Kent (1966) suggested were related to a pattern of basement fractures.

The floor of relatively dense high-velocity pre-Carboniferous rocks lies below the epicenter (text-fig. 1) at an estimated depth of about 9,000 ft. (Plate 5, Kent 1967). Movement giving rise to the tremor may well have occurred within that floor. Extrapolation of the 45 degree fault hade suggests that the location of the movement was on that fracture or an associated fracture, since at this same order of depth it would lie below the Berry Hill - Rainworth district. However, it is possible that the corresponding basement structure is complex.

The north to south elongation of the IInd isoseismal does not necessarily detract from this interpretation, it may be due to the tremor being more readily felt on the relatively rigid "Bunter" sandstone outcrop than on the adjacent "Marl" formations.

Acknowledgements

The author is indebted to Dr. R.C. Lilwall of the Institute of Geological Sciences, Edinburgh, Dr. H.I.S. Thurlaway of the Atomic Energy Authority, Dr. R.G. Bilham of the Department of Geodesy and Geophysics, Cambridge University and Mr. R.G. Riddle of the Department of Geology, University of Durham, for statements incorporated in the text and to Dr. R.C. Lilwall and Dr. P.E. Kent for reading the draft and offering comments.

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APPENDIX

Modified Mercalli Intensity Scale of 1931

(Details selected [by the author] from several abridged versions

I	Not felt by public; detected by seismometers.
II	Felt only by some persons, usually at rest.
III	Felt indoors but many people do not recognise it as an earthquake; vibrations like passing of a light lorry.
IV	Felt by some persons outdoors; hanging objects swing; some loose objects disturbed including dishes, windows and doors; vibrations like passing of a heavy lorry or jolt like a heavy ball striking a wall.
V	Felt by nearly everyone; most or many awakened. Small unstable objects displaced.
VII	Many persons frightened and ran outdoors; slight damage to plaster, windows, dishes, glassware; small articles fall off shelves or pictures off walls; furniture disturbed. Trees and bushes rustled and all suspended objects swing.
VII	General alarm; walls crack; plaster falls; some chimneys and other susceptible structures damaged; water disturbed and ponds become muddy; noticed by drivers of motor cars in motion.
VIII	Car drivers seriously disturbed; masonry fissured; chimneys fall; poorly constructed buildings damaged.
IX	Some houses collapse where ground begins to crack, and pipes break open.
X	Ground cracks badly; many buildings destroyed and railway lines bent; landslides on steep slopes.
XI	Few buildings remain standing; bridges destroyed; all services (railways, pipes and cables) out of action; great landslides and floods.
XII	Total destruction; objects thrown into air; ground rises and falls in waves.

TEETH OF *DALATIAS BARNSTONENSIS* IN THE BRITISH RHAETIC

by

J.H. Sykes

Summary

Teeth of the shark *Dalatias barnstonensis* Sykes from the bone beds of the Westbury Formation of the Rhaetic at nine British localities are recorded, some being figured and briefly described, including a lower tooth with root attached, showing previously unknown features.

Introduction

Dalatiid teeth of Rhaetian age were first discovered during an excavation organised by the East Midlands Geological Society at the Barnstone railway cutting, Nottinghamshire (Sykes, Cargill and Fryer, 1970). The species *Dalatias barnstonensis* Sykes was established on specimens from this source (Sykes, 1971). Examination of bone bed material, collected from other localities, in museums and in private collections has shown that this species has a widespread distribution in the British Rhaetic.

Text-fig.1 shows the nine localities from which the teeth of *D. barnstonensis* have been obtained. All the material studied came from bone beds in the lower part of the Westbury Formation. Barnstone is the only locality which has so far yielded a large number of these teeth; here a large amount of bone bed was available and it was possible to extract the teeth from many kilograms of the friable rock by simple sieving and sorting. In contrast, the characteristics of the samples from the other localities were extremely varied. Only a few grams were available from Gainsborough, a museum sample, but it was easily disintegrated, and contained a large number of teeth. A large sample from Barrow-on-Soar was poorly fossiliferous, difficult to break down and yielded only rare teeth. A sample weighing about 1 kg., obtained from Blue Anchor Bay, Somerset, yielded after acetic acid treatment two teeth referred to *D. barnstonensis*.

Specimens of the teeth recorded from Aust, Westbury, Penarth, Lavernock and Axminster, were loaned to the author or examined in museums. The original characteristics and weights of the bone bed samples from which they were obtained is unknown.

Teeth of *D. barnstonensis* are always associated with other Rhaetian bone bed fossils and a richly fossiliferous sample of the bed is the one most likely to provide specimens of these teeth.

Description of the D. barnstonensis teeth from the nine localities

1. Aust Cliff, Gloucestershire (Grid Reference not known).

Four lower teeth from Aust Cliff have been obtained from varying sources.

Lower, left, posterior, lateral tooth

Leicester Museum and Art Gallery, Specimen No. O.S.1. 1973, figured Pl.2, fig. 6. The inner face is attached to the matrix. The outer face has a complete crown, a base with

Mercian Geol. Vol.5. No.1, 1974.
pp. 39-48, 3 text-figs. Plate 2.

Text-Figure 1

Localities from which *Dalatias barnstonensis* has been recorded anterior and posterior processes also an external depression and external depression groove. Part of the root is attached.

Lower, right, lateral tooth

British Museum (Natural History), Specimen No. P 55871. This tooth has a very worn crown, a base and part of the root (1.7 mm high and 1.4 mm. long).

Lower, left, lateral tooth and lower tooth, possibly median

Mrs. P. Catchpole, personal collection. The lateral tooth has a crown and base (3 mm. high, 2.1 mm. long). The possible median tooth has the lower part of the crown and uppermost part of the base; it appears to be tall, upright and symmetrical (3 mm. high, 2.5 mm. long).

2. Axminster, Devonshire (Grid Reference not known)

Three specimens were found in one sample of sieved bone bed belonging to the Institute of Geological Sciences Museum. (Hereafter I.G.S.)

Three lower teeth fragments

I.G.S. London, No. G.S.M. 414.

Two of these have characteristics of the base and one is a serrate crown tip. Though fragmentary, their internal characteristics are also diagnostic (Sykes, 1971, p. 13).

3. Barrow-on-Soar, Leicestershire (SK 575173)

A few kilograms of a weathered, basal bone bed has yielded few diagnostic Rhaetian fossils and only two lower teeth.

Two lower teeth fragments

J.H. Sykes personal collection. These fragments show the internal depression of the base and a few serrations of the crown.

4. Blue Anchor Bay, Somersetshire (ST 042432)

An extremely hard sample of very fossiliferous bone bed has yielded two specimens.

Upper tooth

I.G.S. No. Zr9723, figured Pl. 2, fig. 8, text-fig. 2, fig. 6. This tooth has a complete crown which has a lateral point on either side. The internal protuberance with the internal median foramen is present and also part of the root. The basal anterior and posterior extensions are broken off.

Lower median tooth

J.H. Sykes personal collection. A part of the base is contained within the matrix showing a section with two internal depressions.

5. Gainsborough, Lea Railway Cutting, Lincolnshire

A 6½ oz (185 grams) sample of rotted, pyritic bone bed supplied four teeth (3 lower and 1 upper).

Lower tooth, possible median

Wollaton Hall Museum of Natural History, Nottingham, (Chamberlain Collection). This tooth has its inner face attached to the matrix; it has almost a complete, tall, upright, equilateral crown and part of the base with an internal depression (4.5 mm high (2.5 mm. long).

Abbreviations used in Text-Figures

(Mostly after Casier, 1961)

a.p.	anterior process
b.a.e.	basal anterior extension
b.p.e.	basal posterior extension
b.n.	basal notch
e.d.	external depression
e.d.g.	external depression groove
e.m.f.	external median foramen
i.d.	internal depression
i.m.f.	internal median foramen
i.p.	internal protuberance
m.c.	median canal
p.p.	posterior process
r.	root

EXPLANATION OF TEXT-FIGURE 2

Fig. 1 Lower, median tooth; inner view, same specimen as on pl. 2, fig. 1. No Zr9724 (2.8 mm × 1.6 mm).

Fig. 2 Lower, right, anterior, lateral tooth; outer view, same specimen as on pl. 2, fig. 2, No. Zr9718, (5.0 mm × 2.7 mm).

Fig. 3 Lower, left, lateral tooth; outer view, same specimen as on pl. 2, fig. 4, No Zr9719 (4.0 mm × 3.3 mm).

Fig. 4 Lower left, posterior, lateral tooth; inner view, same specimen as on pl. 2, fig. 5, No Zr9720, (2.1 mm × 2.4 mm).

Fig. 5 Upper tooth; outer view, same specimen as on pl. 2, fig. 7, No Zr9721, (3.0 mm × 1.0 mm).

Fig. 6 Upper tooth; lateral view, same specimen as on pl. 2, fig. 8, No Zr9723, (1.8 mm × 0.8 mm).

Zr numbers refer to specimens in the Institute of Geological Sciences, London.

Quoted measurements are of the heights and widths respectively in each figure.

EXPLANATION OF TEXT-FIGURE 3

Figs 1 to 4 Lower tooth fragment, possible median or left lateral; same specimen as on pl. 2, fig. 9, No Zr9722.

Fig. 1 Outer view, (4.1 mm × 2.1 mm).

Fig. 2 Inner view, (4.1 mm × 2.1 mm).

Fig. 3 Lateral view with internal depression, showing axes of root and tooth, (4.1 mm × 1.5 mm).

Fig. 4 Lateral view of broken area, (4.1 mm × 1.5 mm).

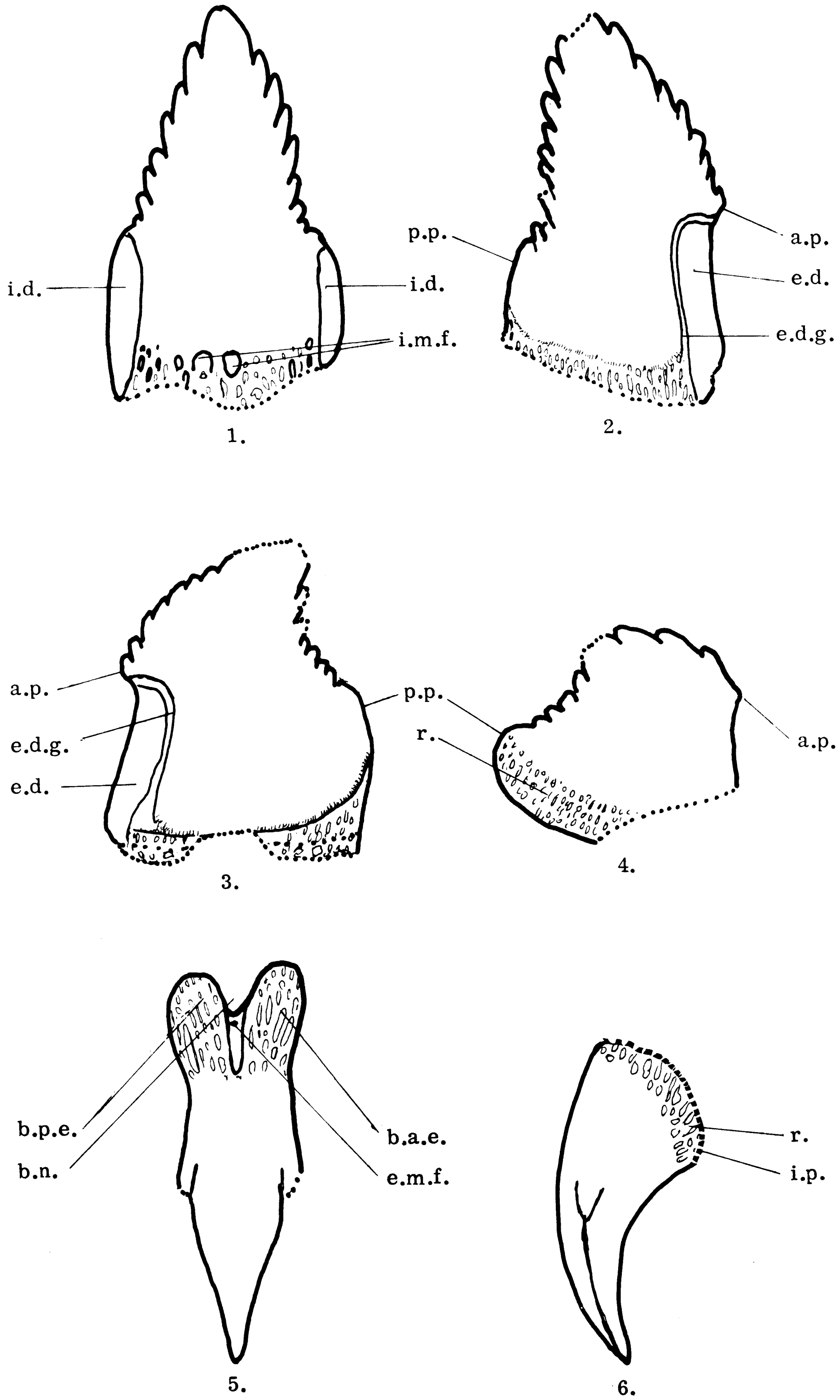
Fig. 5 Upper tooth; lateral view, same specimen as on pl. 2, fig. 7, No Zr9721, (3.0 mm × 1.4 mm).

Fig. 6 Diagram of the relationship between axes of tooth, root and median canals.

Zr numbers refer to specimens in the Institute of Geological Sciences, London.

Quoted measurements are of the heights and widths respectively in each figure.

Text-Figure 2



Two lower tooth basal fragments

Wollaton Hall (Chamberlain Collection). Both have a distinctive external depression with external depression groove.

Upper tooth

Wollaton Hall (Chamberlain Collection). This tooth has most of the crown with one lateral point on either side. The internal protuberance with the internal median foramen is present, also part of the root.

6. Lavernock foreshore, Glamorganshire (ST 187682)

A sample of the excellent Storries Bed owned by Dr. H. Ivimey Cook provided one lower tooth whilst a large sample from a less fossiliferous horizon at the same locality yielded one lower tooth fragment. Both samples were broken down by acetic acid treatment.

Lower, left, lateral tooth

I.G.S., No. Zr9670. This tooth has the lower part of the crown and part of the base with the internal depression (2.3 mm. high, 2.2 mm. long).

Lower tooth fragment

J.H. Sykes personal collection. This is a fragment of a crown with a few serrations and characteristic internal structure.

7. Penarth, Glamorganshire (ST 186697)

Eight *D. barnstonensis* teeth (7 lower and 1 upper) were found amongst the unclassified specimens collected from this locality by Dr. J. Griffiths.

Lower, median tooth

I.G.S., London, No. Zr9724, figured Pl.2, fig.1, text-fig.2, fig.1). This has a complete crown with seven serrations on either side. The base extends laterally, equally on either side and has two internal depressions. The preserved part of the root has fairly complete median canals.

Lower, left, lateral tooth

I.G.S., No. Zr9725. An almost complete crown and part of the base with an anterior process, external depression and external depression groove (2.7 mm. high, 1.5 mm. long).

Lower, left, lateral tooth

I.G.S., No. Zr9726. A part of a crown with part of the base showing anterior process, external depression and external depression groove.

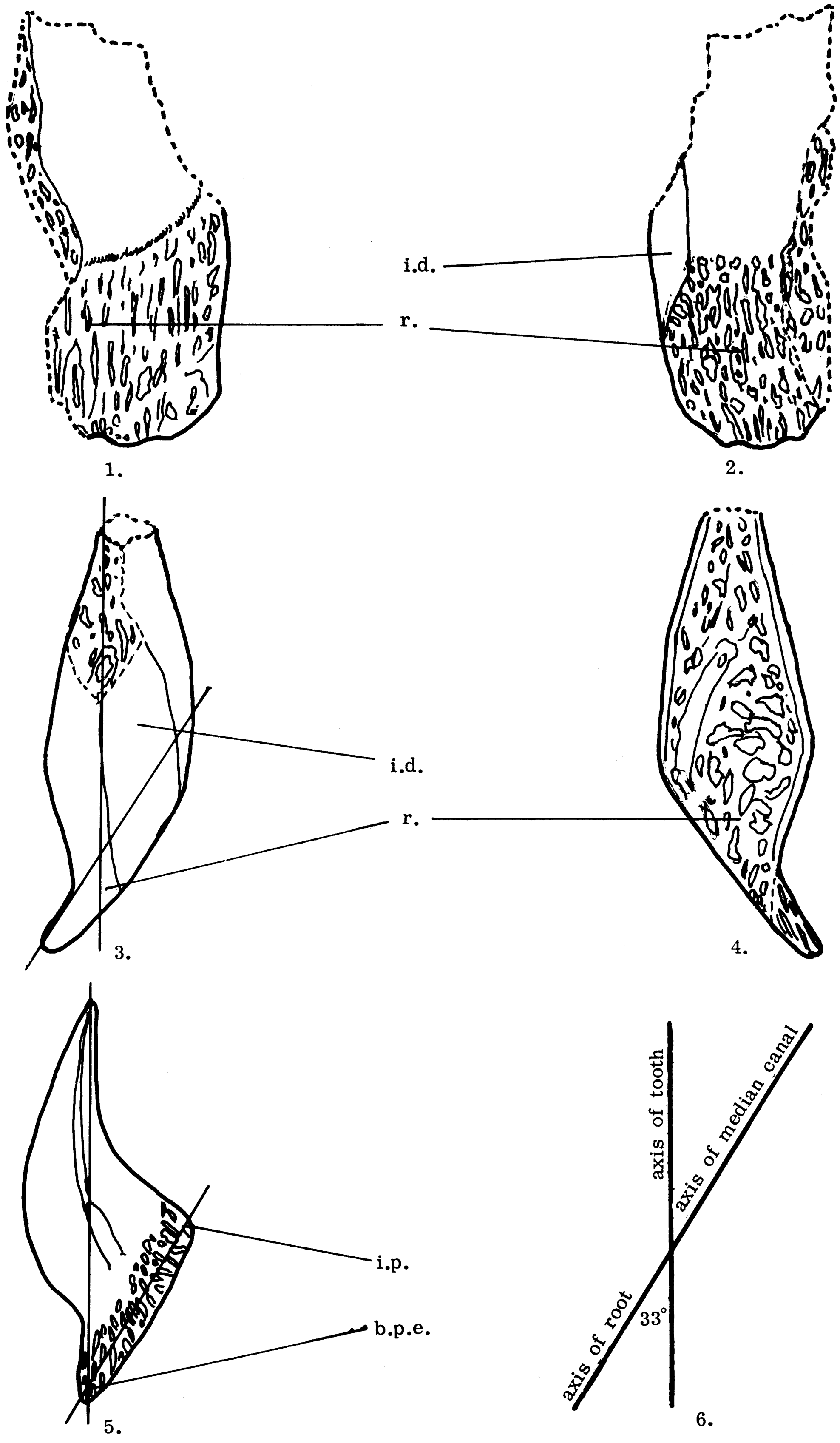
Four detached crowns

I.G.S., No. Zr9727. One with the tip broken off.

Upper, right, lateral tooth

I.G.S., No. Zr9728. An almost complete tooth with one lateral point on either side (8 mm. high, 2 mm. long).

Text-Figure 3



8. Westbury-on-Severn, Gloucestershire (Grid Reference not known)

One lower tooth loaned from the collection of Mr. C. Duffin.

Lower, left, anterior, lateral tooth

Mr. C. Duffin personal collection, figured Pl. 2, fig. 3. The specimen is attached to the matrix by the inner face. The crown is almost complete. The base shows the anterior and posterior processes also the external depression and the external depression groove. Part of the root is also present.

9. Barnstone Cutting, Nottinghamshire (SK739358)

158 lower and 35 upper teeth have been collected from this locality. They are distributed in three groups in the following manner.

66 Lower teeth (25 left, 19 right, 7 median, 15 fragments) and 14 Upper teeth

British Museum (Natural History) including holotype and paratypes Nos P51407 to P51414.

88 Lower teeth (36 left, 43 right, 9 median) and 20 Upper teeth

J.H. Sykes personal collection

4 Lower teeth (2 left, 1 right, 1 fragment) and 1 Upper tooth

Institute of Geological Sciences, London, Nos Zr9718 to Zr9722, figured Pl. 2, figs. 2, 4, 5, 7, 9, text-fig. 2, figs. 2, 3, 4, 5, text-fig. 3, figs. 1, 2, 3, 4, 5.

Briefly, the lower teeth are transversely compressed having a single, serrate, triangular crown on a rectangular base and a root which is usually broken off at or above the median canals. The median teeth have a tall, upright, near equilateral crown on a base which is laterally expanded on both sides having two internal depressions overlapping the teeth immediately on either side. In the lateral teeth the crowns vary between high, almost upright, anterior types to low, inclined, posterior types. Each base has a small anterior process and a larger posterior process. They have a posterior internal depression and an anterior external depression which allows the base of each tooth to overlap the one immediately posterior to it. The upper teeth have a thorn-like crown; the majority have one but some have up to three lateral points on either side, near the base. They have a bifid root (text-fig. 2, fig. 5) with a median canal passing through parallel and close to the base (text-fig. 3, fig. 5).

The Roots of the Lower Teeth

Sharks' teeth are continually being broken off and shed into the water by the progression of a series of teeth towards the edge of the mouth. In *Dalatias barnstonensis* the transverse thinning of the lower teeth and the vascular system of the root tend to create a weakness which detaches the tooth from the lower part of the root. However, one specimen from Barnstone has been found with a part of the base of its root intact (Pl. 2, fig. 9, text-fig. 3, figs. 1, 2, 3, 4).

Description of the Root Specimen

This tooth is broken off above the base; it is also broken longitudinally and lacks the median canals. The distinct root is transversely compressed; when viewed laterally it is curved outward and tapered downward to a rounded basal edge. The lower part of the internal depression is present and it extends about half the length of the root. The preserved edge is slightly concave towards the base. The basal edge is rather worn but its median rounding suggests the possible presence of a basal notch. The broken edge exposes the pulp cavity with its many connecting pores, the larger ones being near the thickest part of the tooth. On the outer face, the distinct boundary of the root extends obliquely, posteriorly upwards. The outer root area is depressed and bears pores and longitudinal striations. On the inner face, the upper boundary of the root is almost horizontal; the surface is rather worn, but has longitudinal corrugations similar to those on the inner face of the roots of the upper teeth.

Angles of Roots and Median Canals in relation to the Axis of the Tooth

Two lower teeth were found to have been broken off with sufficient of the root intact to show the angle of inclination between the axis of the root and the axis of the tooth. When viewed from the side with the median canals upright, the axes of the roots were also upright. This shows that the direction of the axis of the root coincides with the direction of the median canals (text-fig. 3, figs. 3, 6). The respective angles between these coincident directions and the axes of the teeth are 33° and 34°. In the specimen with part of the root base intact (pl. 2, fig. 9), the angle between the root and tooth is estimated at 31° (text-fig. 3, fig. 3) thus the average angle is about 33°.

One specimen shows the median canals partly broken away and has part of the inner root surface intact. This shows that the median canals run close to the base of the root, as is the case in the upper teeth (text-fig. 3, fig. 5) where the internal and external median foramina can be seen in complete specimens (text-fig. 2, fig. 5, and pl. 2, figs. 7, 8).

Comparison with other Dalatiid Teeth

The species *D. barnstonensis* was founded on comparison with other fossil Dalatiid teeth and also with those of the modern species *Dalatias licha.*

When viewed transversely, the outline of the *D. barnstonensis* root compares well with those of *D. licha* figured in Bigelow and Schroeder (1948, p. 502). Casier (1961, p. 20) shows that in *D. licha* the internal depression extends about half way down the root, as in the root specimen *D. barnstonensis* (text-fig. 3, figs. 2 & 3). In *D. licha* there is a groove which runs from the basal notch to an opening. These features are unproven in *D. barnstonensis* though from the evidence available it is to be inferred that the median canals are nearer to the base of the root in *D. barnstonensis* than in *D. licha.* When viewed laterally the root of *D. licha* is almost straight (Casier 1961, p. 20) whereas the lower part of the *D. barnstonensis* root is angled outwards. This feature combined with the characteristic of the median canals running parallel and close to the inner surface of the root is common to the lower and upper teeth of *D. barnstonensis* (text. fig. 3, figs. 3, 5) and also to the upper teeth of *D. licha* (Casier, 1961, p. 20).

Conclusions

Although only a few specimens of teeth are recorded from localities other than Barnstone it is to be concluded that the species *D. barnstonensis* is geographically widespread in the Westbury Formation of the British Rhaetic.

The root of the lower tooth curves outward to an angle of approximately 33° from the axis of the tooth and tapers to a rounded basal edge.

Acknowledgements

I should like to thank Dr. J. Griffiths for the kind donation of his collection and also Mr. C. Duffin and Mrs. P. Catchpole for the loan of specimens.

I am grateful to Mr. M.D. Jones of the Leicester Museum, Dr. C. Patterson of the British Museum (Natural History), Mr. B.R.P. Playle of the Wollaton Museum and Dr. H. Ivimey Cook of the Institute of Geological Sciences for their generous assistance in providing access to museum material. I should like to thank Dr. H. Ivimey-Cook and Mr. A.M. Honeyman for reading the typescript, and making useful suggestions on the presentation of the paper. I am further indebted to the Dept. of Geology and Wolfson Institute of Nottingham University and to Mr. J.S. Cargill for assistance in producing Plate 2.

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EXPLANATION OF PLATE 2

Fig. 1 Lower, median tooth; outer view, × 24 Penarth, (text-fig.2, fig.1), No. Zr9724.

Fig. 2 Lower, right, anterior, lateral tooth; inner view, × 13, Barnstone, (text-fig. 2, fig. 2), No Zr9718.

Fig. 3 Lower, left, anterior, lateral tooth; outer view, × 15, Westbury-on-Severn, Mr. C. Duffin personal collection.

Fig. 4 Lower, left, lateral tooth; inner view, × 13, Barnstone, (text-fig. 2, fig. 3), No. Zr9719.

Fig. 5 Lower, left, posterior, lateral tooth; outer view, × 17, Barnstone, (text-fig. 2, fig. 4), No. Zr9720.

Fig. 6 Lower, left, posterior, lateral tooth; outer view, × 14, Aust, Leicester Museum, No. O.S.1.1973).

Fig. 7 Upper tooth; inner view showing internal median foramen × 22, Barnstone (text-fig. 2, fig. 5; text-fig. 3, fig. 5), No. Zr9721.

Fig. 8 Upper tooth; inner view showing internal median foramen, × 32, Blue Anchor Bay, (text-fig. 2, fig. 6), No. Zr9723.

Fig. 9 Lower tooth fragment; outer view showing root features, × 16.5, Barnstone (text-fig. 3, figs. 1 - 4), No. Zr9722.

Zr numbers refer to specimens in the Institute of Geological Sciences, London.

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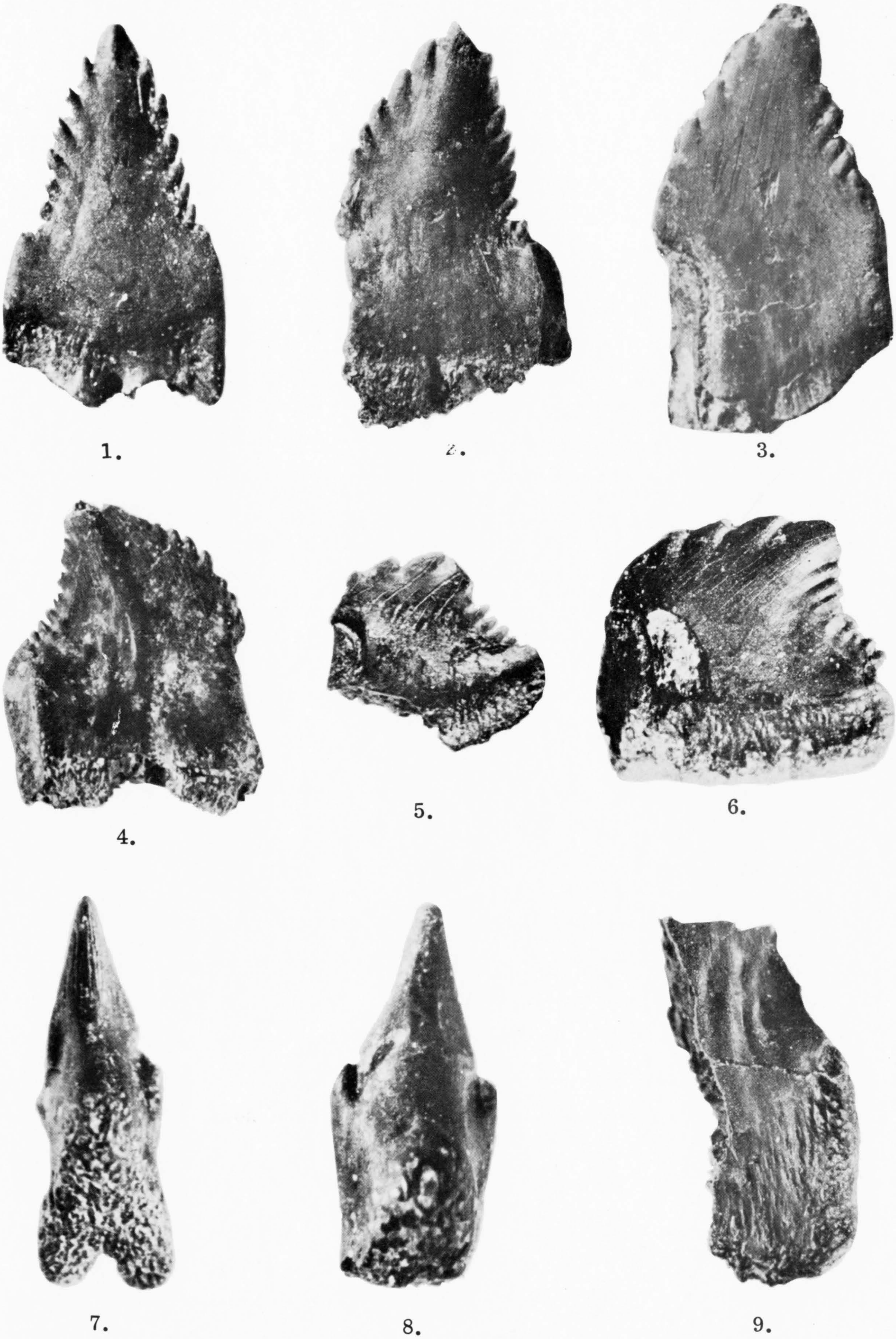
Plate 2



Teeth of *Dalatias barnstonensis*.

ON ELASMOBRANCH DERMAL DENTICLES FROM THE RHAETIC BONE BED AT BARNSTONE, NOTTINGHAMSHIRE

by

J.H. Sykes

Summary

Elasmobranch dermal denticles from Rhaetic bone beds are described including a new minute form. Their affinities with the family Dalatidae, various hybodont genera and the family Squalorajidae are discussed.

Introduction

Dermal denticles are small tooth-like structures which protrude from the skin of sharks giving it a roughness which has caused it to be known as shagreen. In text-fig. 1, fig.2, the typical parts of a denticle are illustrated, following the terms used by Applegate (1967).

The majority of the denticles forming the subject of this paper were collected from the Barnstone Railway Cutting, approximately 850 metres east of Barnstone, Nottinghamshire, (SK 739358). Here a section exposing the Rhaetic Bone Bed was excavated by Members of the East Midland Geological Society, (Sykes, Cargill and Fryer, 1970).

The Barnstone denticles, along with others found in Rhaetic bone bed exposures of additional localities including Aust, Axminster, Gainsborough, Lavernock and Penarth, fall into three groups, two of which (A and B) are common, and one (C) is rare. Each group has its exclusively distinguishing characteristic features. Denticles of one of the common groups (A) are much smaller than the other two and are considered, on the comparison with the upper teeth and general Dalatiid characteristics, to have affinities with the fish species *Dalatias barnstonensis* Sykes (1971). The common group, (B), of large dermal denticles can be referred, (by comparison with established hybodont denticles) to genera of hybodonts. The third group (C), which are large in size, conical in shape but quite rare in occurrence, are considered to be dermal denticles of Chimaeroid fish.

Samples of bone bed weighing 183 grams from both Gainsborough and Barnstone yielded the following count of *D. barnstonensis* teeth and dermal denticles. The Gainsborough Bone Bed, because of its pyritic matrix, did not yield as many specimens as did the more friable Barnstone Bone Bed.

Table 1 - Specimens of teeth and denticles from Rhaetic Bone Bed

	D. Barnstonensis Teeth		Dermal denticles		
	Upper Jaw	Lower Jaw	Minute [A]	Hybodont [B]	Rare [C]
Gainsborough	1	3	55	10	1
Barnstone	3	3	278	22	0

Mercian Geologist, Vol. 5, No. 1. 1974. pp. 49-64, 3 text-figs. Plate 3.

TABLE 2 SHOWING THE COMBINATIONS OF FEATURES IN 80 WHOLE RHAETIAN DERMAL DENTICLES

		Crowns	Pointed	Medium Broad	Broad	Triple Keeled	Bifurcate Keels	Extra Keels	Upper View Quadrate	U.V.Quad & Pointed Rear	U.V.Rounded	U.Surface Flattened	U.S. Part Smooth	U. Surface Smooth	Lateral Points	*Pedicels*	Broad	Medium	Slender	Sub-Square	Laterally Compressed	Transversely Comp.	Short	Medium	Long	*Basal Plates*	Sub-Square	Laterally Compressed	Med. Trans. Compressed	Transversely Comp.
			12	54	14	5	65	10	42	19	11	10	15	9	13		19	50	11	35	4	41	33	45	2		30	4	34	12
Crowns		80																												
Pointed	12		12	0	0	5	7	0	0	4	0	0	0	0	4		2	10	0	11	1	0	5	7	0		12	0	0	0
Medium Broad	54		0	54	0	0	44	10	39	15	0	7	15	8	5		17	32	5	22	3	29	23	29	2		16	4	28	6
Broad	14		0	0	14	0	14	0	3	0	11	3	0	1	4		0	8	6	2	0	12	5	9	0		2	0	6	6
Triple Keeled	5		5	0	0	5	0	0	1	1	0	0	0	0	2		1	4	0	5	0	0	5	0	0		5	0	0	0
Bifurcate Keels	65		7	44	14	0	65	0	33	16	11	10	8	8	11		15	40	10	26	4	35	23	40	2		24	4	28	9
Extra Keels	10		0	10	0	0	0	10	0	0	0	3	7	1	2		3	6	1	4	0	6	5	5	0		1	0	6	3
Upper View Quadrate	42		0	39	3	1	33	0	42	0	0	8	12	6	1		12	28	2	19	2	21	18	23	1		15	2	21	4
U.V. Quad & Pointed Rear	19		4	15	0	1	16	0	0	19	0	1	3	1	3		5	11	3	7	2	10	8	10	1		6	2	9	2
U.V. Rounded	11		0	0	11	0	11	0	0	0	11	0	0	1	4		2	3	6	1	0	10	3	8	0		1	0	4	6
U. Surface Flattened	10		0	7	3	0	10	3	8	1	0	10	3	4	0		4	5	1	6	1	0	4	6	0		6	0	2	2
U.S. Part Smooth	15		0	15	0	0	8	7	12	3	0	3	15	0	1		6	7	2	7	1	5	7	8	0		6	2	7	0
U. Surface Smooth	9		0	8	1	0	8	1	6	1	1	4	0	9	0		5	2	2	6	1	2	4	5	0		3	2	2	2
Lateral Points	13		4	5	4	2	11	2	1	3	4	0	1	0	13		2	7	4	2	1	8	10	1	2		3	1	6	3
Pedicels																80														
Broad	19		2	17	0	1	15	3	12	5	2	4	6	5	2		19	0	0	12	1	6	12	7	0		10	0	8	1
Medium	50		10	32	8	4	40	6	28	11	3	5	7	2	7		0	50	0	20	3	27	20	30	0		19	3	19	9
Slender	11		0	5	6	0	10	1	2	3	6	1	2	2	4		0	0	11	3	0	8	1	8	2		1	1	7	2
Sub-Square	35		11	22	2	5	26	4	19	7	1	6	7	6	2		12	20	3	35	0	0	14	21	0		29	0	5	1
Laterally Compressed	4		1	3	0	0	4	0	2	2	0	1	1	1	1		1	3	0	0	4	0	1	3	0		0	4	0	0
Transversely Comp.	41		0	29	12	0	35	6	21	10	10	0	5	2	8		6	27	8	0	0	1	18	21	2		1	0	29	11
Short	33		5	23	5	5	23	5	18	8	3	4	7	4	10		12	20	1	14	1	18	33	0	0		11	3	16	3
Medium	45		7	29	9	0	40	5	23	10	8	6	8	5	1		7	30	8	21	3	21	0	45	0		19	1	17	8
Long	2		0	2	0	0	2	0	1	1	0	0	0	0	2		0	0	2	0	0	2	0	0	2		0	0	1	1
Basal Plates																										80				
Sub-Square	30		12	16	2	5	24	1	15	6	1	6	6	3	3		10	19	1	29	0	1	11	19	0		30	0	0	0
Laterally Compressed	4		0	4	0	0	4	0	2	2	0	0	2	2	1		0	3	1	0	4	0	3	1	0		0	4	0	0
Med. Trans. Compressed	34		0	28	6	0	28	6	21	9	4	2	7	2	6		8	19	7	5	0	29	16	17	1		0	0	34	0
Transversely Comp.	12		0	6	6	0	9	3	4	2	6	2	0	2	3		1	9	2	1	0	11	3	8	1		0	0	0	12

EXPLANATION OF TABLE 2

Individual characteristics of the CROWNS, PEDICELS and BASAL PLATES are listed under those headings on the left.

In each case, the figure in the first column on the left shows how many of the eighty denticles have that particular characteristic.

Subsequent figures along the row enumerate the quantities of other characteristics (listed above) held by denticles of that particular group.

EXAMPLE: Under the heading CROWNS on row No. 7 is listed the characteristic of 'quadrate upper view'; the first column of figures shows, that, out of the eighty, there are 42 denticles with this feature.

By consulting the figures along the row, under the characteristics listed above, it is possible to note that out of the 42 denticles with a quadrate upper view, 12 of them have crowns with the upper surface partly smooth, only 2 of them have slender pedicels, 21 of them have a basal plate which is average or medium transversely compressed, and so on.

Dalatiid Dermal Denticles (Group A)

The minute denticles are quite common in the finer residues from Barnstone. Many of them are broken, especially the large and more fragile ones, but a large number are preserved whole. In order to obtain an estimate of the relative amounts of the various types of these denticles, a further total extraction of 280 specimens was taken from an unspecified amount of bone bed, including complete and broken examples. The denticles display a great diversity in the combinations of their minor features. To assess this diversity, the chief morphological features of each part of the denticles were listed (Table 2) and eighty of the complete specimens were closely examined, their characteristic features being plotted in Table 2.

From an inspection of the whole of the denticles it was possible to note the major commonly occurring groupings of characteristics and to define distinct types. The denticles fall broadly into three chief groups (Nos. 1, 2 and 3) and two minor groups (Nos. 4 and 5). Groups 1, 2 and 3 have variations on the common type which are either extreme forms or intermediate between the groups. Table No. 2 generally confirms the broad outlines of these groupings but it also shows the complexity of individual specimen types.

The three samples of minute, group A, denticles were divided in the following manner:

Table 3 - Minute Denticles (Group A)

Type Nos.	1	1a	1b	2	2a	2b	3	3a	3b	4	5	total
Locality												
G	1	0	0	32	0	5	10	1	2	4	0	55
B.1.	15	15	1	131	4	15	66	13	8	8	2	278
B.2.	10	18	3	133	4	6	69	114	4	10	9	280

Key to Table 3:-

G = Gainsborough (Wollaton Museum, Nottingham, Chamberlain Collection)

B.1. = Barnstone 183 grams (278 denticles grouped under No. Zr9681, Institute of Geological Sciences, London. (I.G.S).

B.2. = Barnstone second sample (denticles 1-80, Zr9682 and 200 denticles, Zr9683, I.G.S.).

The following is a general summary of the characteristics of the various types of minute denticle (Group A):-

Type No.1, pl. 3, figs. 1-2; text-fig. 1, fig. 1; text-fig. 2, fig. 8.

Basal Plates are expanded and mostly sub-square.

Pedicels are upright and of medium width.

Crowns are pointed and inclined posteriorly at an angle of approximately 45°.

Keels extend from the basal plate to the crown tip, approximately half of the denticles having bifurcate keels, apparently a random feature.

EXPLANATION OF TEXT-FIGURE 1

Rhaetian Denticles illustrating the
Relationships of the Types

Fig. 1 Type No. 1 Zr9684, upper view (.6 mm × .4 mm), anterior view (.5 mm × .4 mm), lateral view (.5 mm × .5 mm).

Fig. 2 Lateral view showing denticle features, Zr9685, (.4 mm × .5 mm).

Fig. 3 Illustration of Basal Plate shapes (Table 2), a, laterally compressed, Zr9686, (.4 mm × .3 mm). b, Sub-square, Zr9687, (.3 mm × .3 mm). c, medium transversely compressed, Zr9688, (.4 mm × .25 mm). d, transversely compressed, Zr9689, (.5 mm × .2 mm).

Fig. 4 Type No. 1a Zr9690, upper view (.5 mm × .4 mm), anterior view (.5 mm × .4 mm), lateral view (.5 mm × .5 mm).

Fig. 5 Type No. 2b Zr9691, upper view (.4 mm × .4 mm), anterior view (.4 mm × .4 mm), lateral view (.4 mm × .4 mm).

Fig. 6 Type No. 1b Zr9692, upper view (.4 mm × .2 mm), anterior view (.6 mm × .2 mm), lateral view (.6 mm × .3 mm).

Fig. 7 Type No. 2 Zr9693, upper view (.3 mm × .5 mm), anterior view (.4 mm × .5 mm), lateral view (.4 mm × .6 mm).

Fig. 8 Type No. 3b Zr9694, upper view (.6 mm × .7 mm), anterior view (.9 mm × .7 mm), lateral view (.9 mm × .7 mm).

Fig. 9 Type No. 2a Zr9695, upper view (.3 mm × .4 mm), anterior view (.4 × .4), lateral view (.4 mm × .4 mm).

Fig. 10 Type No. 3a Zr9696, upper view (.4 mm × .5 mm), anterior view (.5 mm × .5 mm), lateral view (.5 mm × .5 mm).

Fig. 11 Type No. 5 Zr9697, upper view (.4 mm × .2 mm), anterior view (.7 mm × .2 mm), lateral view (.7 mm × .5 mm).

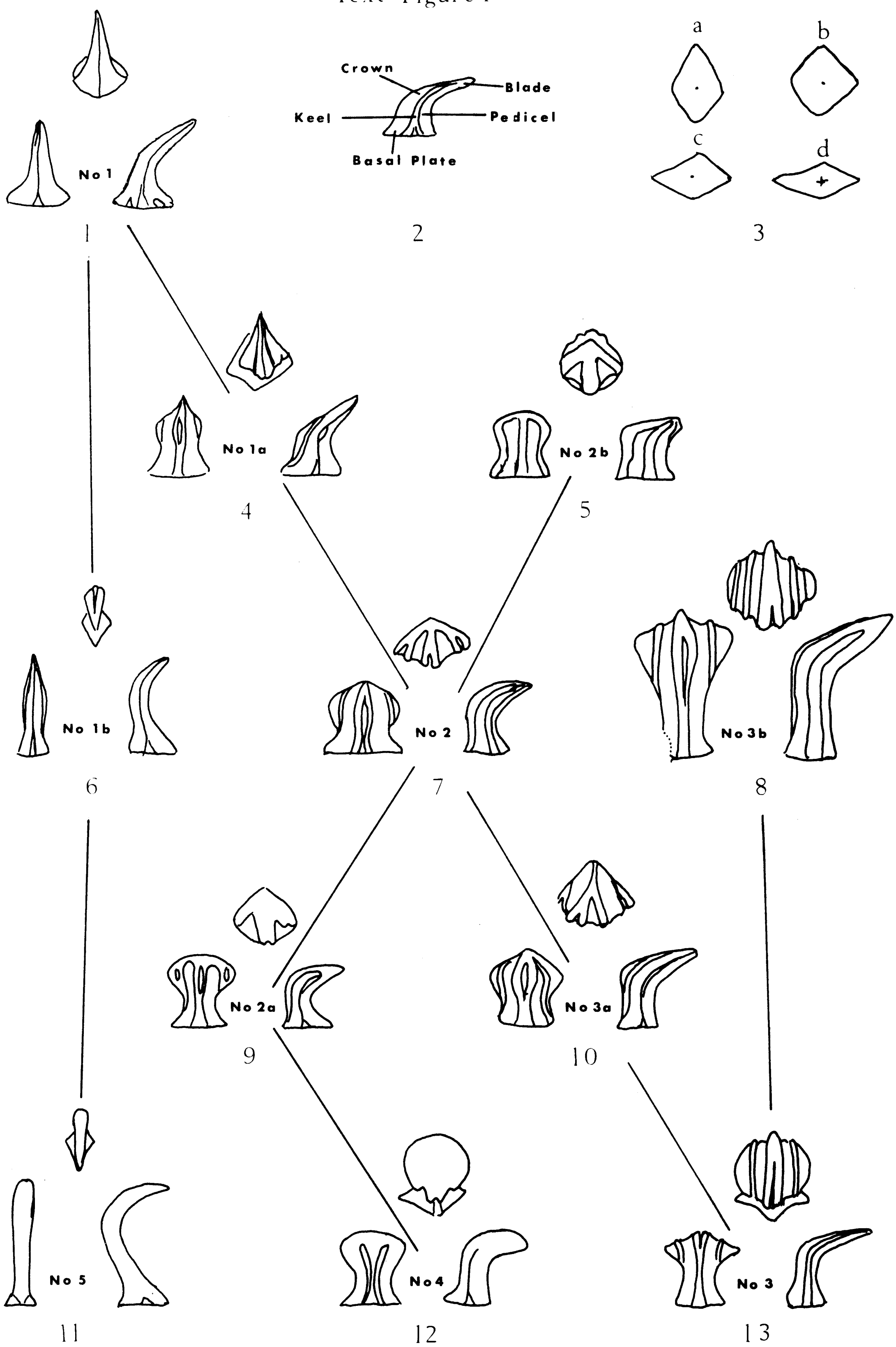
Fig. 12 Type No. 4 Zr9698, upper view (.5 mm × .4 mm), anterior view (.5 mm × .4 mm), lateral view (.5 mm × .5 mm).

Fig. 13 Type No. 3 Zr9699, upper view (.5 mm × .5 mm), anterior view (.5 mm × .5 mm), lateral view (.5 mm × .5 mm).

All denticles are drawn to the same scale and the quoted measurements are of heights and widths respectively in each figure. In each case the upper figure is an upper view, the one on the left an anterior view and the one on the right a lateral view.

Specimens are deposited in the Institute of Geological Sciences, London and numbered Zr9684 to Zr9699.

Text-Figure 1



Type No. 1a, pl. 3, fig. 3; text-fig. 1, fig. 4

The crown is wider especially near the base, some having lateral points. These denticles are transitional to type no. 2.

Type No. 1b, text-fig. 1, fig. 6

The pedicels and crowns are more rounded in section and on some, the pedicels are inclined anteriorly, resembling type no. 5 though keeled; the crowns are rather inflated.

Type No. 2, pl. 3, figs. 4-5; text-fig. 1, figs. 2 & 7; text-fig. 2, figs. 5-6.

Basal Plates are generally less expanded than in type no. 1; about 25% are subsquare and most of the rest transversely compressed.

Pedicels are upright, tending to be short and broad with many being rather transversely compressed.

Crowns are inclined posteriorly at a low angle from the horizontal and they all have a short blade and a quadrate upper view. Many have the whole or part of the upper surface smooth and without keels.

Specimens of no. 2 type are the commonest and have the most varied forms.

Type No. 2a, text-fig. 1, fig. 9

The basal plate is rather smaller; the pedicel narrower and the crown develops a rounded posterior edge. The lateral keels are faint or missing and the hollow between the keels deepened. Denticles of type 2a are transitional to those of type no. 4.

Type No. 2b, text-fig. 1, fig. 5

Specimens allocated to this sub-division are an extreme form almost without blade extension of the crown. The upper surface is almost horizontal and often smooth. Some are very broad with extra keels and some have short keels on the posterior face.

Type No. 3, pl. 3, figs. 7-8; text-fig. 1, fig. 13; text-fig. 2, figs. 15-16.

Basal Plates are usually widespread laterally and transversely compressed.

Pedicels are generally of medium width or narrow.

Crowns are all broad, nearly all of them having bifurcate keels; most of the lateral ones ending as separate points near the tip.

Denticles of no. 3 type are mostly transversely compressed in all their features.

Type No. 3a, text-fig. 1, fig. 10

Basal plate and pedicel are transversely compressed. The crown is less rounded in upper view and narrower. Lateral keels may or may not reach the tip of the crown. Type 3a denticles are intermediate in morphology between types no. 2 and no. 3.

Type No. 3b, text-fig. 1, fig. 8

Specimens of this type are larger than the rest. They have narrow, transversely compressed basal plates; elongate, narrow pedicels and broad, high-angled crowns. The keels are strong, ending in distinct points.

Type No. 4, pl. 3, fig. 6; text-fig. 1, fig. 12; text-fig. 2, fig. 7

The basal plates are transversely compressed and the pedicel is so narrow that most of the crowns are detached. The horizontally inclined crown has a smooth, convex upper surface with a rounded posterior edge. Most denticles of this type have two deep grooves which extend from the basal plate to part of the upper surface of the crown.

Type No. 5, pl. 3, fig. 9; text-fig. 1, fig. 11

Specimens of type no. 5 have a quadrate basal plate that narrows to a smooth needle-like hook which is circular in section. This hook inclines anteriorly from the basal plate and then curves sharply posteriorly to a pointed tip. Denticles of this group may be clasper hooks such as occur on the claspers of the male sharks.

Discussion on the affinity of Group A denticles

Size and distribution of Minute Denticles

The minute denticles from Barnstone range in size from a height of approximately 0.3 mm and a length of 0.2 mm to a height of 0.9 mm and a length of 0.7 mm. The majority of the denticles are approximately 0.5 mm high and 0.5 mm long.

If these denticles belong to *D. barnstonensis* the teeth of the same species should occur with the same strata. This has proved to be so at nine localities and though specimens are sometimes rare, all bone beds examined have yielded specimens of the teeth and denticles. (Sykes, 1974).

Dermal Denticles of the Order Squalea

In the Order Squalea, to which the Family Dalatiidae belongs, there is a variation in dermal denticles between plate-like and spiny types. White (1957, p. 59) considers that there was possibly a development from one type to the other, with the plate-like type being the more primitive. Characteristics of the minute Rhaetian denticles are to be found in many of the denticles of modern squalid sharks. Many like *Isistius braziliensis* are minute and have a quadrated basal plate. Some have triple keels, *Somniosus microcephalus* (text-fig. 2, figs. 9-10) having both single and bifurcate keels. *Squalus acanthus* (text-fig. 2, figs. 11-12), *Centroscymnus coelolepis* and others have distinct quadrate pedicels and blade-like, transversely compressed crowns, whilst those of *Etmopterus hillanus* are quadrate with an expanded base and a curved, pointed crown (all figures in Bigelow and Schroeder, 1948).

Most of the species in the Order Squalea have varying forms of denticles on different parts of their body.

Dermal Denticles of the recent species, *Dalatias licha*

Specimens of *Dalatias licha* in the British Museum (Nat. Hist.) show that over the body as a whole the denticles have an expanded quadrate base which narrows to a low, broad pedicel. The crowns have a quadrate upper view with slightly concave sides; they are inclined posteriorly at an angle of about 45°. On the dorsal surface of the fish the crowns are wider and more rounded. The denticles have three keels which are bifurcate on the broader denticles (text-fig. 2, figs. 1-2). Under the snout the denticles are strongly transversely compressed. Their basal plates are expanded and they have upright pedicels with crowns inclined posteriorly almost at right angles having a rather rounded upper view. There are rather faint single and bifurcate keels which on some denticles do not extend across the smooth upper surface of the crown (text-fig. 2, fig. 3). On the denticles towards the tail of the fish, the crowns narrow and become pointed. The expanded quadrate base narrows to a short upright pedicel, the crowns

EXPLANATION OF TEXT-FIGURE 2

Fig. 1 *Dalatias licha* (Bonaterre) 1788, outline of median section of body denticle (after Daniels, 1934, p. 32).

Fig. 2 *Dalatias licha*, upper view of body denticle (after Bigelow and Schroeder, 1948, p. 502) (.8 mm × 9 mm).

Fig. 3 *Dalatias licha*, upper view of denticle from the ventral surface of the snout (after Bigelow and Schroeder, 1948, p. 502) (0.9 mm × 0.9 mm).

Fig. 4 *Dalatias licha*, lateral view of tail denticle, Zr9700, (0.8 mm × 1.0 mm).

Fig. 5 Rhaetian denticle, type No. 2, lateral view, Zr9701, (0.4 mm × 0.4 mm).

Fig. 6 Same specimen as figure No. 5, upper view (0.3 mm × 0.4 mm).

Fig. 7 Rhaetian denticle, type No. 4, upper view, Zr9702 (.4 mm × .4 mm).

Fig. 8 Rhaetian denticle, type No. 1, lateral view, Zr9703 (0.5 mm × 0.4 mm).

Fig. 9 *Somniosus microcephalus* (Block & Schneider, 1801), lateral view (after Bigelow & Schroeder, 1948, p. 517) (.9 mm × 1.1).

Fig. 10 *Somniosus microcephalus*, upper view (after Bigelow & Schroeder, 1948, p. 517) (1.2 mm × 1.1 mm).

Fig. 11 *Squalus acanthus* Linnaeus, 1758, upper view (after White 1937, pl. 4) (app. .8 mm × .6 mm).

Fig. 12 *Squalus acanthus* posterior view (after White, 1937, pl. 4) (app. .6 mm × .6 mm).

Fig. 13 *Dalatias barnstonensis* Sykes, 1970, upper tooth, lateral view (after Sykes, 1970, pl. 21) (3.2 mm × 1.0 mm).

Fig. 14 *Dalatias licha*, upper tooth, lateral view (after Casier, 1961, p. 20) (6.0 mm × 1.3 mm).

Fig. 15 Rhaetian denticle, type No. 3, upper view, Zr9704 (0.3 mm × 0.4 mm).

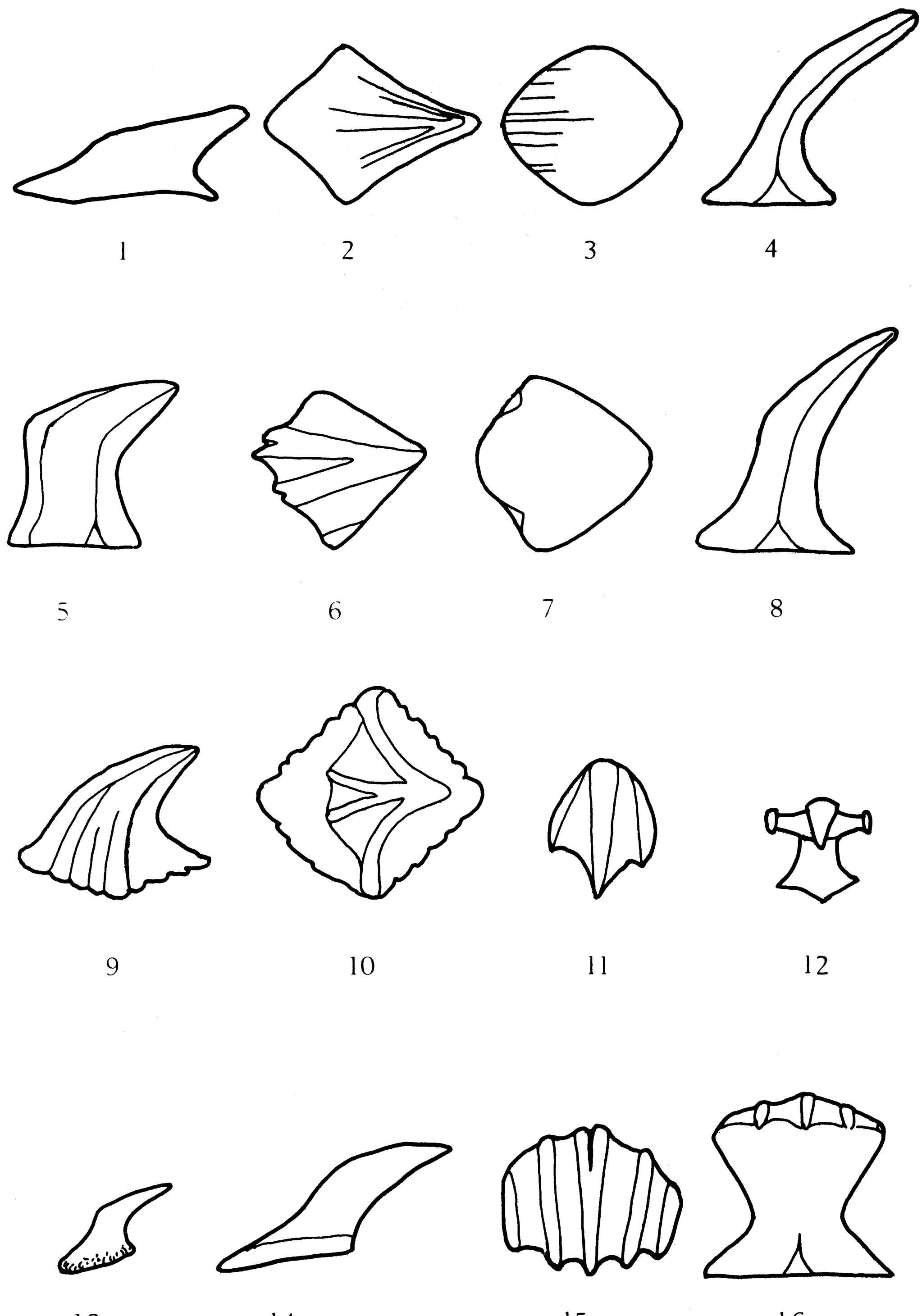
Fig. 16 Same specimen as figure No. 15, posterior view (0.4 mm × 0.4 mm).

The teeth (figs. 13 & 14) are drawn to the same scale; figures 1, 2, 3, 9, 10, 11 & 12 are all to a scale four times the size of the teeth; figures 4, 5, 7, 8, 15 & 16 are all to a scale ten times the size of the teeth.

The quoted measurements are of the height and width respectively in each figure.

Specimens numbered Zr9700 to Zr9704 are deposited in the Institute of Geological Sciences, London.

Text Figure 2



inclined posteriorly at approximately 45° (text-fig. 2, fig.4). The fins have much smaller denticles with narrower pedicels and pointed crowns.

Comparison between the Group A Denticles and those of *Dalatias licha*

The Rhaetian minute denticles (Group A) and those of the recent species *D. licha* have several features in common. Both forms of denticles are small, ranging in width from about one-fifth to one-eighth of the width of the respective teeth. They both have a flat based, quadrate, expanded basal plate, though the expansion is greater in *D. licha* along with a tendency for the basal plate to have more acute corners.

The pedicels of both types are quadrate though in *D. licha* they are shorter and less upright.

The crowns of the majority of denticles of both Group A and *D. licha* have a quadrate upper view varying in breadth and posterior elongation from denticle to denticle. They are both ornamented with keels which generally extend from the basal plate to the tip of the crown. On the Rhaetian denticles the keels are mostly bifurcate with some having extra keels. This feature of bifurcate keels is also present in some of the *D. licha* denticles.

The minute pointed denticles of *D. licha* and the pointed Rhaetian denticles show the greatest similarity between the two forms (text-fig. 2, figs. 4, 8).

Relationship of Teeth and Denticles

Shark teeth and denticles are closely related. The denticles have the same internal structure as the teeth and could be regarded as specialised dermal denticles (Applegate, 1967, p. 45).

The species *D. barnstonensis* was largely based on a comparison of Rhaetian teeth with those of *D. licha*. The similarities between the tail and fin denticles and the upper teeth of *D. licha* (text-fig. 2, figs. 4 and 14) suggest a similar compatibility between the denticles and teeth of *D. barnstonensis* Apart from the differences of ornamentation and in the nature of the roots and basal plates, such a resemblance is found between the upper teeth of *D. barnstonensis* and the pointed Rhaetian denticles (text-fig. 2, figs. 8 and 13). If the Rhaetian denticles are from *D. barnstonensis* the differences in the teeth of the two species may well be reflected by differences in their respective denticles. The upper teeth of *D. barnstonensis* differ from those of *D. licha* in being slightly angled at the base of the crown; this feature is present in most of the no. 1 type Rhaetian denticles and not in those of *D. licha*. Another feature is the development of side points on some of the type no. 1 Rhaetian denticles comparing with the lateral points on the upper teeth of *D. barnstonensis* and in contrast to the absence of side points in *D. licha*. The lower teeth of *D. barnstonensis* have more strongly developed serrations which may be reflected in the stronger ornamentation of the Rhaetian denticles as a whole.

Position of Denticles

It has been pointed out (White, 1937, p. 61) that the denticles of sharks are flatter and less strongly keeled in the least exposed parts of the body and they are typical on the flanks and dorsal surface. If this is the case with the Rhaetian denticles it is possible that those of types no. 2 and 2b, with a smooth and flattened upper surface, came from the belly of the fish whilst those modified type no. 4 are from under the snout (text-fig. 2, figs. 3 and 7). Those with a partly smooth upper surface being intermediate to type no. 2 found on the flanks and then a continuing modification to the most armoured type no. 3 on the dorsal surface.

Possibility of association with Hybodont Sharks

With such an abundance of the type A denticles and a predominance of hybodont teeth in the bone bed, it is open to consideration that the type A denticles and hybodont teeth must go together. A conclusion upon statistical evidence alone would ignore all the comparative morphological evidence that link type A denticles with *D. barnstonensis* teeth. Amongst the minute denticles the nearest approach to a hybodont denticle is in the small number of specimens allocated to the type no. 2b which are, however, a minor variation. Possible explanations why the teeth should be rare and the denticles common are that originally there were many more denticles than teeth on each fish and their minute size may have helped them to move more easily with the current after deposition thus avoiding abrasion. The teeth have a spongy interior which makes them more fragile than the more solid denticles. It is therefore considered that the type A denticles show closer affinity to Dalatiids than to Hybodonts.

Hybodont Denticles (Group B)

The hybodont genera *Hybodus* and *Acrodus* are closely related (Day, 1864) and dermal denticles from Liassic species of hybodonts such as *Acrodus nobilis*, *Acrodus anningae* and *Hybodus becherei* are very similar. Many of them consist of a round, well-defined basal plate with a domed crown bearing longitudinal ridges (text-fig. 3, fig. 1). Others have a number of narrow crowns spread laterally on a basal plate (Woodward, 1889, pl. 8, figs. 2-5).

Denticles of the Triassic species *Lissodus africanus* (Brown) are also described (Brough, 1935, p. 40) as being shaped like a pointed dome with a ridged surface. Stensiö (1921, pl. 1 fig. 14) figures a domed type of dermal denticle (text-fig. 3, fig. 2) which he considers to be a hybodont though found in isolation detached from the fish. He also figures (1921, p. 25, fig. 9) poorly preserved denticles of a Triassic species *Acrodus oppenheimeri* Stensiö, the denticles of which are laterally extended (text-fig. 3, figs. 3-4).

In the Rhaetic bone bed at Barnstone, prior to the finding of the dalatiid, *D. barnstonensis* the Elasmobranch species, as recognised from teeth and jaw fragments, all belonged to the hybodont genera *Hybodus*, *Acrodus* and *Polyacrodus*.

The commoner (Group B) of the two groups of large denticles found at Barnstone can be related to each other by transitional types and are associated with hybodont sharks (Sykes et al 1970, p. 254, pl. 17, figs. 1-5, text-fig. 5, figs. 8-9). The denticles of group B range in size from 1.0 to 1.5 mm in height and 1.0 to 3.0 mm in length.

The simplest of these Rhaetian hybodont type denticles have a single, fluted, stud-like crown on a spreading, subcircular base which has a concave undersurface (text-fig. 3, figs. 5-6). Some of the denticles have two to six crowns on a similar base, a number having the rear crowns inclined rearwards. There are denticles which are extended laterally and have narrower, rearward inclined crowns. These are transitional to the commonest type which consist of a number of striated, closely packed crowns on a base which is considerably extended laterally. The crowns are narrow and all are curved rearwards. The pedicel on this latter type is merely a narrowing above the base which is similar to that figured by Stensiö (text-fig. 3, figs. 3 and 7).

Hybodont dermal denticles are generally not very well known but there is sufficient evidence to link these Rhaetian denticles with hybodont species.

Chimaeriforme Dermal Denticles (Group C)

Rare specimens of the Holocephalon *Squaloraja* have been found in the Rhaetic rocks of Beer Crowcombe (More, 1861) and thought to have been found in the bone bed at Redland, Bristol (Short, 1904). This genus belongs to the family Squalorajidae in the Order Chimaeriformes. The dermal denticles of the primitive Chimaeriformes are based on cone-like structures (Patterson, 1965) and in addition, some denticles have well developed or divided crowns. The basal plates are large and expanded, usually striated or fluted with a concave undersurface.

EXPLANATION OF TEXT-FIGURE 3

Figures 1 to 8 hybodont dermal denticles.

Fig. 1 *Hybodus delabechei*, lateral view of head denticle (after Woodward, 1889, p. 260, pl. 8, fig. 3) (3.7 mm × 3.3 mm).

Fig. 2 Hybodont denticle, general view (after Stensiö, 1921, pl. 1, fig. 14).

Fig. 3 *Acrodus oppenheimeri* Stensiö, 1921, lateral view (after Stensiö, 1921, p.25, fig. 9) (.8 mm ×.9 mm).

Fig. 4 *Acrodus oppenheimeri*, anterior view (after Stensiö, 1921, p. 25, fig. 9) (.8 mm × 1.0 mm).

Fig. 5 Rhaetian hybodont denticle, lateral view, Zr9705 (1.1 mm × 2.0 mm).

Fig. 6 Same specimen as figure No. 5, upper view (1.7 mm x 2.0 mm).

Fig. 7 Rhaetian hybodont denticle, lateral view, Zr9706 (.9 mm × 1.4 mm).

Fig. 8 Same specimen as figure No. 7, anterior view (1.3 mm × 1.4 mm).

Fig. 9 *Menaspis armata* Ewald, lateral view of enlarged median denticle (after Patterson, 1965, p. 170, fig. 36) (5 mm × 3 mm), size of average body denticle is app. 2 mm × 1 mm).

Fig. 10 *Menaspis armata*, lateral view of enlarged median denticle (after Patterson, 1965, p. 124, fig. 12) (3 mm × 2.6 mm).

Fig. 11 *Squaloraja polyspondyla* Agassiz, upper view of dorsal denticle (after Patterson, 1965, p. 124, fig. 12) (4.0 mm × 1.5 mm).

Fig. 12 *Squaloraja polyspondyla*, upper view of dorsal denticle (Patterson, 1965, p. 124, fig. 12) (2.5 mm × 2.1 mm).

Fig. 13 Rhaetian denticle, Barnstone, lateral view, Zr9707, (3.0 mm × 2.2 mm).

Fig. 14 Rhaetian denticle, Barnstone, upper view (after Sykes, et al, 1970, pl. 17, fig. 6) (2.4 mm × 2.2 mm).

Fig. 15 Rhaetian denticle, Barnstone, lateral view, Zr9708 (2.2 mm × 1.6 mm).

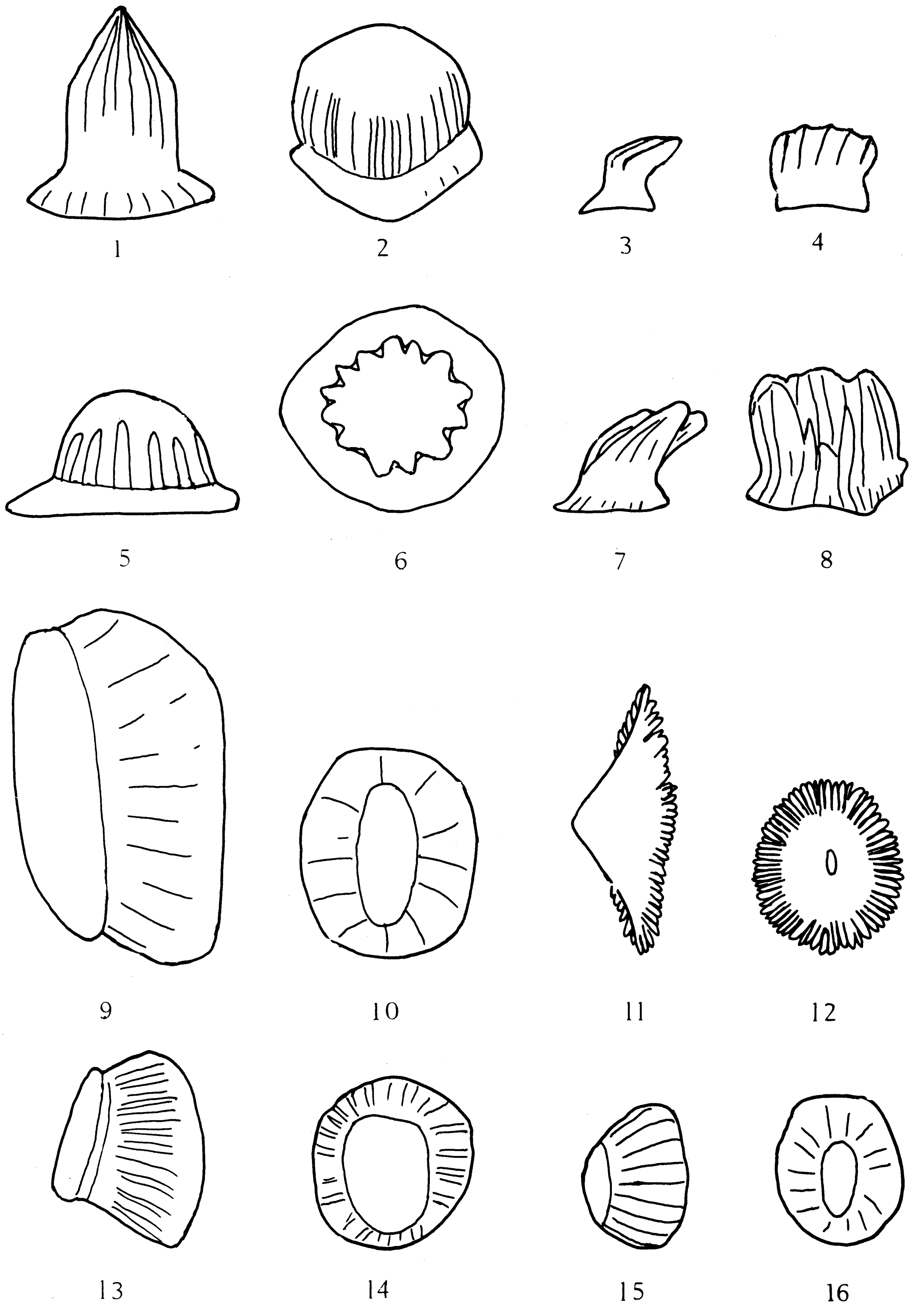
Fig. 16 Same specimen as figure No. 15, upper view (2.2 mm × 1.9 mm).

Figures 1 & 2 are drawn to the same scale; figures 3 to 8 are all drawn to a scale twice the size of figures 1 & 2; figures 9 to 16 are all drawn to a scale of 17 to 14 times the size of figures 1 & 2.

The quoted figures are of the height and width respectively in each figure.

Specimens numbered Zr9705 to Zr9708 are deposited in the institute of Geological Sciences.

Text-Figure 3



The rare type of Rhaetian denticles vary in size from 1.2 to 2.2mm high and 2.0 to 3.0mm long. They consist of a simple rounded, conical structure with a smooth, depressed crown which varies in size between denticles (Sykes et al., 1970, p. 255, pl.17, fig. 6, text-fig. 5, fig. 10). The basal plate is large and radially grooved with a slightly concave undersurface. They compare closely (text-fig. 3, figs. 9-10, 13-14) with the denticles of the Chimaeriformes *Menaspis armarta* Ewald (Patterson, 1965, p.170) and generally (text-fig. 3, figs. 11, 12, 15 and 16) with the denticles of *Squaloraja polyspondyla* Agassiz (Patterson, 1965, p. 124).

There is, therefore, good comparative evidence that the group C denticles belong to the rare Rhaetian genus *Squaloraja*.

Conclusions

The dermal denticles of the Rhaetic bone bed samples can be classified into three distinct groupings, the denticles of one group being smaller than those of the other two. One of the larger, group B, denticles, which are common, are associated with hybodont sharks. The other larger, group C, denticles are quite rare and have affinities with a rare Rhaetian Holocephalon. The third, common and minute, group A denticles, show affinities with the species *D. barnstonensis*.

Acknowledgements

I should like to thank Dr. C. Patterson of the British Museum (Nat.Hist.) and Dr. H. Ivimey-Cook of I.G.S., for reading the paper and for their advice and useful suggestions. I am indebted to the Wolfson Institute and the Department of Geology of Nottingham University for use of an electron stereoscan microscope for photographing specimens and also to Mr. J.S. Cargill for assistance in producing Plate 3.

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EXPLANATION OF PLATE 3

Fig. 1 Dermal denticle type No. 1, lateral view × 100, No. Zr9709.

Fig. 2 Dermal denticle type No. 1, upper anterior view, × 50, No. Zr9710.

Fig. 3 Dermal denticle type No. 1a, anterior view, × 85, No. Zr9711.

Fig. 4 Dermal denticle type No. 2, upper view, with extra median keel, × 130, No. Zr9712.

Fig. 5 Same specimen as Fig. 4, general anterior view, × 130.

Fig. 6 Dermal denticle type No. 4, upper anterior view × 90, No. Zr9713.

Fig. 7 Dermal denticle type No. 3, upper view, × 120, No. Zr9714.

Fig. 8 Dermal denticle type No. 3, general anterior view, × 85, No. Zr9715.

Fig. 9 Dermal denticle type No. 5, lateral view, × 80, No. Zr.9716.

All specimens in the Institute of Geological Sciences, London, Nos. Zr9709, ZR9716.

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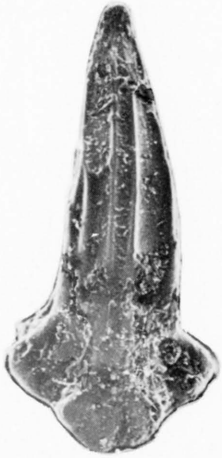

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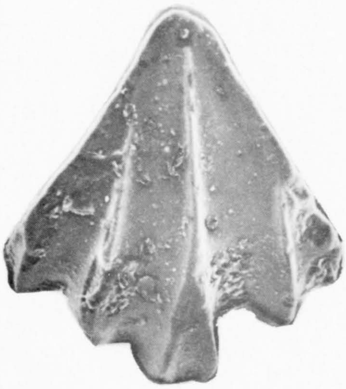

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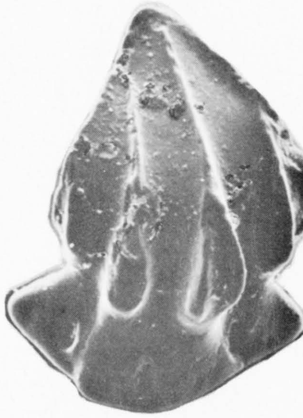

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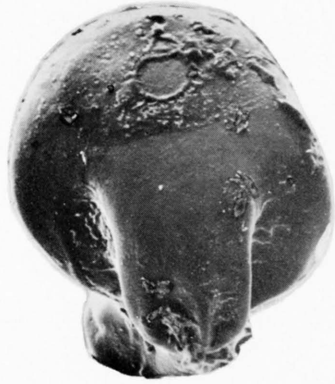

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Rhaetian Elasmobranch dermal denticles

WESTERN BOUNDARY OF THE MALVERNIAN, NORTH MALVERN HILLS WORCESTERSHIRE

by

D.W. Bullard

Summary

A temporary exposure at North Malvern is described, which exposes red Cowleigh Park Beds (Llandovery) adjacent to Malvernian diorites and dolerites. The contact is marked by a thin band of black shale dipping at 65° to the east. Evidence from other nearby exposures of Wych Beds and Groom's detailed records from this area (1900) suggests that, as proposed by Brooks (1970), the western boundary of the Malvern Hills is an unconformable junction cut by a series of parallel faults.

Introduction

The new exposure lies to the east of the road known as the Old Hollow Lane which runs around the northern tip of the Malvern Hills (76554730). It has been excavated for building development. The exposure occupies an area of 20 x 30 metres, most of which was covered in July 1973 by much loose debris derived from higher slopes of the Pre-Cambrian mass. (text-fig.1).

The local succession

The oldest rocks exposed in the Malvern area are the Pre-Cambrian diorites, granites, dolerites and gneisses. Structurally, these rocks are very complex and have only been described in fairly general terms by previous workers. A recent summary of the Malvernian rocks is given in the Geologists' Association Guide to the Malvern Hills (Penn, 1971).

The remaining rock types belong to the Cambrian and Silurian Systems. Those of the Cambrian have been recorded from the southern Malverns where the following succession has been described:

Bronsil Shales: grey shales

Whiteleaved Oak Shales: black shales

Hollybush Sandstone

Malvern Quartzite

There is no present day evidence for Cambrian rocks in the north Malverns area, but Groom (1900) recorded black shales from a well, the log of which is given in a later section.

The lower Silurian rests unconformably on the Cambrian and Pre Cambrian in the southern Malverns. The local succession of the Silurian rocks in the North Malvern - Cowleigh Park area is:

Mercian Geologist, Vol. 5, No. 1, 1974. pp. 65-70. 3 text-figs.

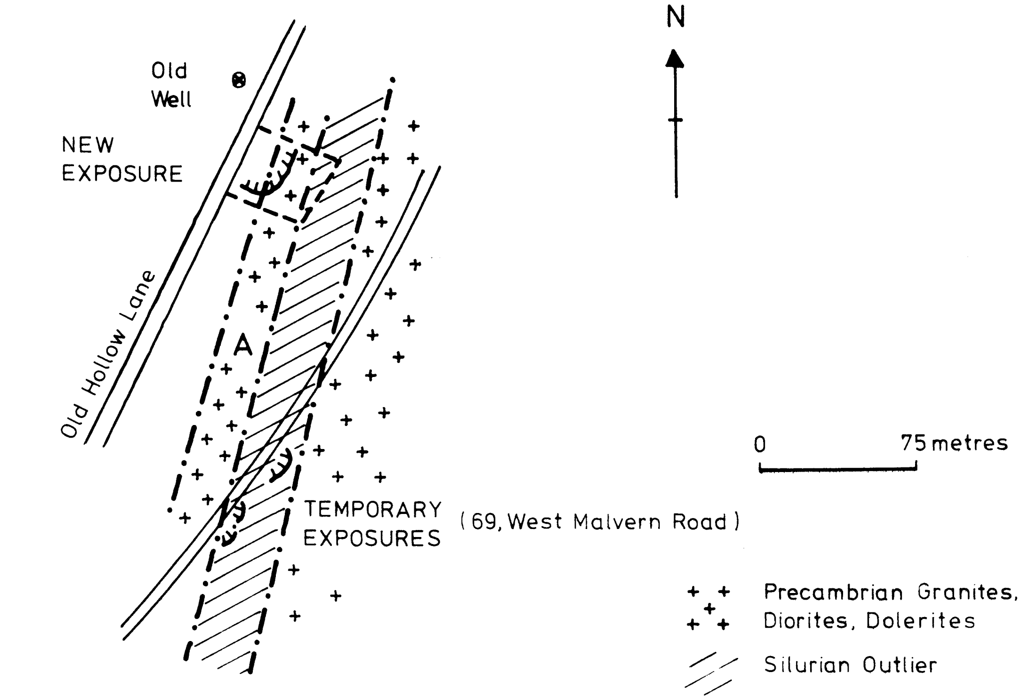


Fig. 1A Locality Map of the New Exposure

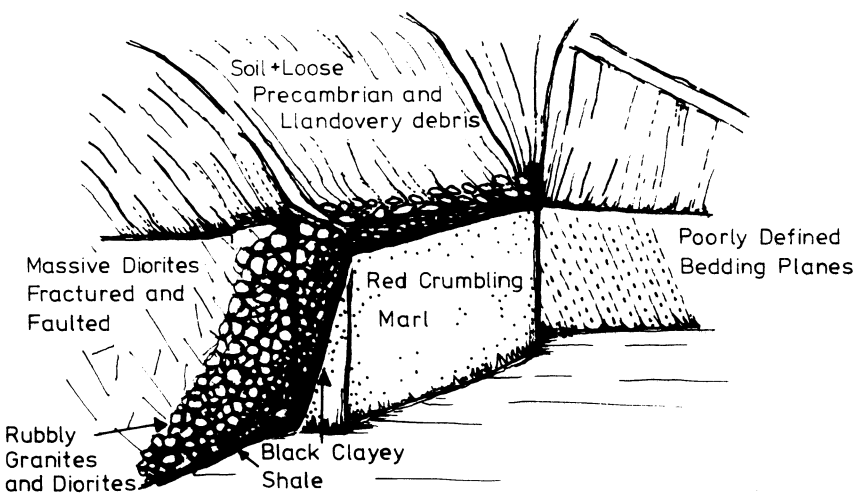


Fig. 1B Field Sketch of Exposure looking S.E.

Text-fig. 1 - Temporary exposure at North Malvern.

Woolhope Limestone	30 metres	Wenlock
Wych Beds	100 metres	Llandovery
Cowleigh Park Beds	100? - 130? metres	

The thicknesses are quoted from Ziegler, Cocks and McKerrow (1969)

Description of the exposure

A large scale plan of the exposure is reproduced as text-fig.1B. In the middle of the south-east corner, a fresh cut exposed 8 × 5 metres of red marly sandstone dipping 80° to the west. At the northern end of the cut, an angled east-west face exposed the contact of the red marly sandstone with the Pre-Cambrian rocks. This contact dipped 65° to the east and was seen to strike approximately north - south, the line of contact not being exposed far enough to get an accurate strike determination. Four cm. of black fine grained clayey shale was overlain by a yellow rubbly breccia of Pre-Cambrian detritus, mostly diorite with some granite. The breccia graded rapidly into massive Pre-Cambrian diorites. About 10 metres to the north of the contact, massive dolerite was seen to intrude into the diorites striking north-west to south-east, with contacts not clearly exposed.

Both the red marly sandstone and black shale were sampled. The sandstone was free of any fossiliferous material, being mostly composed of rounded and angular grains of quartz and felspar up to 1 cm. diameter set in a fine grained marly iron - rich matrix. Nearly all the grains were coated by haematite, except for about 2%, which were small angular masses of a yellow sandstone similar to the Hollybush Sandstone of the southern Malverns. The samples were processed for microfossils, but none were found.

In the black shale, two very small specimens of Lingulids were discovered but otherwise it proved to be unfossiliferous. Age dating of these sediments has been a problem. The red marly sandstone is thought to be the equivalent of the basal Cowleigh Park Beds seen at Eastnor, and exposed by Butcher in a Geologists' Association dig in 1963. Ziegler and others, (1968), described this basal member as being up to 5 metres thick, but at this new locality it could be thicker, as at least 5 metres were exposed. The age of the black shale is even less certain. It could be a faulted remnant of the Cambrian shales adhering to the Pre-Cambrian or it could be the very basal phase of the Upper Llandovery in this locality.

Relationships to other nearby exposures

A temporary exposure (text-fig.1a) at 69, West Malvern Road, (76544714), 160 metres south of the new exposure, was interpreted as Wych Beds, dipping steeply to the west 60 - 80°, but showing some signs of overturning at the top of the exposure, possibly due to hill creep. The rocks were composed of greenish yellow siltstones typical of the Wych Beds in the Malvern area. A little to the north east along the West Malvern Road, further exposures of the greenish yellow sandstones were seen again dipping 60° - 80° to the west. This site is now covered by a concrete foundation for a new house.

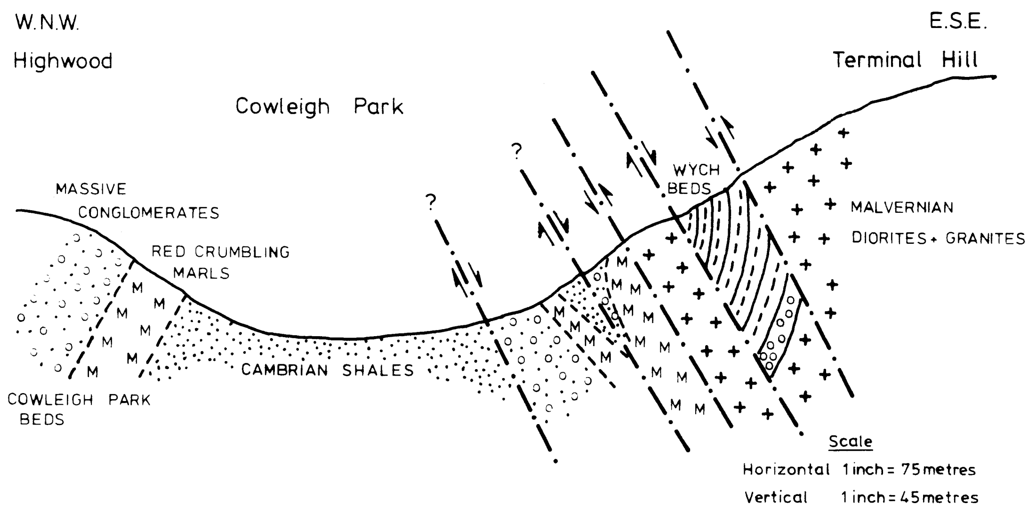
Groom (1900, pp. 152 - 153) probably described the latter exposure, but his details of its position, at that time an old quarry, make it difficult to locate the exact position at the present time. The "archaean" fault contact seen by Groom at the base of the quarry, "striking 3°, dip 60° to the east," was not exposed. This fault if continued northwards would pass about 20 metres east of the contact described by the Old Hollow Lane. The mass of Malvernian rocks, marked A on text-fig.1, is then a wedge in the Silurian sediments. In the overburden at the new exposure much loose Wych Bed detritus was seen, presumably derived from the Llandovery outlier.

The present new exposure beside the Old Hollow Lane is just to the south of the site of an old well (76564733, Brooks 1970). The following log is quoted from Groom (1900, pp. 157 - 158):

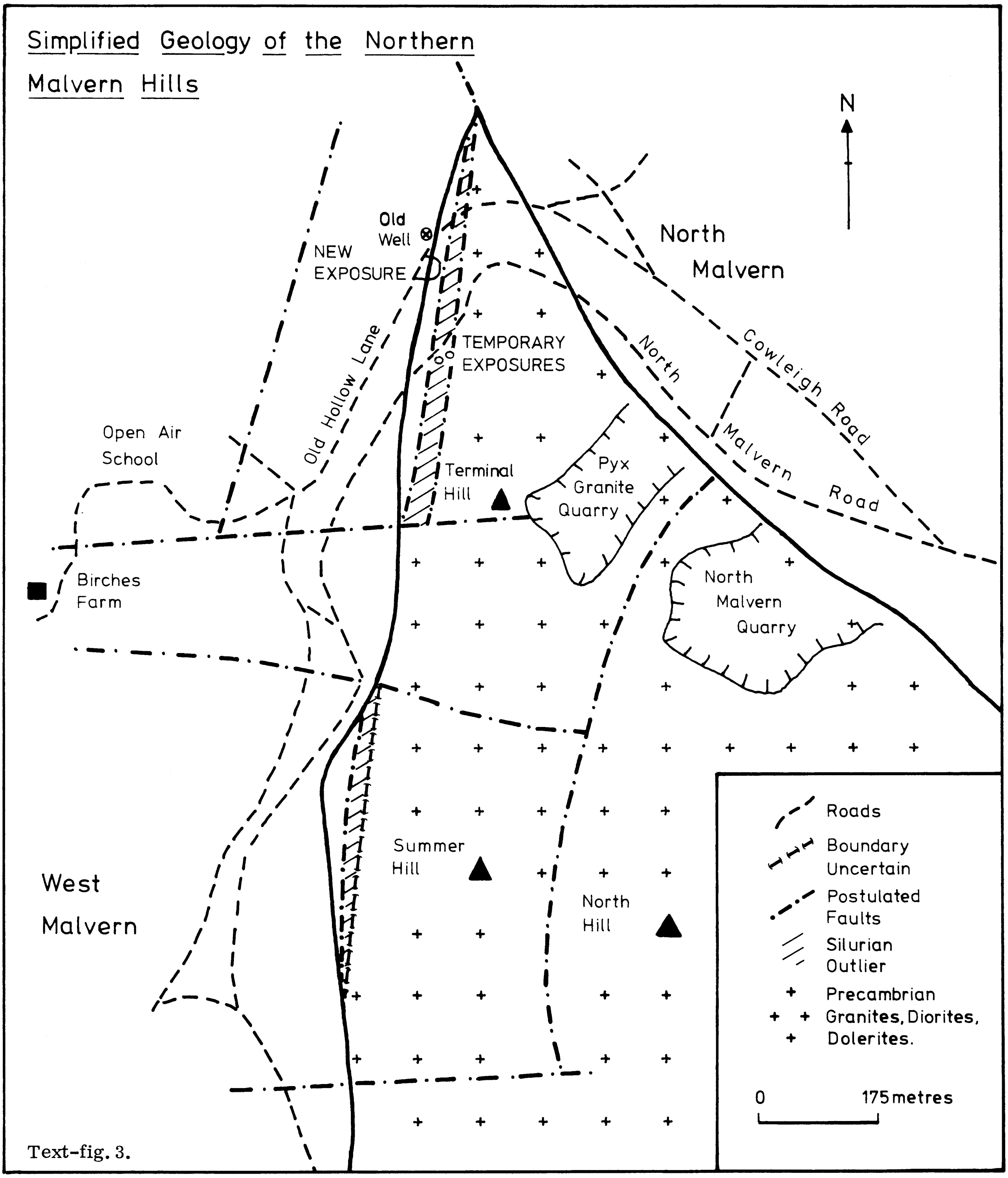
(1)	Surface gravel hill debris	12 ft
(2)	Red crumbling marl with small pebbles	24 ft
(3)	Coarse grey and red sandstone and conglomerate	16 ft
(4)	Very hard breccia of quartz pebbles in a red and yellow matrix	6 ft
(5)	Black Cambrian shale with *Olenus*, *Conocoryphe*, *Lingulella.*	18 ft
(6)	Repetition of beds 2 and 3	13 ft

The red crumbling marls with small pebbles (bed 2) are undoubtedly the equivalent of the red marly sandstone exposed at the Old Hollow Lane locality. Beds 5 and 6 were described later in the same paper by Groom (1900 pl. 62) as dipping 50° to the north east but bed 4 dipped in the same direction at a steeper angle, indicating the presence of a fault between beds 4 and 5. Groom also suggested a fault separated beds 5 and 6, but it is possible that the red beds (bed 2) are resting unconformably on the black shales. Unfortunately the dip and strike of Groom's faults were not recorded, but were interpreted as striking to the north-west. From the other field evidence it seems more likely that they are aligned approximately north-south.

The cross-section, text-fig. 2, combines evidence from Groom's well log, from his quarry exposure and from the new temporary locality on Old Hollow Lane.



Text-fig. 2. Section across the Western Side of Terminal Hill and Cowleigh Park


Simplified Geology of the Northern Malvern Hills
N
Old Well
NEW EXPOSURE
TEMPORARY EXPOSURES
Old Hollow Lane
North Malvern
Cowleigh Road
North Malvern Road
Open Air School
Terminal Hill
Pyx Granite Quarry
Birches Farm
North Malvern Quarry
Summer Hill
North Hill
West Malvern
Roads
Boundary Uncertain
Postulated Faults
Silurian Outlier
Precambrian Granites, Diorites, Dolerites.
0
175 metres

Text-fig. 3.

Structurally, the major movements on the north-south faults are 'normal', as predicted by Butcher (1962) and similar in strike and direction to the eastern boundary fault pattern that produced the deep Mesozoic basin on the eastern side of the Malvern Hills.

In more general terms the north-south faults must be related to the surrounding geology. The important oblique north-west striking fault, forming the north-east face of Terminal Hill and North Hill (text-fig. 3), truncates the north-south faults to the north. To the south, cross faulting in an east-west direction brings a higher structural level of the Malvern fold to the surface just south of Birches Farm (759469). Detailed studies of the Pre-Cambrian geology made by the author suggest that the Terminal Hill block is up-faulted with relation to that of Summer Hill.

Conclusions

The new exposure provides additional information on the nature of the western boundary of the Malvernian of the Malvern Hills and rejects the theory of Phipps and Reeves (1964, 1970) of one large fault forming the whole of the western boundary to the Malvernian. It supports the theories of Pre-Llandovery tectonics in the Malvern area as postulated by Brooks (1970).

Acknowledgements

This piece of work came about as a result of the author's structural and geochemical studies at Nottingham University on the Pre-Cambrian rocks of the northern Malverns. He wishes to acknowledge useful discussion of the Malvern tectonic problem with Dr. R.J. Firman. Dr. R.J. Aldridge, and Dr. J.A.T. Smellie and the technical assistance of Miss S. White for the preparation of samples and Miss B.A. Livingstone for final copies of the maps and diagrams.

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EXCURSION TO THE MALVERN HILLS

Director: W.G. Hardie — 5th - 7th May 1972

Friday evening. Approximately 40 members arrived in Great Malvern to the accompaniment of heavy and continuous rain. Headquarters were at the Montrose Hotel, and after dinner the Director gave an introductory talk, drawing particularly on the work of Groom (1910), Blyth (1952), Reading and Poole (1961), Butcher (1962), Brooks (1968) and Phipps and Reeve (1967, 1969).

Saturday. By morning the weather authorities had intervened, and, to the relief of all concerned, it was dry but dull when the party were introduced to the south Malverns. Cars were parked near to the first exposure (756368), which was the relatively new roadside cutting in Hollybush Sandstone (Middle Cambrian). Both the massive and micaceous flaggy beds of this horizon, as well as the Ordovician sheet intrusion of altered andesite, were examined. The director commented that, in his opinion (Hardie, 1969, p. 51) based on thin section observations, the greenish colour of this rock is due to abundant flakes of chlorite, and not to glauconite, as is usually maintained (Groom, 1910; Penn et al. 1971, p.10), although the latter mineral may be present in small amount.

With prior permission the party then walked southwards through the fields belonging to Fowlet Farm, thus avoiding the ankle-deep liquid mud in the old lane. On the way, a poor exposure of a north-westerly trending sheet of altered andesite was examined, and then a stop was made at the best of the rare exposures (758361) of the Upper Cambrian Whiteleaved Oak Shales (Black Shales). Chase End Hill, the most southerly part of the Malvern Hills, was then ascended, and reasons were given for regarding it as a thrust mass of Malvernian overlying Cambrian. A shallow excavation just south of the summit provided specimens of chlorite-schist, sometimes with a little sheared pegmatite. According to the recent work of Lambert and Holland (1971, p. 329), the strongly sheared Malvernian rocks south of Hollybush are altered diorites.

A north-easterly track allowed the party to descend by a different route, and then, after passing a small roadside quarry of Hollybush Sandstone, Ragged Stone Hill was ascended. Further specimens of chlorite-schist, with occasional streaks of sheared pegmatite, were examined. The marked hollow, which runs the length of the hill and separates the twin peaks, has always been ascribed to down faulted Cambrian and Silurian rocks (Groom, 1910; Ziegler, Cocks and McKerrow, 1968; Phipps and Reeve (1969). A quick descent to Hollybush allowed the party to reach Gullet Quarry (762380) in time for lunch and a heavy shower.

The bottom level of this quarry provided a variety of Malvernian rocks, especially diorite showing varying degrees of shearing and intruded by conspicuous veins of pink pegmatite. Some members discovered small amounts of pyrite and possible chalcopyrite, while some hornblende-schist, chlorite-schist and a dyke of quartz-dolerite were also seen. The hornblende-schist is referred to as epidiorite by Lambert and Holland (1971, p. 340). Attention was then drawn to the complicated arrangement of thrusts and shear zones which dip steeply to the east. These are taken to indicate an upward and westerly movement of the rocks during both Taconian (late Ordovician) and Hercynian (late Carboniferous) times (Reading and Poole, 1961, p. 298).

The party then climbed up the quarry road to the excellent exposure of westerly dipping Upper Llandovery Wych Beds.* These consist of fine grained sandstones, shales and occasional beds of partly decalcified limestone, together with a thin basal conglomerate containing pebbles and boulders of Malvernian. The latter was seen to rest against the Malvernian, and it was explained that most geologists agreed with Reading and Poole (1961) that the junction was an unconformity. Phipps and Reeve (1964, p. 397) regarded it as a thrust contact, and still adopt this interpretation (1969, p. 36).

Mercian Geologist, Vol. 5, No. 1.
1974, pp. 71-74.

Once the high ground above the quarry was reached (see aerial photograph in Butcher 1962) the party proceeded northwards over Swinyard Hill with its diorites, granites and occasional pegmatites. The western end of the "Silurian Pass" of Groom (Blyth and Blackith, 1953, sketch-map, p. 443) was crossed, but that afternoon the downfaulted Silurian rocks seemed to be represented by liquid mud. The feature formed by the volcanic Warren House Series (Pre-Cambrian) was then ascended by means of a path, and a stop was made at Clutter's Cave (762394) to study the basalt (spilite) lava with its pillow structures. North-east of this were scattered exposures of slightly shattered greyish pink rhyolite, referred to by Lambert and Holland (1971, pp. 346-7) as quartz-keratophyre and dacite. The best specimens of this rock, however, were obtained from the disused quarry (766397) a short distance down the northerly facing hillside.

A walk to the west brought the party on to the southern side of Herefordshire Beacon, a hill of Malvernian interpreted by all geologists as a westward thrust mass resting on Silurian. The latter beds are inverted, presumably due to the thrusting, and an exposure of inverted shale (dips east) at about the horizon of the Woolhope Limestone, was seen in a narrow lane. North-west of this exposure, and only a short distance west of the Malvernian, a forestry track provided fragments of Wenlock Limestone.

The party then retraced its steps eastwards to Walms Well (761393) where a track approximately along the Silurian/Pre-Cambrian boundary was followed southwards. A stop was made at a small exposure (756381) due west of Gullet Quarry to collect fossils from brownish weathering decalcified sandy Wych Beds. Finally, in a small disused quarry (760380) just south of the track leading to Gullet Quarry, quartzite and conglomerate from the Lower Cambrian Malvern Quartzite was examined. Time did not permit an examination of the exposed unconformable contact of this quartzite with the Malvernian in Hollybush Quarry (Jones et al. 1969, pp. 461-3).

Sunday. The morning began with welcome sunshine when the party drove south, via The Wyche and British Camp, to examine and collect fossils from the extensive roadside exposure (747403) of Aymestry Limestone and Lower Ludlow siltstones and shales. The return journey to The Wyche was made via Colwall Stone, which lies on the relatively flat ground floored by Red Downtonian.

Stops were made at the two old quarries (now car parks) in the Malvernian on the east side of The Wyche. The most northerly of these (Lower Tollgate Quarry, 770441) provided an interesting variety of ultramafic hornblende and pyroxene-rich rocks (Lambert and Holland, 1971, p. 330). Contrasting with these rocks was the slightly streaky red alkali-granite found in the second quarry. After this, the cars were parked immediately west of The Wyche until the middle of the afternoon.

The party first climbed on to the granite ridge and made its way northwards, enjoying good views both east and west before rain intervened. Short of County Quarry, a descent was made to the road on the west, and, a little to the south, a stile gave access to a muddy westerly trending track across Silurian country. As the party slithered and squelched over unexposed Lower Silurian, the voice of a cuckoo wafted towards us. A short digression was then made to the line of old quarries in the Wenlock Limestone of Park Wood (764443), where lunch was eaten, fossils (also live snails) collected and scattered groups of *Orobanche* (broomrape) admired.

After this the westerly traverse was continued, with westerly dipping Lower Ludlow shales being seen in the banks of a stream. No exposures of the succeeding Aymestry Limestone, which formed the wooded ridge to the north and south, were found, so the party continued to the disused Brockhill quarry (757439). Here fossiliferous siltstones and occasional interbedded limestones belonging to the Upper Ludlow Beds were examined, followed by rather weathered Downton Castle Sandstone (Grey Downtonian). The bluff, dividing the quarry into two parts and carrying the thin horizon correlated with the Ludlow Bone Bed, was carefully examined by a few optimists in the hope of extracting phosphatic fragments.

A return was made to the cars, whereupon the party proceeded in welcome sunshine to a parking place due west of Worcestershire Beacon. From here the last two exposures were reached on foot. First to be visited was the classical exposure (764459) of Lower Llandovery, which includes "Miss Phillips' Conglomerate," i.e. the rock (breccia) discovered by the sister of John Philips, writer of the 1848 Memoir covering the Malvern and Abberley Hills. Here grey silty sandstones and a thin decalcified fossiliferous breccia are seen dipping steeply to the west off the Malvernian. These beds, which have been correlated on palaeontological grounds with the Wych Beds (Ziegler, Cocks and McKerrow, 1968, pp. 753-7), are believed by most geologists, including Reading and Poole, (1962, p. 378) and Butcher (1962, pp. 105-7) to rest unconformably on the Malvernian. Phipps and Reeve (1969, pp. 2-4), however, still uphold Groom's 1910 interpretation that the exposed contact marks the course of a powerful western boundary fault, which continues southwards to the Gullet Quarry. Finally, Dingle Quarry (765456) was entered (see Penn et al., 1971, Fig. 15), where further examples of Malvernian pegmatites, granites and diorites, as well as a thick sheet of dolerite, could be seen.

At this stage most members dispersed, but a few of the more indefatigable climbed Worcestershire Beacon for a little more geology and cups of tea in the summit café.

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* In this paper, and the preceding one by Bullard, the spelling of Wych Beds [as apposed to Wyche Beds] is spelt as recommended in Cocks, Holland, Rickards and Strachan, 1971, a correlation of Silurian Rocks of the British Isles *Special Report No. 1. Geol. Soc. London* - Editor.

EXCURSION REPORT: PERMIAN ROCKS OF THE DONCASTER (YORKSHIRE) AREA

Leader: D.B. Smith — Sunday, 4 June 1972

Report by F.M. Taylor in association with the leader

Members of the East Midlands Geological Society met the leader of this excursion at the first locality, adjacent to the A.1. at the Haven Cafe, Skellow (SE 519115). The general geology of the Permian rocks in the Doncaster area was outlined and it was stated that the excursion would visit exposures of the Upper, Middle and Lower Magnesian Limestone (see sequence published in Morrow and Smith 1969) at localities between Skellow and Cadeby, but that most of the exposures were within a few miles of Skellow. The excursion would be concerned with the sedimentary details of the Magnesian Limestone and would supplement the Permian excursion of 1968 (Morrow and Smith 1969). The feature formed by the Lower and Middle Magnesian Limestone was pointed out from Skellow Quarry, situated in the Upper Magnesian Limestone, with the outcrop of the 'Permian Middle Marls' between. The details of Skellow Quarry were then examined.

Skellow Quarry (SE 519115)

The quarry exposes part of the Upper Magnesian Limestone. It exhibits a shallow water facies with a bivalve fauna. The top layers of the quarry have been disturbed by Pleistocene ice-wedges.

Road-side section near Hampole (SE 500106)

The exposure is close to the road bridge, the railway under A. 638 road. Here a section of the Lower Magnesian Limestone can be examined. The well-bedded dolomite is made up of white pisoliths, and similar beds draping over a suspected small reef can be seen in the railway cutting.

Hazel Lane Quarry, Hampole (SE 499109)

At the large working quarry near Hampole, the Lower Magnesian Limestone was again seen to contain ooliths but the rock is also partly mineralised with haematite. In the quarry there are some beds with numerous bivalves, often associated with the haematite, giving a very attractive rock.

South Elmsall (SE 483115)

This locality was visited on the 1968 excursion and is the site of an old quarry now partly filled with rubbish. It is close to the village of South Elmsall. The upper part of the Lower Magnesian Limestone is exposed and shows an algal reef embedded in oolitic and oncolitic dolomite. Some very fine grained patches were examined and a search made for bivalves and stromatolites. An attempt is being made to preserve part of this quarry as a site of special scientific value.

Hooton Pagnell (SE 4808)

This pleasant village is built on a bryozoan reef with interbedded dolomites. There are many exposures, including those near the war memorial, the school, close to houses and at the foot of walls. Special permission to visit the exposures was obtained by the leader of the excursion from the Parish Council. Hammers were left in the coach.

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1974. pp. 75-76.

Bilham Sand Quarry, Hooton Pagnell (SE 488068)

Permission to visit this quarry was not available for the party as a whole but a specimen of highly fossiliferous Lower Magnesian Limestone was available for study. The rock rests on about 3 m. of yellow Basal Permian Sands, there being no 'Permian Lower Marl' or Basal Breccia in this area.

Hampole Limeworks Quarry (SE 515097)

This deep quarry exposes the base of the Middle Magnesian Limestone and the top part of the Lower Magnesian Limestone. At the junction are two clay seams separated by a layer of fenestrate dolomite. These are part of the Hampole Beds (Smith 1968). Some time was spent examining these and the large scale cross-bedding, up to 7 m. thick, in the overlying oolitic dolomite.

Cadeby Quarry (SE 520000)

This enormous quarry, also visited in 1968, has now been further extended. Permission to visit was given by the Steetley Co. Ltd. The rocks exposed are the top part of the Lower and the base of the Middle Magnesian Limestones. The distinctive Hampole Beds could be seen in the quarry face and blocks of them examined on the quarry floor. Plant specimens are preserved in the clay seams. Good examples of algal and bryozoan limestones were collected and occasional bivalves noted.

Sprotbrough Quarry (SE 533015)

The junction of the Middle and Lower Magnesian Limestone at this quarry gave a final opportunity to examine the Hampole Beds, here much thinner than at Cadeby Quarry. A pink mineral with high specific gravity, infilling some of the cavities in the fenestrate dolomite, was said to be barite. Some of the clay from the clay seams had been squeezed into joints of the dolomite, which was domed in places.

The President thanked Mr. Smith for the arrangements he had made for the excursion and for his interesting instructive tour of Permian sedimentary environments.

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EXCURSION TO EMPINGHAM, KETTON AND HOLWELL

Leader: W.S. Moffat. Sunday, 2 July 1972

The main object of this excursion was to see the geology of the Empingham Reservoir site in Rutland and learn something of the engineering geology involved in the construction of the reservoir. The visit to Ketton Quarry, Northamptonshire and the Holwell Quarry, Leicestershire, provided further opportunity to see Lower and Middle Jurassic rocks on the same excursion.

Empingham Reservoir Site (SK 9407)

The EMGS party travelled to Empingham, Rutland, by coach, picking up Mr. Moffat, en route. On the journey out, Dr. F.M. Taylor outlined the geology of the route pointing out various topographical features, including the fine escarpment of the Marlstone Ironstone seen beyond Nether Broughton. At the reservoir site office, Mr. Moffat introduced the resident geologist, Mr. P. Horswill, who first of all showed the party plans of the reservoir and photographs of the site, both before construction began and during construction up to the time of the visit. The geology of the site was explained. It was stated that the valleys to be flooded were floored by Upper Lias Clays, part of the following sequence:

Lower Lincolnshire Limestone	-	lowest beds, flaggy limestones similar to the Collyweston Slates.
Lower Estuarine Series		
Northampton Sand Ironstone	-	about 5 metres thick and not exploited.
Upper Lias Clays	-	a max. thickness of 55 metres but on the site often less.
The Marlstone Rock Bed	-	$2\frac{1}{2}$ metres thick; an oolitic limestone in this area, with abundant water content with an estimated yield of 1 million gallons per day, but not to be used.

Investigation of the site with numerous bore-holes had shown that the centre of the valley (that of the R. Gwash) exhibited classic features of valley bulging, with the Marlstone Rock Bed being pushed upwards closer to the valley bottom than it ought to be. The overlying Lias Clays were thrust upwards and as a result were broken and contorted. The valley was not as impervious as originally thought and it would be necessary to floor much of the site with puddled clay to improve the impermeable characteristics of the foundation. In addition to re-working clay on the valley floor, it would be necessary to import extra clay, both for laying on the sides of the reservoir and for the main clay core of the earth dam. Mr. Horswill went on to describe the siting of the dam just to the west of Empingham church and stated that, because of the low mechanical strength of the local rocks an earth dam with a broad base and relatively low height would be used. Excavations in the Lincolnshire Limestone and the Northampton Ironstone would provide an outer facing for the earth dam to reduce erosion during storms. The method of dam construction was outlined. The timing and problems associated with the earthmoving operations were described and a display of rocks and fossils so far collected was available for Members to see. A highlight of the indoor section of the visit was a topographical scale model, constructed by pupils of Oakham School and by the ingenious use of ultra-violet illumination it was possible to see the site dry and as it would be, when flooded to the final water level. Diagrams were available to see the route of pipes from the reservoir to the pumping stations, situated to the east near Stamford, which would control the water level. Winter flood water from the Rivers Nene and Welland would be pumped into the reservoir and during the dry summer months, the flow would be reversed.

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The members on the excursion then went on to the site and to the 'Borrow Pits', situated upstream from the dam in the valley of the R. Gwash. Sections were examined in the Upper Lias Clays, both *in-situ*, and later, on the dam site, where some of the clay had already been placed in position. Specimens of ammonites, including *Hildoceras*, *Harpoceras*, and *Dactylioceras* were readily available for the collectors and the other common fossil was the bivalve *Nuculana*. Some parts of the Northamptonshire Ironstone and the base of the Lincolnshire Limestone were also examined.

At the time of the visit, the base of the dam, eventually to be 810 m. wide, was exposed and the method of dam construction to an ultimate height of 35 metres was explained. In order to de-water clays in the valley floor, vertical sand drains with drainage blankets were used. Water would be squeezed out of the clay and pass by way of the sand to drainage channels away from the site. The mechanical strength of the clay would be increased as a result of this process. The forces exerted by the impounded water would be spread over a wide surface area and would be very small compared with the total weight of the earth dam.

Water would be impounded behind the dam, producing a reservoir over 8 km long and reaching almost as far west as Oakham; the village of Upper Hambledon would remain on a peninsular between two flooded valleys. At the end of the visit to Ketton, the coach returned and followed the minor road to Upper Hambledon and Members attempted to visualise the state of affairs when the area would be almost surrounded by water.

An expression of thanks was made to Mr. P. Horswill, to the Welland and Nene River Authority and to the consulting engineers Messrs. T & C Hawksley for permission to visit this extremely interesting project.

Ketton Cement Works (SK 9706)

From Empingham, after a rather late lunch, the party continued to Ketton, to see the quarry from which the Ketton Cement Works obtains its raw materials. This is a very large quarry exposing: (Sylvester-Bradley and Ford 1968 Chapter 12)

The Upper Estuarine Series	-	mainly clays.
The Lincolnshire Limestone	-	Weldon Beds, very fossiliferous. Ketton Beds, easily distinguishable by the unweathered blue centres of the limestone blocks. A worm-bored surface occurs at the top.
		Cementstones, oolitic limestones, with broken fossil shells and irregular bedding.

The quarry exposes almost the southern most occurrence of these formations, which further to the south are replaced by the standard Cotswold sequence. Many Members of the Society immediately commenced their examination of the Lincolnshire Limestone sequence.

In the meantime, Mr. Moffat had arranged a demonstration of seismic profile shooting, using a Huntec seismic refraction instrument, and proceded to fire the explosive charges and record the resulting shock waves. The right and wrong way of preparing the charges in the shot holes was effectively demonstrated. Although described here in only a few lines, both the organisation and demonstration of the first ever display of a geophysical technique to the EMGS was carried out very smoothly, and must have necessitated prior thought and activity.

After the pyrotechnics, Members continued their examination of the Ketton Pit, examining the Upper Estuarine Series. The beds here are mainly clays with a fresh water bivalve fauna. Plant remains and rootlet beds were seen and in the lower part of the sequence *Lingula* was obtained by some Members.

Holwell Quarry (SK 743237)

On the return journey to Nottingham, a diversion was made to examine the Marlstone Ironstone Formation and the Middle Lias Shales, which are seen above, in one of the ironstone pits at Holwell. Although the pits have not been worked for some years, it is still possible to see 3 to 4 metres of the ironstone with its characteristic fossils, *Lobothyris* and *Tetrarhynchia*, and a belemnite. Very weathered ammonites were collected from the paper shales above and in the tips specimens of *Gryphaea* could have been obtained.

At the end of this visit, Mr. Moffat left the party to return to Loughborough and the President thanked him on behalf of the assembled Members for organising the visits, arranging his geophysical demonstration and adding appreciably to the engineering and general geological knowledge obtained from the excursion as a whole.

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EXCURSION REPORT : A TRAVERSE ACROSS THE EAST MIDLANDS COALFIELD

Leader: R.E. Elliott — Sunday, 3 September 1972

Assisted by: P.K. Boam

Members of the Society left Nottingham by coach at 9 a.m. and after calling at Chesterfield, continued to the first locality on Duckmanton Moor (SK 425704). This was the disused railway cutting immediately west of Arkwright Colliery. Here small exposures of the Sitwell, 2nd Waterloo and 1st Waterloo Coals were seen. Members spent some time inspecting the roof of the Sitwell Coal and viewing civil engineering works associated with a new drift between the Waterloo Coals at Arkwright Colliery.

The party then continued to Buttermilk Lane (SK 454720) to view small exposures of contorted coal measures alongside a canalised reach of the River Doe Lea. These were overlain by some 10 ft. of head and the leader explained that similar disturbed measures were found to exist to a depth of about 200 ft. in a series of closely spaced boreholes drilled in the nearby Markham Colliery yard. It was explained that these structures were likely to be examples of valley-bulging, as suggested in the Memoir of the Geological Survey covering 1 in. Geological Sheet 112. Members also took the opportunity of searching for fossils on the lower slopes of the nearby colliery spoil heap.

The party then journeyed by 'bus through Bolsover, noting a landslip on the Permian scarp below the castle.

Lunch was taken at Scarcliffe and the traverse was then continued to Pleasley. A disused railway cutting (SK 495637) immediately south of the colliery was approached by way of Batley Lane. Here the Lower Magnesium Limestone was seen to be well bedded and exhibiting cross bedding, stylolites and well-developed joints. Some of the joints had pulled open, particularly at the west end of the cutting, where intermediate blocks of limestone were tilted, the most south westerly one with a dip of 25°. The open joints were seen to be filled by collapse from above and the wider ones had been consolidated by stone walls when the railway was constructed. The normal dip of limestone in an adjacent cutting was referred to by the leader as 1 - 2° east, whereas the tilt of the blocks was directed south-west, valley-wards. The leader explained that the widened and collapsed joint structures have been called gulls and that the tilt had been attributed to cambering in the above mentioned Memoir. He described how these structures and the valley-bulging seen alongside the River Doe Lea were two aspects of the same phenomena, which was usually considered to have originated under peri-glacial conditions.

On the walk back to the 'bus, the party noted springs emerging from the base of the limestone.

The next locality visited was another disused railway cutting (SK 521670) extending SSW from the old station at Shirebrook and on the same line as the Pleasley locality. This was referred to as the Hodhill Cutting and provided a high and extensive section of the uppermost part of the Lower Magnesium Limestone. The leader pointed out six features: a scarp along the line of a fault which is known underground at Shirebrook Colliery and which terminates the cutting at its northern end; numerous mound like structures, revealed by beds dipping up to 25°; wedge and cross bedding associated with these mounds; sedimentary dykes filled with red marl and fine sandstone recalling the overlying Middle Permian Marl known about a mile to the east; and the position of a fault crossing the cutting between the first and second bridges to the south, this also being known from underground workings.

The party returned to the 'bus ahead of schedule and as a result was able to visit Pleasley Vale, where a cave (SK 517650) in the Magnesium Limestone was examined. The leader referred

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to a published list of Pleistocene animal bones found in a nearby cave, including bison, hyena, lynx, reindeer, wolf, arctic fox and woolly rhinoceros.

After this digression the members journeyed across the Bunter outcrop of Sherwood Forest, through Ollerton, to Kirton Brickworks (SK 692680), where the features of the Keuper succession previously seen by the Society in April 1965 (Elliott 1966) were re-examined. About 150 ft. of strata were seen, including the topmost beds of Waterstones, the Radcliffe Formation and higher strata representing the lower part of the Keuper Marl. The green and purple beds of the Radcliffe Formation were well exposed and a relatively coarse sandstone layer close to the top of the waterstones yielded small pebbles of quartzite. Sedimentary structures such as salt pseudomorphs, dessication cracks and ripple marks aroused considerable interest. Only very small traces of gypsum were found, virtually the whole quarry being in the weathered zone.

During the course of the day, a number of features were pointed out en route. These included outcrops of the thicker sandstones in the Coal Measures and the positions of the Clay Cross Two Foot and Mansfield Marine Bands: the leader also gave a few statistics regarding each of the collieries passed by.

The party returned to Nottingham via Chesterfield and disbanded at about 7 p.m.

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Editor's note: The excursion report for the visit on October 1st 1972, to the Monsal Railway Cuttings, led by Dr. T.D. Ford was published as an appendix to the paper by Butcher and Ford (1973), The Carboniferous Limestone of Monsal Dale, Derbyshire, *Mercian Geologist* Vol. 4, No. 3, pp. 179-196. Appendix pp. 193-196.

REVIEW

WATSON, W., 1973 *The Strata of Derbyshire (1811)* Reprint edition by Moorland Reprints, Hartington, Derbyshire; with a new introduction by T.D. Ford, 18pp. (no numbers) 4 text-figs. (1 folded); 1 folded plate, 16pp. (no numbers) 76pp. incl. index; advertisement. Bound in boards, priced at £3.60.

In 1811, the appearance of White Watson's book, *A Delineation of the Strata of Derbyshire*, was no doubt eagerly awaited, by at least 177 subscribers, some of them landowners within the county of Derbyshire, about to profit further from the extraction of raw materials to cater for the needs of the forthcoming industrial revolution. At the present time, the main demand for this book will be from those interested in the history of Derbyshire geology, biography and general readers of the history of the county of Derbyshire. The difficulty in obtaining the original copy, even, so information sources relate, at prices up to £60,00, and its general absence on library shelves, has led the publishers to produce "an exact fascimile of the original" including the folded plate, index to the plate, title page, list of original subscribers, dedication, introduction, 72 pages of description of rock strata, an index and a single page advertisement for Watson's consulting services. T.D. Ford has produced a 'new' introduction, which in keeping with the spirit of the reprint edition is a reproduction of a paper published in 1960 in the Proceedings of the Geologists' Association, but without the 3 plates of the original. The Ford introduction considers the biography and geological work of White Watson and includes lists of the famous Watson stone tablets and a bibliography of his written works.

The great advance in geological knowledge, which has resulted from the search and extraction of limestone, coal, sandstone, shale, ironstone and various minerals, culminating, say, in the modern 6" to 1 mile Geological Survey G.B., maps (2nd ed.) would make a comparison with Watson's section from Buxton to Bolsover somewhat invideous and the text describing the section, to modern eyes appears to be written in a foreign language. The provision of voluminous footnotes suggests that in 1811 some explanation of the curious terms used was necessary for the average reader.

The reproduction of the original text and plate is excellent, with just the right amount of faded print, usually that of the footnotes. It must have been very difficult to obtain a plate that would produce at the same time, the large black print of the main text and the much smaller (3:1 difference) footnote print. The edition is published on a light yellow paper of medium weight, perhaps in deference to the age of the original work. Unfortunately, in the reviewers copy, the main folded plate was inverted and 2 pages had paper creases prior to printing. The book is attractively bound in boards, with a dark blue cloth and gold lettering.

The book will be welcomed by those interested in the history of geology, in biography and in the county of Derbyshire generally. It is useful to have Ford's P.G.A. paper and Watson's main work in the same volume.

F.M. TAYLOR.

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Secretary's Report for 1972-73

At the beginning of its ninth year, the Society contended successfully with the power cuts and blackouts resulting from the coal strike. Before the end of February, evening bookings at the University had been cancelled, and it was decided that the Annual General Meeting should be held at 3 o'clock in the afternoon of March 9th instead of in the evening.

The A.G.M. was uneventful, there was no controversy, the same officers were re-elected and the same Council was re-elected en bloc; but there was a remarkable attendance of some 60 members when the meeting opened, the seal of approval indeed to Council's decision to hold the Collectors' Meeting after the business. The Swinnerton Laboratory had been opened at 2 o'clock so that items could be arranged, and by 3 o'clock the enormous room was crowded by no less than 39 separate exhibits. As the afternoon progressed there were greater crowds, until the whole Society seemed to be present, interested, enthusiastic, and very appreciative.

Perhaps the most popular feature was Mr. Sykes' Bring and Buy Rock Sale, the success of which passed all expectations, and which enabled Mr. Sykes to donate £16.38 to the Society's Trust Fund.

A list of exhibits follows:

1.	V. Paling	a. Geological samples from the China Clay country. b. Semi-precious stones.
2.	A. Shelton	Mineral specimens from Ashover.
3.	B.M. Logan	a. Plaster casts of fossils made in the Dept. of Geology. b. Collection of fish teeth from the Dept. of Geology.
4.	I.D. Sutton	Collection of minerals.
5.	R.W. Morrell	a. Vertebrate and invertebrate fossils. b. Modern molluscs. c. Geological books.
6.	J.C. Macdonald and G. Rothnie	a. Mineral collection and problematica. b. Fossil collection.
7.	A.E.G. Allsop	Rocks from Skye, photographs and minerals.
8.	M. and D. Beaumont	a. "Two amateurs in the Askrigg Block." b. Underground in Craven.
9.	J. Fletcher	Problematica and a dinosaur fossil.
10.	D.M. Morrow	Collection of British igneous rocks.
11.	D. Manning	a. Rocks from Argylle and Skye. b. Problematica.
12.	C. Champion	a. Silicified fossils from a Visèan limestone block. b. Spiriferidina collection.
13.	N. Leiter	Biological specimens.
14.	H.B. Briggs	"The Present is the Key to the Past" - corals, graptolites and a mammalian tooth.
15.	W.S. Moffatt	Demonstration: Proton magnometer.
16.	E. Taylor	Fossils of the future from the Isle of St. Kitts.
17.	P.H. Hanford	Rocks, minerals and fossils.
18.	J.C. and A. Summers	Polished stones and rocks.
19.	M. Wild	Minerals from Italy, Tunisia and Nigeria.
20.	R.E. Jeffcoat	Rocks, Minerals and fossils.
21.	A.D. Uppadine	a. Manners' Brickyard Quarry, Eastwood. b. Granodiorites from Mountsorrel and Dorset.
22.	M. Boneham	Permo-Triassic rocks from Nottinghamshire.

23.	R. Bright	Fossil collection.
24.	R.J.A. Travis	Specimens of Oxynoticeras from the Frodingham Ironstone of Scunthorpe.
25.	F.M. Taylor	Reported "shell bed" in the Bunter Sandstone, actually a "tip" of oyster shells above Trent alluvial deposits and below the road.
26.	P.H. Speed	Argentiferous galena.
27.	E.M. Colthorpe	Basic dyke rock in Lewisian Gneiss, Scourie.
28.	P. Spencer	Geological specimens from local areas.
29.	E. Ramsell	Fossils from North America.
30.	F.M. Taylor	The Mercian Geologist collation process.

The last indoor meeting of the season was held in April, when Mr. P.H. Speed, Treasurer of the Society and Regional Geologist for British Railways, described the work of Engineering Geologists. He spoke of the difficulties encountered in the construction of railway cuttings, canal excavations and building sites, and his lecture was startlingly illustrated by his own professional slides.

The first excursion of the year, a visit to the Malverns was held, as customarily, during the first weekend in May, and led by Dr. W.G. Hardie of the University of Birmingham. The party drove to Great Malvern on Friday evening through torrential rain, and assembled after dinner to hear the leader describe the rocks of the area - an act of faith, since the Malvern Hills were invisible. The weather, however, improved, and the party spent two happy days covering the geology of the whole area. Mr. Hardie will surely not forget his station wagonload of geological ladies who, after the climax of "Miss Phillips' Conglomerate" accompanied him to the summit of Worcestershire Beacon. We were fortunate also to have with us, Mr. D. Bullard of Nottingham University, who was currently conducting research in the area, and who made a great contribution to the excursion.

In June, Mr. D.B. Smith of the Institute of Geological Sciences led an excursion to the Permian rocks of the Doncaster area. Some four years earlier, Mr. Smith had been leader of a joint Y.G.S. and E.M.G.S. weekend excursion to the Permian of Yorkshire, based in York. It was good to have this acknowledged expert again to describe his latest conclusions.

In July, excursion, arranged by Mr. W.S. Moffat of Loughborough University, brought a large party to the site of the new Empingham Reservoir in Rutland. After hearing from the site geologist a description of the underlying rocks, the geological problems involved, and the methods used by the engineers in dealing with them, the party was shown over the site, to the appalling din of the tractors, tearing back and forth at breakneck speed, and shifting earth as if life depended on it.

Later, in Ketton Quarry, Mr. Moffat gave a demonstration of seismic survey equipment, a most interesting addition to an unusual excursion.

The September excursion made a geological traverse from Chesterfield to Ollerton and was led by Mr. R.E. Elliott, Vice-Chairman of the Society. Because of the narrow roads and difficulties of parking at the various exposures, the party was restricted to one coach load. There were many very interesting features to be seen during the traverse, and an unforgettable smell associated with the River Lee and the adjoining Coalite plant.

Once again in October, Dr. T.D. Ford found time to lead a Society excursion, this time to the abandoned Monsal Dale Railway Cutting. At the start of the meeting, however, he set a field exercise. The party was divided into four groups, and each given a section of the cutting wall to map. Members reacted with enthusiasm, and appreciated very much the instruction in mapping techniques which Dr. Ford gave some half an hour later. It was felt that this was a valuable addition to the excursion. The traverse along Monsal Dale completed the section which members saw with Professor Cope in 1970.

The first indoor meeting of the winter was held at the end of October. Dr. A.C. Waltham of Trent Polytechnic gave a brilliant description of his expedition to the Himalayas in 1970. The immense audience was amused and delighted by his admirable slides and his rapid, witty narrative.

A decision had been made by Council to hold some indoor meetings during the afternoon, and the first of these took place in the middle of November in St. Helen's House, Derby. There was not, however, the customary large audience, and as a result, subsequent meetings were rearranged for evenings. On this occasion, Dr. R.J. Allen of the University of Reading spoke of the Old Red Sandstone of Southern Britain, a subject which had considerable bearing on the field excursion to the Wye Valley, Herefordshire, led by Dr. P.L. Hancock in 1971. Dr. Allen's excellent description of conditions of deposition of the beds linked together the diverse rocks collected on the excursion.

Early in December, Mr. P.J.E. Woods of Cleveland Potash Ltd., gave an interesting lecture which described the methods used by his firm to mine the potash deposits of North Yorkshire.

The Eighth Annual Dinner was held in December at the University of Nottingham Staff Club. This has always been a very informal and friendly occasion, and one which seems year by year to become more so. It was good to see that many of our newest members were present.

After dinner there was a showing of excursion slides which brought back happy recollections of our earlier meetings of the year.

The new year brought an increase in activities, and three meetings were held in January.

Dr. R.J. Firman had informed Council of sedimentary structures to be seen in the settling pond at the old Mill Close Lead Mine in Derbyshire, at the present time being worked for fluorspar and other minerals. It would be necessary to arrange a visit at once, before the entire mass was removed, and it was decided that notice should be given in the circular, and members should be invited to make their own way to the site at 2.30 p.m.

In spite of the bitterly cold day, the fog, the ice-laden wind and the total lack of shelter, an Arctic-clad party of 26 assembled, and spent a most interesting afternoon examining the structure and contents of the former dam. Dr. Firman was assisted by Mr. R. Ridgeway, who had been involved in the project, and Mr. G. Wozencroft a mining post-graduate student who has conducted research on the material.

Later in the same day, the annual joint meeting was held in Tawney House, Matlock Green with the Matlock Field Club. The subject of the lecture was the Economic Geology of Derbyshire, and the Speaker, Dr. P.R. Ineson of Sheffield University. The tireless E.M.G.S. were again present at the meeting among the large audience of 110, who made it evident that the exploitation of Derbyshire minerals was a matter of much concern to them.

Later in January a programme of geological films was arranged by Mr. E.H. Marriott, and shown in the University of Nottingham. The theme was oil exploration, and the following films were shown: Oil Search, North Sea Quest, and Angle Bay, Pembrokeshire.

At the last meeting of the Society's year, the President of the Society, Dr. F.M. Taylor gave his third Presidential Address, "The Permian and Lower Triassic Landscapes of Nottinghamshire". He gave a vivid picture of the geography of Permo-Triassic times, and related the deposits most convincingly with those of present day desert areas north of the equator. The address will be published in the "Mercian Geologist" in due course.

Perhaps the most popular innovation of the year was the Buffet Supper which following the meeting, and which rounded off the President's term of office. Mrs. Taylor and her helpers arranged the food, the wine was provided by the President and the Treasurer, and some 50 members of the Society were present to enjoy it, a most happy ending to the year's activities.

In all, there were 15 meetings during 1972-73, 6 field excursions, 5 lectures in Nottingham, Derby and Matlock, an A.G.M., and Collectors' Meeting, a Presidential Address, a film show and an Annual Dinner.

The Editor had many reverses and difficulties during 1972, and Vol. 4, no.3 of the Mercian Geologist was delayed until very late in the year. Work was in hand, however, for subsequent issues, and it was expected that later parts could be published at shorter intervals.

Eleven monthly circulars were sent out during the year, a big item in postal costs, but greatly reduced by the 17 members who kindly continue to deliver by hand to people who live in the same district.

Membership rose considerably in 1972, 52 new members were elected, including 27 Ordinary members, 16 Juniors, 2 Joint memberships and 1 Institution. There was an increase in membership of 44.

The present state of membership is as follows:

Honorary	Ordinary	Joint	Junior	Institutional	Total
2	260	100	39	128	529

The Society learned with regret of the death of Mr. C.H. Milner, a founder member, and a keen supporter of Society affairs.

It is pleasant to report that the Society is lively and vigorous at the end of its ninth year, and grateful to all those who made its many activities possible, to the excursion leaders, Messrs. W.H. Hardie, D.B. Smith, W.S. Moffat, R.E. Elliott, Dr. T.D. Ford and Dr. R.J. Firman, and the speakers, Mr. P.H. Speed, Dr. A.C. Waltham, Dr. R.J. Allen, Mr. P.J.E. Woods, Dr. P.R. Ineson, and not the least, the President, Dr. F.M. Taylor.

The Society also recognises with gratitude the support given by Professor the Lord Energlyn and the University of Nottingham, who continue to make us welcome on their premises.

1973 publications continued from p. 84.

TREWIN, N.H. and HOLDSWORTH, B.K. — 1973. Sedimentation in the Lower Namurian Rocks of the North Staffordshire Basin. *Proc. Yorks. geol. Soc.* vol. 39, pt. 3, pp. 371-408.

TURNER, S. — 1973. Siluro-Devonian thelodonts from the Welsh Borderland. *Q. Jl. geol. Soc. Lond.* vol. 129, pp. 557-584.

WALTER, B. and POWELL, H.P. — 1973. Exceptional preservation in cyclostome Bryozoa from the Middle Lias of Northamptonshire. *Palaeontology.* vol.16, pt. 1, pp. 219-220. 1 plate.

1973, 1974, papers on Midlands Geology **not** noted in the above list, should be sent to The Editor, E.M.G.S., Department of Geology, The University, Nottingham, if they would like an entry in the next issue of the Mercian Geologist.

THE MERCIAN GEOLOGIST

Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time, 16 parts, comprising 4 volumes have been issued, the last, vol. 4, no. 4 in December 1973. The Mercian Geologist publishes 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 provide 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 letter 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.

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