PALAEONTOLOGY, STRATIGRAPHY AND SEDIMENTOLOGY OF THE KINDERSCOUTIAN AND LOWER MARSDENIAN (NAMURIAN) OF NORTH STAFFORDSHIRE AND ADJACENT AREAS

by

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The folder in volume II contains six folded diagrams, referred to as Appendix Figures I-VI in the text.

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ABSTRACT

The thicker-shelled goniatite fauna of the Kinderscoutian and the Marsdenian up to the *R. bilingue* s.s. marine band is described in detail. The lower part of the Kinderscoutian is almost completely fossiliferous and the goniatites are described from "horizons" rather than marine bands. Five marine bands have been identified in R1b, and faunas from two marine bands noted in R1c. The *R. gracile*, *R. bilingue* early form and *R. bilingue* s.s. marine bands are described from the Marsdenian. Identification of material from the Brund Boreholes confirms the succession deduced from field evidence, and a revision of the *R. dubium* subzone is suggested on the basis of palaeontological evidence from North Staffordshire.

As well as the faunal marker horizons, eight thin, kaolinised ash bands have been used in correlation of the succession. The existence of these bands and the establishment of the faunal succession has enabled the stratigraphy of the sandstones to be studied in detail.

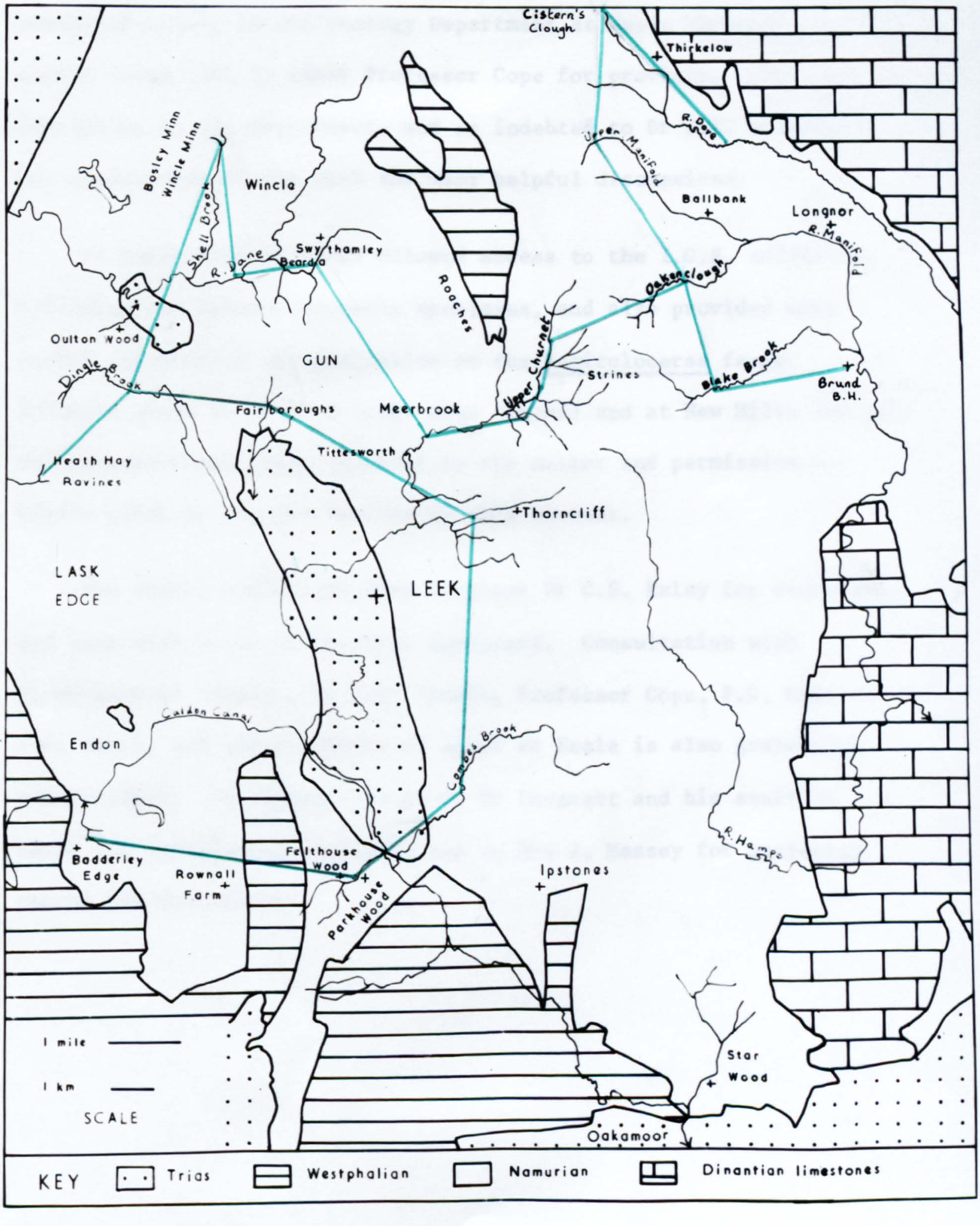
The K-feldspathic lithofacies, derived from the north, is composed entirely of turbidites. It has been divided up into seven sublithofacies by the use of such characteristics as average bed thickness and sandstone:shale ratios. The K-feldspathic lithofacies is diachronous, making its first appearance in R1c in the north of the area and R2b in the south. Rhythms superimposed on a megarhythm, or sandstone unit between two marine bands, have been recognised and described in detail from an R2a section.

The lowest Kinderscoutian protoquartzite units known are in the upper part of R1a in the south of the area. Representatives of this lithofacies as deltaic deposits are known at various horizons up to

R2b in the south, but the lithofacies occurs more rarely in the north, extending as tongues of turbidites from the deltaic area in R1b and R1c.

The differing rates of sedimentation and environments of deposition of the protoquartzites and K-feldspathic sandstones on occasion influence the thickness of the marine bands and their faunas. Variations are noted in the distribution of these faunas in relationship to the sediments, particularly within the *R. gracile* sequence.

Figure I   GENERALISED MAP OF THE AREA



line of section, Appendix Figure III

ACKNOWLEDGEMENTS

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Dr Ramsbottom at Leeds allowed access to the I.G.S. collection, including the Ashover Borehole specimens, and also provided much useful information and discussion on the *Reticuloceras* fauna. Borehole cores from the Longnor area (Brund) and at New Mills (Colne), and Stainland were also examined by the author and permission was kindly given to use the results in this account.

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CHAPTER I

PALAEONTOLOGY

INTRODUCTION TO PALAEONTOLOGY

The total succession covered includes the Kinderscoutian (R1) and the lower part of the Marsdenian from R2a to the R. bilingue Bisat s.s. marine band. The faunal succession of these two stages is set out in Figures 1.A and 1.B. Although Bisat (1924) described the Marsdenian fauna in his account of the Namurian goniatites, and Bisat and Hudson (1943) expanded on the Kinderscoutian goniatites, later publications have revealed more details on these goniatites and the full succession.

Previous publications were found inadequate, however, to explain in detail the whole succession seen in North Staffordshire. The thicker-shelled goniatite fauna has therefore been reinvestigated in detail to elucidate the complex relationships between the sandstone units, particularly those in R1b where the faunal succession appeared to be least well known. Several new species (a list is given below) have been described from the succession, and data from local boreholes incorporated into the text. Details of the boreholes are given in the Appendix to Chapter 1 and Appendix Figure I.

The Thorncliff area exposes a large part of the R1a-b faunal succession. R1c is also well exposed but the goniatites fail in the higher part of this succession. A map of this area is given in Figure 1.C. R2a - $R2b_{ii}$ is best exposed in the Upper Churnet Valley (Figure 1.D) where the marine bands are repeatedly exposed along the strike-stream section. A few localities in R1 have also provided useful information.

Depository

Type material and figured specimens described in the following account are deposited at the Institute of Geological Sciences at Leeds.

NEW SPECIES DESCRIBED

1. *Reticuloceras* species nova of *R. pulchellum* Bisat and Hudson group, p.43
2. *Reticuloceras prereticulatum*, $R1b_v$, p.88
3. *Reticuloceras* species nova (non-crenulate form), $R1b_v$, p.156
4. *Reticuloceras* sp. nova, *R. coreticulatum* subzone, p.101
5. *Reticuloceras retiforme*, R2a, p.115
6. *R. gracilingue* Ramsbottom MS., sp. nov., R2a, p.123
7. *R. latelirifer*, p.126
8. *R. graciloides* Ramsbottom MS., sp. nov., R2a, p.129
9. *Reticuloceras* species nova $R2b_i$, p.141
10. *Reticuloceras* species nova of *R. bilingue* group, $R2b_{ii}$, p.146
11. *Reticuloceras* species nova, $R2b_{ii}$, p.149

ABBREVIATIONS OF GENERIC NAMES

A = Anthracoceras

D = Dimorphoceras

G = Gastrioceras

Gl = Glyphioceras

H = Homoceras

Ht = Homoceratoides

Hd = Hudsonoceras

P = Parametacoceras

R = Reticuloceras

Figure 1.A

THE KINDERSCOUTIAN FAUNAL SUCCESSION

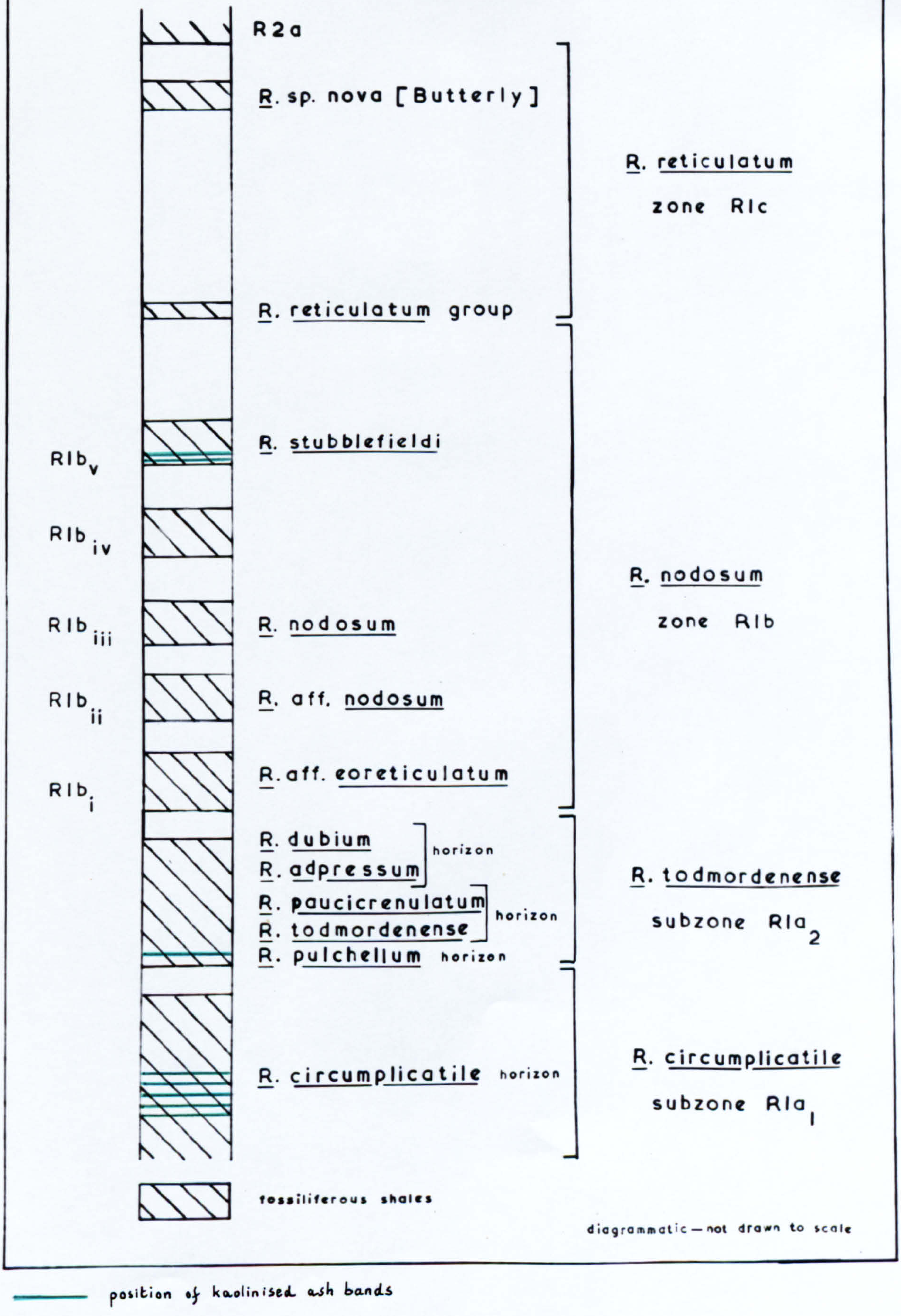
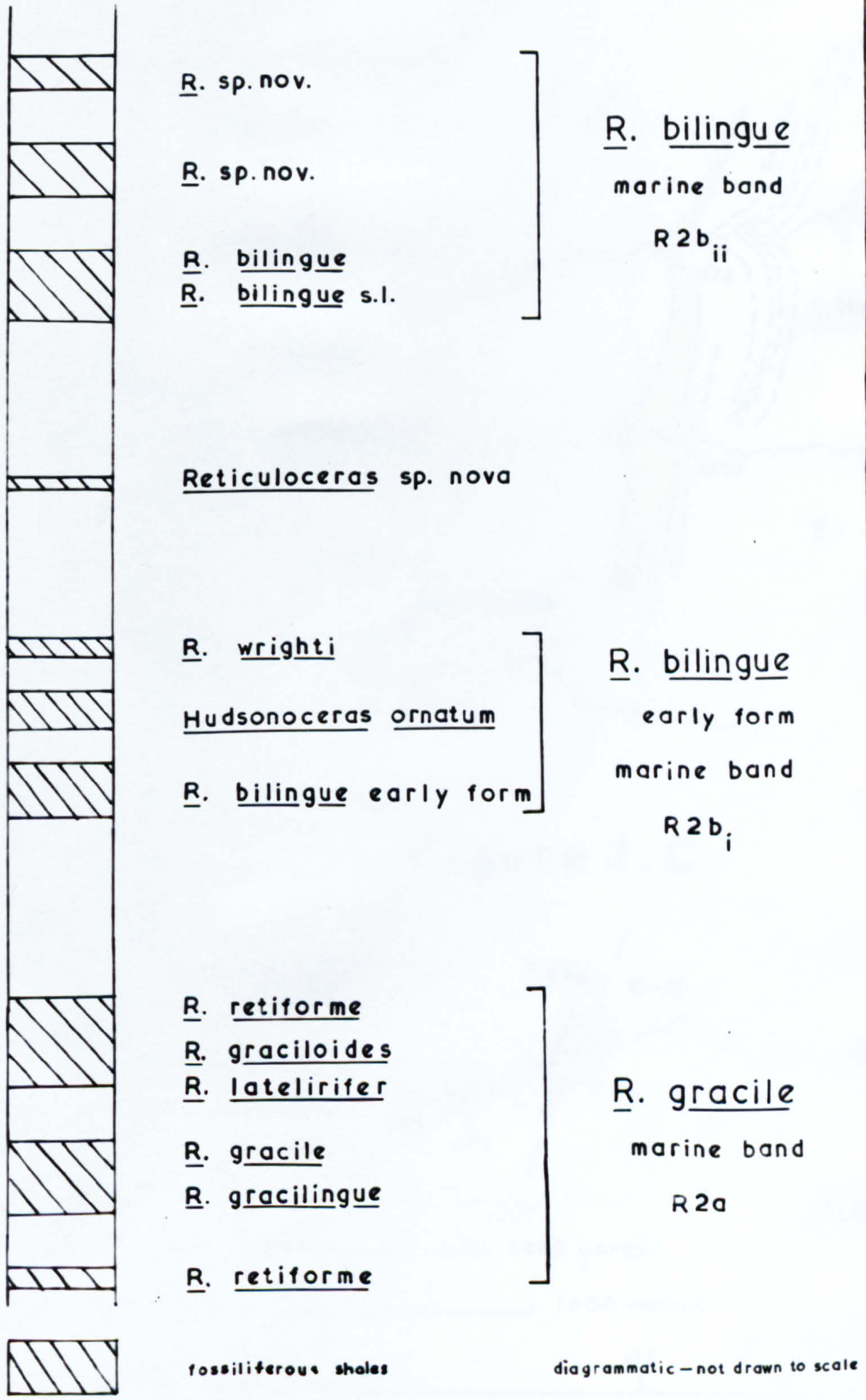
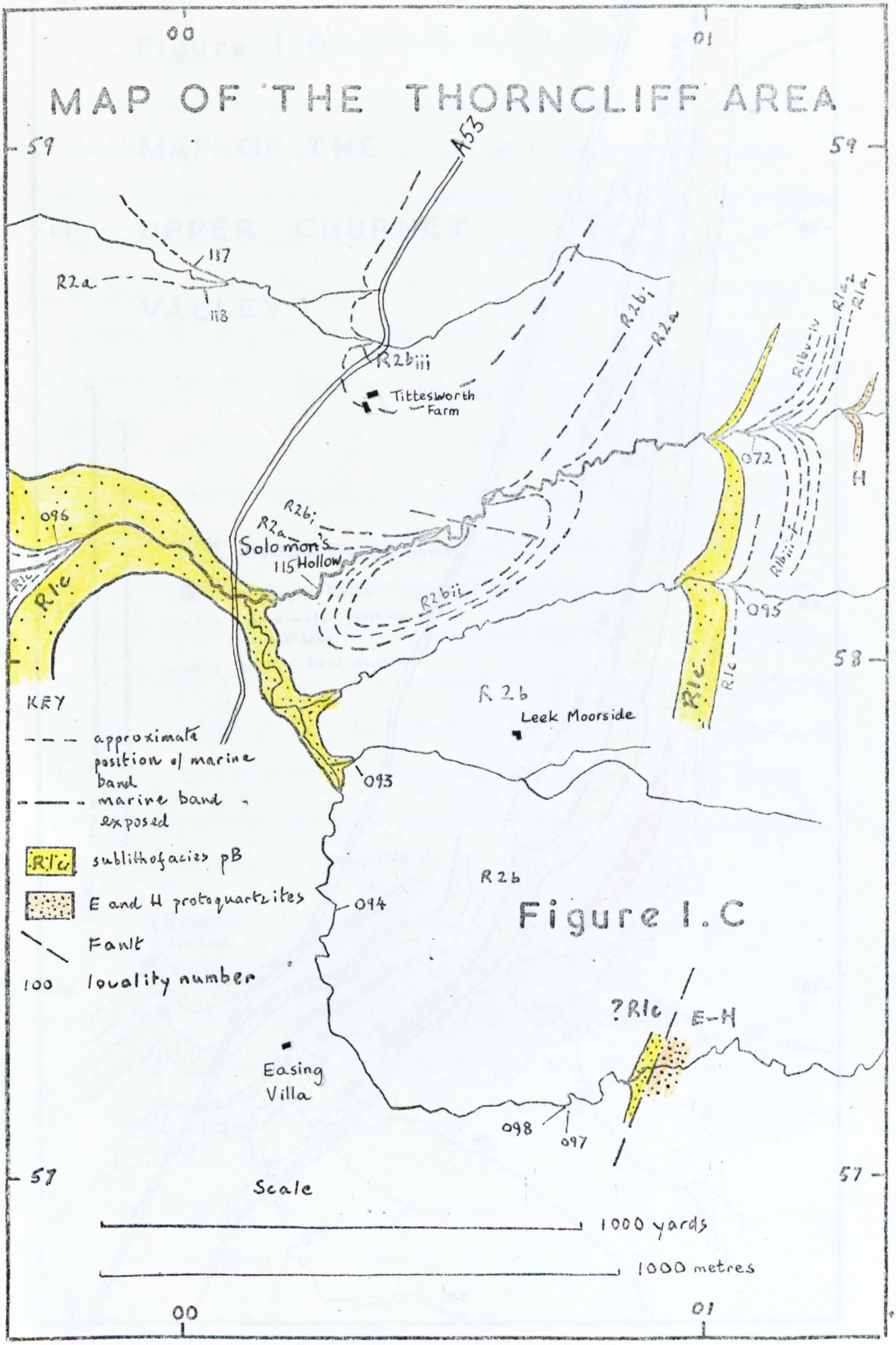


Figure 1. B

THE LOWER MARSDENIAN FAUNAL SUCCESSION




MAP OF THE THORNCLIFF AREA
00
01
59
58
57
A53
R2a
117
118
R2b iii
Titteswoth Farm
R2b i
R2a
072
H
096
R2b i
R2a
Solomon's Hollow
115
R2b ii
R1c
095
R1c
R2b
Leek Moorside
093
KEY
approximate position of marine band
marine band exposed
R1c sublithofacies pB
E and H protoquartzites
Fault
100 locality number
R2b
094
Figure I.C
?R1c
E-H
Easing Villa
098
097
Scale
1000 yards
1000 metres

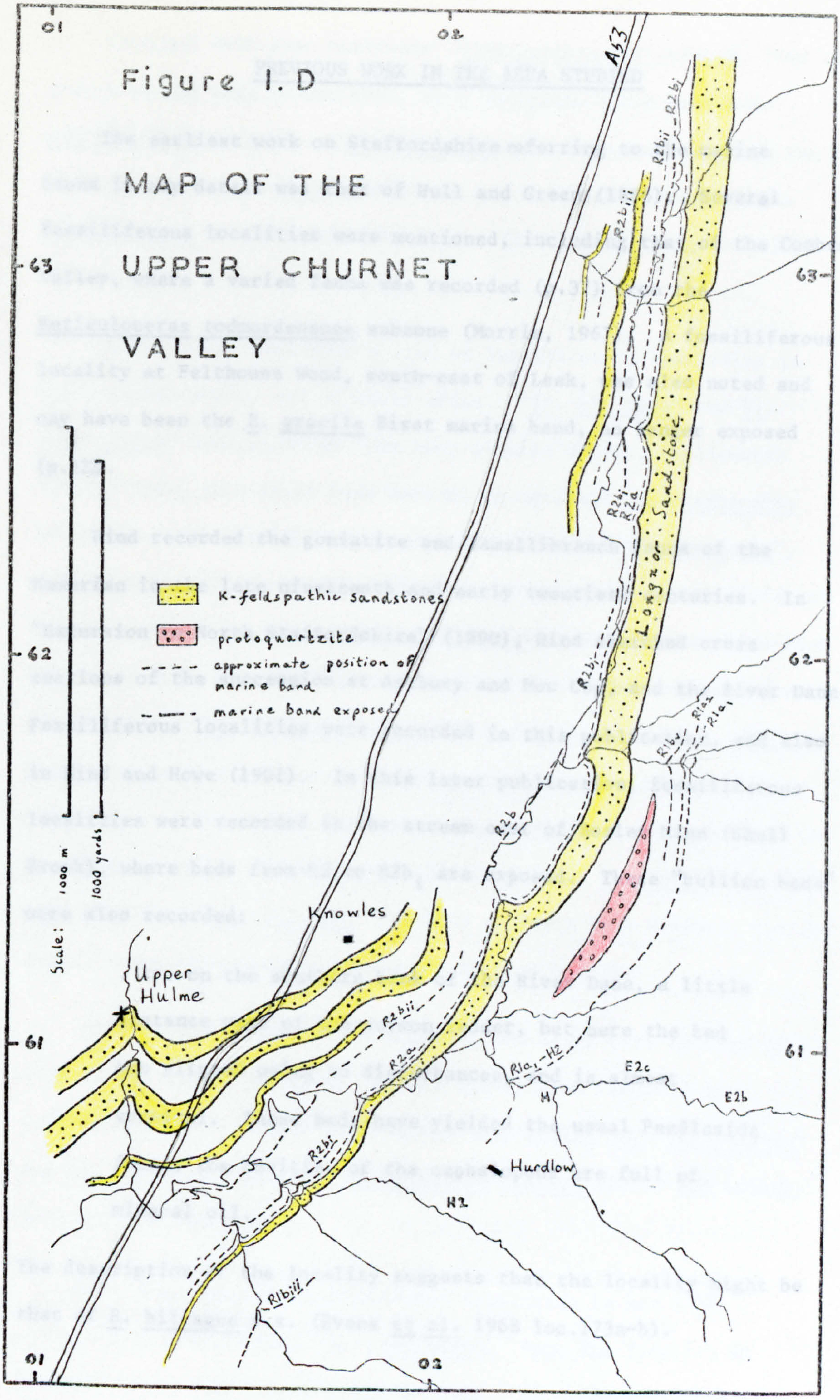


Figure 1.D

MAP OF THE UPPER CHURNET VALLEY

PREVIOUS WORK IN THE AREA STUDIED

The earliest work on Staffordshire referring to the marine fauna in any detail was that of Hull and Green (1866). Several fossiliferous localities were mentioned, including that of the Combes Valley, where a varied fauna was recorded (p.37) from the *Reticuloceras todmordenense* subzone (Morris, 1967). A fossiliferous locality at Felthouse Wood, south-east of Leek, was also noted and may have been the *R. gracile* Bisat marine band, no longer exposed (p.122).

Hind recorded the goniatite and lamellibranch fauna of the Namurian in the late nineteenth and early twentieth centuries. In "Excursion to North Staffordshire" (1890), Hind sketched cross sections of the succession at Astbury and Mow Cop, and the River Dane. Fossiliferous localities were recorded in this publication, and also in Hind and Howe (1901). In this later publication, fossiliferous localities were recorded in the stream east of Bosley Minn (Shell Brook), where beds from E2 to $R2b_1$ are exposed. These "bullion beds" were also recorded:

> . . . on the southern bank of the River Dane, a little distance west of the salmon ladder, but here the bed has slipped owing to disturbances, and is almost vertical. These beds have yielded the usual Pendleside fauna; the cavities of the cephalopods are full of mineral oil.

The description of the locality suggests that the locality might be that of *R. bilingue* s.s. (Evans *et al.* 1968 loc.173a-b).

Hind and Howe also mentioned "Glyphioceras reticulatum" from the shales at the base of Mam Tor. Such specimens could have been Reticuloceras from R1b. "Gl. bilingue" was also recorded from the bed of the River Hamps (ibid. p.372) but may well have referred to a Eumorphoceras marine band since Hester (1932, p.41) recorded E2 in this section.

Hind (1902a) published a list of fossiliferous localities in North Staffordshire and adjacent areas. "Gl. bilingue" and "Gl. reticulatum" were recorded from near Glutton Bridge. Holdsworth (1963a) found that these beds were E2 in age, and a Eumorphoceras specimen at the British Museum, formerly labelled "Glyphioceras", indicates that Hind probably called goniatites from widely different horizons by the same name. "Gl. reticulatum" was again recorded from the River Dane, but the figured specimens are of goniatites too small to identify. "Gl. bilingue" (ibid. Pl.2 fig.6) could be R. bilingue s.s. because of the pronounced lingua and the non-crenulate appearance of the radial ornament. Fig.7 (ibid. Pl.2) appears to be an internal mould. Evans et al. (1968) recorded R. gracile in the area of Hind's "Gl. bilingue" locality at North Rode viaduct, but the exposure may have changed subsequent to Hind's work.

Hind (1902b) compared the fauna of the River Dane section with that of the Dinant district. Stobbs (1902) also recorded the section beneath the sandstones at Mam Tor, naming "Gl. reticulatum" and "Gl. spirale" (possibly Hudsonoceras ornatum (Foord and Crick) from the R1b section).

Hind also recorded fossiliferous localities in his 1910 publication, but omitted "Gl. reticulatum" from the locality at Glutton Bridge, mentioned in Hind, 1902a. He clearly thought that

"*Gl. bilingue*" occurred high in the succession:

> . . . as the presence of *Glyphioceras bilingue* shows that the fault {between the limestone and black shales} is of some considerable throw, as this is the fossil which characterises the upper part of the series immediately below Farey's Grit which crops out in the hill above Longnor . . . .

Hind could possibly have confused the strong lingua of large smooth specimens of *Eumorphoceras* with the same feature on the internal mould of *R. bilingue*. No fault in fact occurs in this area, the black shales resting unconformably on the Dinantian limestones. "*Glyphioceras bilingue*" was believed to occur higher in the succession than the "*Glyphioceras reticulatum*" zone exposed in the River Dane section (R2a-R2b) and around Leek (probably R2, but extending down to R1a in parts).

Fossiliferous localities were also recorded in the Geological Survey Memoirs for the Stoke-on-Trent and Macclesfield areas. The Stoke-on-Trent volume (Gibson *et al.*, 1905) recorded the succession of the Endon and Stanley anticline, which exposes the "Millstone Grit Series". Several sections with goniatites were mentioned, but only one is likely to be of *Reticuloceras* age, ie. that near Rownall Farm (p.272 of this account) in Gibson *et al.* (1905) and Gibson and Wedd (1905, p.9). Poorly preserved specimens of "*Glyphioceras (Goniatites) bilingue*" were obtained from nodules, and "*Glyphioceras (Goniatites) bilingue*" and "*Gl. reticulatum*" were also identified from the area by Hind (in Gibson *et al.* 1905, p.307).

In the old Macclesfield Memoir (Pocock *et al.*, 1906, p.18), "*Gl. reticulatum*" and "*Gl. bilingue*" were re-recorded from the River Dane (in the section near Wincle) and at the North Rode Viaduct locality. "Gl. bilingue" was also re-recorded from a locality south-west of Foxt, and probably referred to the exposure of R. superbilingue Bisat.

Alkyns (1923) recorded the fauna of Star Wood, Oakamoor, mentioning the fauna of at least two marine bands. "Glyphioceras bilingue" (possibly from the R. bilingue Bisat early form marine band) was recorded in great numbers, and Posidoniella laevis, "Posidonomya" membranacea and "Pterinopecten papyraceus". "Glyphioceras spirale" (probably Hd. ornatum from $R2b_i$) was noted, and comment made that this form was different from "Gl. spirale", lower in the series where it was used as the zone fossil (Hd. proteum (Brown)), and that a distinction should be made between the two.

Alkyns described the R. gracile limestone as a ". . . hard red ironstone--haematite--which has replaced the limestone originally present". He recorded only a single specimen of "Pterinopecten papyraceus", but numerous ammonoids and nautiloids.

Subsequent records of the fauna in North Staffordshire are better documented and more readily reidentified since they follow the classification of Bisat (1924). Faunal records after this date are referred to in detail where appropriate in the description of the fauna.

The R. gracile marine band was noted by Bisat (1924) at Star Wood, Oakamoor, and R. gracile (?)late form, figured from this locality. The locality was subsequently mentioned (Bisat, 1933), when comment was made upon a "markedly Gastrioceras-like form" (p.120).

Challinor (1929) used Bisat's "zones" based on the goniatite fauna, and recorded several Reticuloceras localities. His localities S 14 and S 17 were recorded as "R. reticulatum mut. beta, zone R, suggesting sub-zone R2", and are in fact localities at the R. bilingue s.s. marine band. Loc. S 16 ("R. reticulatum zone suggesting subzone R2") is the same marine band, and was identified as R. bilingue by Cope (1946).

An R1a or R1b locality was also recorded at S 28 ("R. reticulatum, zone R suggesting subzone R1") in the Thorncliff stream section, and loc. S 29 (un-named, in Solomon's Hollow) is probably that of loose bullions containing R. gracile (Morris, 1966a).

Hester (1932) also recorded exposures in the River Dane of R. bilingue (typical and early) and R. reticulatum (Phillips) from Shell Brook (possibly R1c, but could be R1b). R. bilingue Bisat (typical and late) were also recorded from the Upper Churnet, and the early form from Harston Wood. R. gracile was recorded from Star Wood and Felthouse Wood. An "inconstans" fauna was mentioned from Dingle and Shell Brook where there are numerous exposures in R1a, and from Corda Well (near Limekiln Brook, probably $R1a_2$ in this account).

Bisat (1932a) briefly referred to sections at Mam Tor and to R1 at Earle's Cement Works (Hope) -- the type locality for R. stubblefieldi, Bisat and Hudson. Jackson (1927) also described the succession below the Kinderscout Grit in North Derbyshire, recording the "R. inconstans" zone and that of R. reticulatum. These two "zones" are separated by a bed containing numerous "E. ornatum", probably $R1b_{ii}$ of this account.

Bisat and Hudson (1943) revised the Lower *Reticuloceras* fauna and mentioned an R1c locality in the Upper Dove, now thought to be $R1b_v$, and an occurrence of *R.* aff. *umbilicatum* Bisat and Hudson. These exposures were also found by Holdsworth (1963a) and are amongst others mentioned in the relevant parts of this text from Holdsworth 1963a and 1966a.

Morris (1966a) covered a part of the area -- that around the Upper Churnet, Leek and Ipstones -- and recognised several *Reticuloceras* localities, listed below.

Stage	Identification	Locality no. (Morris)	Grid ref. Morris 1966a	Previous references
R1	*R.* sp., *circumplicatile* subzone.	55	(0114, 5812)	
R1	*R. pulchellum* Bisat and Hudson	60	(0042, 5239)	
R1	*R. paucicrenulatum* Bisat and Hudson	92	20 yds down-stream from loc. 60.	Hull and Green 1860
R1	"*Inconstans*" zone	97	(0112, 5846)	
R1	*Reticuloceras* sp. *Hudsonoceras* sp.	104	(0058, 5832)	
R1a-b	*Hd.* aff. *ornatum*	106	(0116, 5812)	
R2a	*R. gracile*	112	Star Wood	
R2a	*R. gracile*		Felthouse Wood	Hester, 1932
R2a	*R. gracile*	113	(0032, 5819)	Challinor, 1929
R2b	*R. bilingue* early form	110	(0611, 4609)	
R2b	*R. bilingue* s.s.	111	(0614, 4605)	
R2b	*R. metabilingue* Wright	109	(0617, 4640)	
R2b	*R. bilingue* late form	102 and 103	(0138, 6061) and (0132, 6057)	
R2c	*R. superbilingue*	108	(0379, 4809)	

Loc. 104 of Morris (1966a) is now known to be $R2b_i$ (p.61). Hd. ornatum was described from this locality and also loc. 110 from the R. bilingue early form marine band.

Fossiliferous localities in the area have subsequently been noted by E.A. Francis (1967), who recognised the R2 fauna of the Upper Churnet, and by Evans et al. (1968) in the new Macclesfield Memoir.

- THE KINDERSCOUTIAN STAGE -

THE SUBDIVISIONS OF THE KINDERSCOUTIAN, R1

The basis of the modern systematic subdivision of the Namurian, using thicker-shelled goniatites as index fossils, was published by Bisat in 1924. The recognition of the four principal genera -- Eumorphoceras, Homoceras, Reticuloceras and Gastrioceras -- and their various species facilitated the subdivision of the Namurian into "zones". The "zones" of R1 and R2 (ibid. p.49-51) correspond to the stages of the Kinderscoutian and Marsdenian, Bisat having introduced these terms in his 1928 publication. The base of the Kinderscoutian is marked by the incoming of the genus Reticuloceras, the base of the stage, however, generally being recognised by the more common accompanying species of Homoceras magistrorum Hodson (Hodson, 1957). The base of the succeeding stage, the Marsdenian, is marked by the first occurrence of the distinctive group of R. gracile ("Reticuloceras reticulatum mutation alpha"), thought by Bisat to represent the first of a series of "mutations" derived from R. reticulatum (Phillips). The "mutations" of gracile, bilingue and superbilingue are in fact more clearly differentiated from each other than some of the R1 species, and in this account the term mutation, which implies a slight gradation, has been discarded in favour of the use of specific names.

Bisat's "zone" of R1 was further divided into "zones" of lesser status -- _R_. "_inconstans_" and _R_. "_reticulatum_" -- on the basis of the succession in a section at Roughlee, Lancashire. In the 1928 publication a new zone was introduced to the Kinderscoutian which was now divided into three zones of "_inconstans_", "_eoreticulatum_" and _reticulatum_ (the latter still retained), as it was found that _Reticuloceras reticulatum_ (Phillips) occurred at a higher level than the specimens named _R_. _reticulatum_ from Roughlee in 1924. The latter were now referred to a group intermediate between "_inconstans_" and _R_. _reticulatum_ (Phillips), and were redefined as _R_. _eoreticulatum_ Bisat. These three "zones" were satisfactory as they represented the ranges of the particular index fossils, known at the time.

Bisat and Hudson (1943) further divided the Kinderscoutian into six zones, each containing one or more marine bands {see accompanying table}. Each of the zones accepted in 1928 was divided into two parts, as further examination of the material had enabled specific identification of a number of new _Reticuloceras_ species, so that six divisions, each characterised by a certain index fossil, could be determined. The "_inconstans_" zone was revised and divided into a lower zone of "_inconstans_" and an upper zone of _R_. _todmordenense_ named after a new species. This species occurs in the upper part of the original zone, where _R_. _inconstans_ (Phillips) (equivalent to _R_. _circumplicatile_ (Foord), Bisat 1924, p.49) does not occur, or is represented by only a few late derivatives.

THE KINDERSCOUTIAN SUCCESSION

Bisat 1924	Bisat 1928	Bisat and Hudson 1943
Zones		Zones
	R. *reticulatum* (Phillips) type	R. *coreticulatum* Bisat and Hudson
R. *reticulatum*		R. *reticulatum* s.s.
	R. *eoreticulatum* Bisat	R. *nodosum* Bisat and Hudson
		R. *dubium* Bisat and Hudson
		R. *todmordenense* Bisat and Hudson
R. *inconstans* (Phillips)	R. *inconstans* (Phillips)	R. *inconstans* s.l.

Hudson and Cotton, 1943

Zone	Subzone
R. *reticulatum*, R1c	R. *coreticulatum* R. *reticulatum* s.s.
R. *eoreticulatum*, R1b	R. *nodosum* R. *dubium*
R. *inconstans*, R1a	R. *todmordenense* R. *inconstans* s.l.

Hudson, 1945a. As Hudson and Cotton, 1943

J.V. Stephens et al. 1953. As above.

J.R. Earp et al. 1961. As above.

D. Price et al. 1963

Zone	Subzone
R. *reticulatum*, R1c	R. *coreticulatum* R. *reticulatum*
R. *eoreticulatum*, R1b	R. *nodosum* R. *dubium*
R. *circumplicatile*, R1a	R. *todmordenense* R. *circumplicatile* (Foord)

W.B. Evans et al. 1968

Zone	Subzone
R. *reticulatum* R1c	R. *coreticulatum* R. *reticulatum*
R. *nodosum*, R1b	R. *nodosum* R. *dubium*
R. *circumplicatile*, R1a	R. *todmordenense* R. *circumplicatile*

A goniatite previously included in the (1928) "*inconstans*" zone by Stephens *et al*. (1942, p.355) was described by Bisat and Hudson (1943) and named as *R. dubium*. This species was regarded as belonging to the *R. eoreticulatum* zone of Bisat (1928) as it was thought to occur above the *R. todmordenense* zone, presumably in the succeeding marine band.

In Bisat and Hudson (1943) it was emphasised that the position of *R. eoreticulatum* in the succession was far from clear; it might lie in the *R. todmordenense* zone (see the succession at Lumbutt's Clough, *ibid*. p.393) or in their *R. dubium* zone. The *R. eoreticulatum* zone of 1928 was thus justifiably discarded in name on this basis, and the part of the succession between the *R. todmordenense* and *R. reticulatum* (1943) zones divided into those of *R. dubium* and *R. nodosum*, after two new species. The original *R. eoreticulatum* zone was divided into these two zones despite incomplete knowledge of the succession. The total number of marine bands was not known with certainty, and thus the total range of the index fossils was unknown. *R. nodosum* Bisat and Hudson was, however, seen to occur two marine bands below a form named *R. stubblefieldi*, the *R. stubblefieldi* marine band being included in the *R. nodosum* zone.

Bisat and Hudson's six zones were later used by Hudson and Cotton (1943, p.152-3). The preservation of the fauna around Alport was sufficiently good to be able to recognise most of Bisat and Hudson's 1943 divisions. But the information was incomplete and Bisat's original concept of three zones (the *R. eoreticulatum* zone having been replaced by the subzones of *R. dubium* and *R. nodosum*) was retained, and these three divisions given the index letters R1a, R1b and R1c in current usage.

Hudson (1945a) also used the tripartite division instead of using the six (1943) zones, as the succession in Bisat and Hudson's _R. dubium_ and _R. nodosum_ zones was uncertain (as pointed out above), and no objective data were available to define the succession.

The Bradford and Skipton Memoir (Stephens _et al_. 1953) retained Hudson's 1945 nomenclature in preference to that of Bisat and Hudson, for although Bisat and Hudson had claimed that all six of their 1943 zones could be recognised in that area, only the top two could be seen in close juxtaposition (_ibid_. p.98), and neither the order of the six zones or the total succession in R1b could be verified.

This nomenclature was retained in the Clitheroe and Nelson Memoir (Earp _et al_. 1961) as _R. eoreticulatum_ was thought to lie about 9m (30') above _R. paucicrenulatum_ Bisat and Hudson, but its stratigraphical position was uncertain (_ibid_. p.192-3). The Macclesfield Memoir, however, (Evans _et al_. 1968), replaced the _R. eoreticulatum_ zone by the _R. nodosum_ zone because of the confusion over _R. eoreticulatum_, and retained the same R1b subzones as the 1961 Memoir.

Stephens _et al_. (1953) still used the _R. inconstans_ zone for R1a, but Ramsbottom (1962, p.125) used the _R. circumplicatile_ zone in preference to _R. inconstans_, as "_R. inconstans_ (Phillips) cannot be recognised from its original description", and could thus not be used as an index fossil. This practice of naming R1a the _R. circumplicatile_ zone was followed in Evans _et al_. (1968) and in Price _et al_. (1963).

R. inconstans was abandoned in favour of _R. circumplicatile_ for a number of reasons. _Reticuloceras inconstans_ (Phillips) and _R. circumplicatile_ (Foord) were said to be identical species (Bisat 1924, p.50, 118). But subsequent work by Bisat and Hudson (1943) showed that, "It is becoming increasingly difficult to ascribe to R. inconstans any one of the rapidly increasing number of closely related species of Reticuloceras now known to form the lower part of R1".

The name R. inconstans (Phillips) is now restricted to the specimens figured by Phillips (1841 {the original specimens from Exeter are no longer available}), and the zone is replaced by R. circumplicatile. The zone is divided into the two subzones of R. circumplicatile and R. todmordenense.

THE KINDERSCOUTIAN, R1, IN STAFFORDSHIRE - INTRODUCTION

The Kinderscoutian fauna has previously been described and illustrated by Bisat and Hudson (1943), and their paper has been referred to extensively in this account of the Kinderscoutian goniatites of Staffordshire and adjacent areas. Other major references are the Memoirs of The Geological Survey of Great Britain for the Preston, Clitheroe and Nelson, and Macclesfield areas, Holdsworth (1963a) and Ramsbottom et al. (1962). The Brund Boreholes, put down to the south-east of Longnor, have yielded useful information on the R1a-R2b faunas (particularly those of R1a-R1b), and these faunas are referred to in the text and in the appendix to the chapter.

Division of the Kinderscoutian stage was initially made in the form currently used by the Geological Survey, as set out below.

Zone	Subzone
R. reticulatum, R1c	*R. coreticulatum*
	R. reticulatum
R. nodosum, R1b	*R. nodosum*
	R. dubium
R. circumplicatile, R1a	*R. todmordenense*
	R. circumplicatile

This scheme has been modified, however, to facilitate the description of the succession in Staffordshire. The *R. circumplicatile* subzones have been assigned numbers, as in Figure 1.A. The *R. nodosum* zone is unfortunately less clearly defined because the status of *R. dubium* as an R1b index fossil is in doubt (p.94), and is thought to be erroneous. The *R. nodosum* zone is therefore split into five divisions which correspond with the five R1b marine bands recorded in the Ashover boreholes (Ramsbottom *et al*. 1962). The *R. nodosum* and *R. dubium* subzones are discarded. The *R. reticulatum* zone is poorly represented by fossiliferous horizons in North Staffordshire, and there is little justification for the division of the *R. reticulatum* zone into subzones in the area covered.

The term "horizon" has been adopted in this account because it was found that successively higher levels within the thicker marine bands were characterised by markedly different faunas (eg. $R1a_2$), as in the case of some of the R2 marine bands also. Apart from the unfossiliferous shales immediately underlying the *R. paucicrenulatum* marine band, no definite fossiliferous/non-fossiliferous alternations could be recognised in $R1a_1$, but a particular level, marked by kaolinised ash bands, proved more fossiliferous than most of the $R1a_1$ sequence. This level has also been termed a horizon.

Kaolinised ash bands, of volcanic origin (Ch.2), have been recognised in the Rlb_v marine band (two ash bands), in the R. pulchellum horizon (one ash band), and in the R. circumplicatile horizon (five ash bands). These features have proved useful in correlation of the marine bands over large areas.

THE RETICULOCERAS CIRCUMPLICATILE ZONE, Rla

THE RETICULOCERAS CIRCUMPLICATILE SUBZONE, Rla_1

Stratigraphy

The lower boundary of the subzone is not defined by an unfossiliferous shale leaf, because the Homoceratoides prereticulatum Bisat, H. magistrorum and R. circumplicatile horizons are contained within a continuously fossiliferous shale sequence. In a completely exposed section in the Upper Manifold (loca. 010 and 023), only 30 cm of the whole of the R. circumplicatile subzone above the R. circumplicatile horizon appears to be barren. This unfossiliferous interval immediately underlies the R. paucicrenulatum marine band.

The shales between the R. circumplicatile horizon and the barren interval in the Upper Manifold Valley section contain a sporadic fauna of R. aff. pulchellum, Homoceras sp. and other poorly preserved goniatites. The sporadic nature of the fauna suggests that several alternating faunal phases may be present within this part of the subzone, as indicated in the Ashover boreholes (Ramsbottom et al., 1962, p.126), but preservation of the fauna makes detailed investigation of the sequence at loc. 010 impossible. Corresponding parts of the succession at other localities eg. the Blake Brook, have failed to yield a fauna of goniatites and may well be represented by a spat phase only.

Apart from Homoceras of the H. henkei Schmidt group and Homoceratoides aff. varicatus Schmidt, the Ashover boreholes yielded only crenulate and barely crenulate forms of Reticuloceras between the R. paucicrenulatum marine band and the R. circumplicatile horizon. Sections in the Sabden Shales summarised in the Clitheroe and Nelson Memoir (Earp et al. 1961, p.192) and the Preston Memoir (Price et al. 1963, p.62) show a composite section compared in Figure 1.E with that of $R1a_1$ at Storris House, Otley (Stephens et al. 1953). Reticuloceras fragments found between the R. circumplicatile horizon and the R. paucicrenulatum marine band are poorly preserved in North Staffordshire and identification of these forms is impossible except from material collected from the Dingle Brook up to 120 cm above the highest $R1a_1$ kaolinised ash band. Description of the $R1a_1$ forms is thus limited to the R. circumplicatile horizon and this slightly higher part of the succession.

Previous work within North Staffordshire

Holdsworth (1963a) identified R. circumplicatile from the Ballbank area (loc. 011) some 7.5 m below R. todmordenense Bisat and Hudson. A second specimen from the same locality suggested R. paucicrenulatum rather than R. circumplicatile, and may have been similar to the specimens described here as R. aff. circumplicatile.

Holdsworth's fauna of R. cf. pulchellum from the Blake Brook section is now known to have come from the R. paucicrenulatum marine band, and the H. magistrorum horizon has been re-identified as the R. circumplicatile horizon from the occurrence of two kaolinised ash bands and the presence of R. circumplicatile. This establishes the full faunal succession of the Blake Brook.

Correlation with other areas

The *R. circumplicatile* horizon is a useful and widely recognised marine phase in Europe. Hodson (1957) correlates this marine horizon in N.W. County Clare and Foynes Island with occurrences of the same marine band in England, Belgium and Germany. Delepine (1941) also figures "*R. inconstans*" which may be *R. circumplicatile* or *R. circumplicatile* group from Djerada, North Africa. The *Homoceras magistrorum* horizon is equally persistent in Europe.

Of the R1a *Reticuloceras* species succeeding *R. circumplicatile*, only those of the *R. todmordenense* subzone appear to be persistent. Hodson (1957) records *R. pulchellum* and *R. umbilicatum* from Roughlee, Lancashire, but it appears from his correlation table (Hodson 1957, Pl.II) that these species do not form a widely recognised horizon. Shales at corresponding stratigraphical levels to the Roughlee section have a poorly preserved fauna, or none at all, in North Staffordshire, so that conditions between the deposition of the *R. circumplicatile* horizon and the *R. todmordenense* subzone may not have been at an optimum for goniatite population.

Measurement of sections

As no *Reticuloceras* specimens have been found beneath the *R. circumplicatile* horizon, and the identification of *H. magistrorum* was found to be difficult in the poorly preserved material, sections have been measured wherever possible from the top of the more distinctive *Ht. prereticulatus* horizon (H2) or from the kaolinised ash bands which occur in the *R. circumplicatile* horizon (Ch.2). The *R. circumplicatile* and *R.* aff. *pulchellum* fauna is referred to the *R. circumplicatile* "horizon" rather than "marine band" as there is no obvious development of unfossiliferous shales between successive faunas.

Thickness variations and lithology of the subzone

Over the North Staffordshire basin and the southern Pennine area, the thickness and lithology of the subzone are remarkably constant. Sandstone development is absent in North Staffordshire within the basin area, and in the areas around Edale, Alport and Ashover. At Otley in Yorkshire, however, sandstone beds overlie the *R. pulchellum* horizon ($R1a_1$) in the section at Storris House, and thin sandstones occur above *R. pulchellum* and *R. umbilicatum* in the section at Roughlee, Lancashire. In Colsterdale, no goniatites were recorded in $R1a_1$ by A.A. Wilson (1960). Between *H. subglobosum* Bisat and the Libishaw sandstone (R1b), the typical black shale facies of the N. Staffordshire basin is replaced by barren shales with fireclays and siltstones.

The lithology of the subzone in North Staffordshire consists of dark grey and black marine shales which are darkest in colour at the *R. circumplicatile* horizon, and beneath it where *H. magistrorum* should occur. Impure limestone beds and ankerite concretions are common in the area, and in Edale. Calcite bullions are rare at the *R. circumplicatile* horizon, but have been recorded with an *H. magistrorum* fauna in the Upper Dove (Holdsworth, 1963a).

The *R. circumplicatile* horizon has not been located in the southern portion of the North Staffordshire basin. Morris (1967) suggested that the Sharpecliffe Conglomerate, exposed near the Combes, Ipstones, is R1 in age, occurring beneath the *R. todmordenense* subzone. This is a possibility, but the conglomerate may well be in H (p.202) in which case the *R. circumplicatile* subzone is likely to be represented by a shale succession, though doubtless modified from the typical basin facies by the proximity of the area to the Mercian land mass and the development of deltaic sandstones, such as those in $R1a_2$ and R1b.

Preservation of the fauna

The best specimens have been obtained from the weathered exteriors of ankerite bullions. Fresh surfaces of the ankerites fracture through the specimens. Impure limestones have yielded partially crushed shells, but the ornament in these cases is obscured. Rare specimens have been obtained from the shales at a few localities.

The distribution of the goniatites within the bullions is not even. The ankerites are often laminated, and goniatites occur only on certain bedding planes with spat.

General characteristics of faunal horizon

Goniatites at the *R. circumplicatile* horizon are comparatively rare, and only a few *Reticuloceras* specimens (less than six) have been collected from any one exposure. Frequent *Homoceras* specimens occur, and coiled and orthocone nautiloids. Goniatite spat are rare and have been recognised only at loc. 008 and 012. Hodson (1957) recorded *Ht. varicatus* at the *R. circumplicatile* horizon in Ireland, and used the occurrence of this *Ht.* species to help distinguish between the *R. circumplicatile* horizon and Rla_2, as this form did not occur in the latter. This *Ht.* species has not been collected from North Staffordshire, but *Ht. varicatus* was recorded in the Highoredish borehole (Ramsbottom *et al.* 1962, p.126).

Fauna of the R. circumplicatile subzone

R. circumplicatile (Foord)

R. aff. *circumplicatile*

R. aff. *umbilicatum* Bisat and Hudson

R. aff. *pulchellum* Bisat and Hudson

Homoceras sp. (not described)

Localities

Ballbank (loc. 168b, Holdsworth, 1963a) Loc. 011....R. circumplicatile

Bearda, Near River Dane Loc. 014 Three ash bands....R. circumplicatile

Blake Brook Loc. 012 a-1 Two ash bands ....R. circumplicatile, Homoceras sp.

Dingle Brook Locs. 017 and 018 Two ash bands ....R. cf. circumplicatile and R. aff. pulchellum, Homoceras sp.

Traveller's Rest Loc. 010 Three ash bands....R. circumplicatile and R. cf. pulchellum group

River Dove Loc. 009 Two ash bands ....R. circumplicatile

Thorncliff stream Loc. 020 Two ash bands ....R. aff. umbilicatum

Upper Churnet Loc. 007 Three main ash bands ....R. circumplicatile
Two subsidiary ash bands

Loc. 008 Two ash bands ....R. aff. circumplicatile

Upper Shell Brook Loc. 016 Ankerite only exposed....R. sp. of R. circumplicatile group and Homoceras sp.

Heath Hay Ravines, Biddulph Moor Loc. 019
No ash bands ....R. circumplicatile group

Description of the Reticuloceras circumplicatile (Foord) fauna

Reticuloceras circumplicatile (Foord)

Gastrioceras circumplicatile Foord, 1903, p.200, pl.xlix, figs.12a, 12b, 13.

Reticuloceras inconstans (Phillips). Bisat, 1924, pl.iii, fig.6.

R. circumplicatile (Foord). Bisat and Hudson 1943, p.425, pl.xxiv, fig.1. Lectotype refigured from Foord

1903 and Bisat, 1924. Also pl.xxiv, fig.2 and pl.xxix, figs.2a,2b.

R. circumplicatile (Foord). Hodson, 1957, pl.B, figs.1,2,4.

R. circumplicatile (Foord). Holdsworth, 1963a, p.134-6, pl.12, fig.1.

Localities: 010, 012 and 014.

Description

All specimens show umbilical plications which persist up to at least 27 mm lingual diameter. The plications bifurcate or may trifurcate at a narrow angle and degenerate in strength to form ribs (Pl.1.1a). Two to four striae of equal strength to the ribs are interpolated between the sets of ribs arising from the plications. The striae do not reach the umbilical edge until at least 27 mm diameter. Larger specimens were not obtained.

The ribs and striae are delicately crenulate, but spirals are absent on the lingua although these are clearly seen in the lectotype. Spirals do, however, occur on the umbilical edge and lower flank, as in the lectotype, and have been noted in specimens 010 and 014. They are absent in other specimens. The apparent absence of spirals may be due to preservation of the material, or may be a slightly different feature in forms otherwise similar to the lectotype. A weaker development of the spiral ornament in goniatites from North Staffordshire than in the lectotype was also noted by Holdsworth (1963a, p.135).

A fragment of R. circumplicatile crushed in shale (loc. 014, Pl.1.1b) shows a slight thickening on the internal cast, forming a node, where the plications are bent at the umbilical rim. This is, however, less well developed than in the specimens of R. aff. circumplicatile (p.23).

DIMENSIONS OF R. CIRCUMPLICATILE GROUP AND POSITION OF FAUNA

IN RELATIONSHIP TO KAOLINISED ASH BANDS

R. circumplicatile

Locality	Lingual Diameter	Projn. Lingua	Depth of hy. sinus	Number of interpol-ated ribs	Position in relation to ash bands
012	27 approx.	1.0-1.2 mm	2.0 mm	3	17 cm above band 5
010	12 approx.	0.8-1.0 mm	-	2-3	Immediately above band 5
014	20 approx.	1.2 mm	-	2-3	43 cm above ash band 5

Internal moulds of R. circumplicatile or R. aff circumplicatile

Solid specimens, loc. 008, Strines, Upper Churnet.

Solid diameter	Width of umbilicus	Position in relation to ash bands
6 mm	3.0 mm	Immediately beneath band 5
11	5.0	
14.5	6.0	

Reticuloceras aff. *circumplicatile*

Solid specimens, loc. 008, Strines, Upper Churnet.

Lingual diameter	Projn. Lingua	Hy. sinus	Interpol-ated ribs	Umbilicus	Position
11.0 mm	1.0 mm	1.0 mm	1-2	5.5 mm	Immediately beneath band 5

The ribs of the R. circumplicatile specimens are not radial, as the umbilical plications tend to be bent forwards. The lingua is not pronounced, reaching only 1.0-1.2 mm forwards at 27 mm lingual diameter, so that the ribs and striae, which are of equal strength on the lingua, appear to be simply prosiradiate rather than bent into a definite lingua. The hyponomic sinus is more clearly developed, attaining a depth of 2.0 mm at 27 mm diameter. The form is strongly evolute (see accompanying table), the umbilical diameter being 24% of the diameter of the solid specimen at 14.5 mm diameter.

Although the forms described here are ascribed to R. circumplicatile, the nature of the spiral ornament suggests that they may be slightly different from the lectotype. The species was originally founded by Foord on a number of specimens. Associated with the type material was one specimen (G.S.E. K 4803) ". . . with a high whorl section, more moderate umbilicus, and more delicate ornament which is not so strongly prosiradiate" (Bisat and Hudson, 1943, p.425). This specimen was chosen as the lectotype for R. circumplicatile (ibid. p.425) although it was described as a "variant". It is possible that this more delicately ornamented "variant" has a better developed concentric ornament than the other specimens with which it was associated, hence the apparent lack of forms with a spiral ornament in North Staffordshire, since the material associated with the lectotype appears to have been somewhat more common than the more delicately ornamented form.

Reticuloceras aff. circumplicatile (Foord)

R. circumplicatile. Hodson, 1957, pl.A.

Locality: Strines, Upper Churnet (008). Specimens collected by B.K. Holdsworth.

Material

Two specimens showing the external ornament of the shell were collected from an ankerite bullion. One specimen shows the typical R. circumplicatile ornament but the other differs considerably from R. circumplicatile described above and is similar to the specimen figured by Hodson (1957).

Description

Regular trifurcation of the umbilical plications takes place at a slightly wider angle than the bifurcating and occasionally trifurcating umbilical plications seen in R. circumplicatile. Only one or two striations are interpolated between the sets of bifurcating primaries in contrast to R. circumplicatile in which at least 2-3 striae are generally interpolated. The forward flexure and sharp twist of the plications at the umbilical edge is a notable feature in the Strines specimen and that figured by Hodson (1957), as is also the extremely strong development of a node on the plication at the umbilical rim. A concentric ornament is present on the lower flank and at the umbilicus as in the specimen figured by Hodson.

Because only one specimen showing this type of external shell ornament has been found, it is possible that it may not be a distinctly different form from R. circumplicatile. The specimen from Strines may, for example, exhibit a pathological deformity, which is suggested by the more regular form of the ornament on the right-hand side of the conch (Pl. 1.2). The strong resemblance of the specimen to that figured by Hodson suggests, however, that this could be a distinct form which occurs at the same horizon (determined by the kaolinised ash bands) as R. circumplicatile s.s. Similar specimens named R. aff. coronatum Bisat and Hudson (I.G.S. specimen Da 2005) have also been recovered from Bed 2, Storris House, Otley.

Plate 1.1

1.1a *Reticuloceras circumplicatile* (Foord)

x9

Locality: Blake Brook (012)

"Solid" specimen from weathered ankerite.

1.1b *Reticuloceras circumplicatile* (Foord)

x12

Locality: Bearda (014)

Impression of external umbilical ornament.

Plate 1.2

Reticuloceras aff. *circumplicatile*

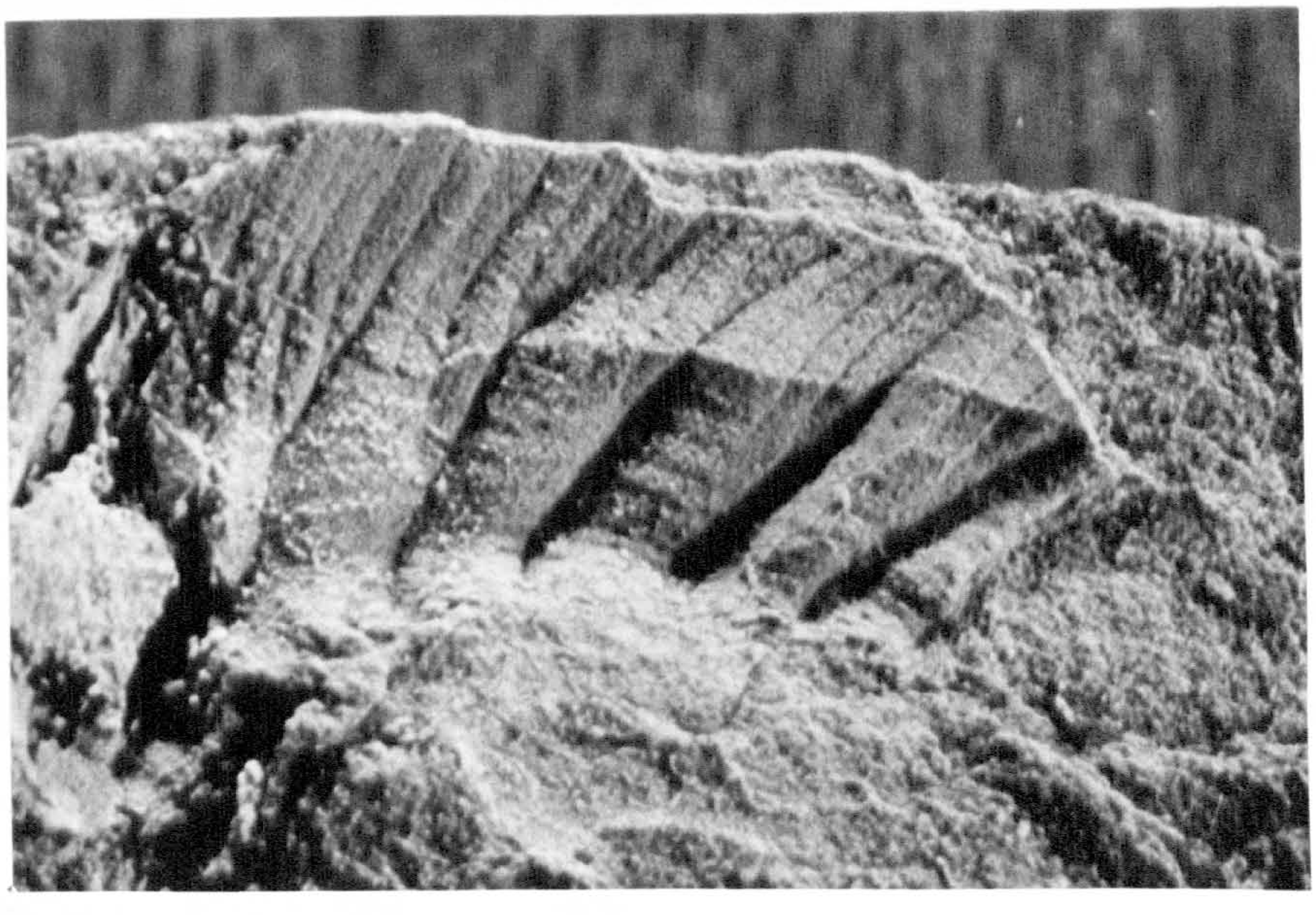
x10

Locality: Upper Churnet (008)

Artificial mould of external ornament from external impression in weathered ankerite bullion.

Pl. 1.1

a



b

The specimen is like R. paucicrenulatum in the reduction of the number of interpolated striations between the sets of ribs arising from the umbilical plications, and in the strong twist forwards of the plications over the umbilical rim. The two forms can be distinguished from each other by the trifurcation of the plications and the interpolation of up to two striations in R. aff. circumplicatile and bifurcation of the plications and interpolation of only one striation in R. paucicrenulatum.

Reticuloceras umbilicatum Bisat and Hudson

R. umbilicatum Bisat and Hudson, 1943, p.421-422.

R. umbilicatum Bisat and Hudson. Stephens et al., 1953, pl.vi, fig.10.

Reticuloceras aff. umbilicatum

Localities: Thorncliff stream, 020, 30 cm above ash band 5. R. circumplicatile horizon.

Upper Shell Brook, 016, Isolated exposure of ankerite bed.

Preservation and number of specimens

Two large specimens were obtained from 020 half crushed in shale. A single poorly preserved and half crushed specimen was obtained from the ankerite in Shell Brook.

Descrition of R. aff. umbilicatum

Both of the specimens obtained from 020 are unsuitable for specific identification because of their large size. No specimens of R. circumplicatile at this diameter have been collected, and the specimens were initially thought to be gerontic forms of R. circumplicatile, since the ribs are slightly prosiradiate and form only a shallow lingua 1.0-1.5 mm deep.

Locality 020	Lingual diameter	Umbilical diameter	Projn. lingua	Projn. hy. sinus
1	36 mm	8 mm	1.5	2.5
2	38	8	-	-

Umbilical plications are absent, secondary ribs arising from the bifurcation of the primary ribs at approximately 22 mm diameter. At 35 mm diameter, all of the radial ornament emerges directly from the umbilicus. One constriction is seen in the quarter whorl fragment.

The primary ribs regularly bifurcate at a narrow angle and, in contrast to R. circumplicatile, only one striation is interpolated in the areas between the sets of bifurcating primaries.

A third specimen collected from the same locality as the above resembles R. circumplicatile more closely. The primaries both bi- and tri-furcate, and up to three striations are interpolated between the sets of primaries.

A similar specimen was found at loc. 016, but showed bifurcating or trifurcating primaries and one or two interpolated striations. As in specimens from 020 the ornament is virtually radial, with only a very slight forward projection of the ribs at the umbilicus. The radial ornament is feebly crenulate and also lacks spirals. The lingua is slight. This form may be referable to R. circumplicatile group. A specimen of H. cf. henkei was also recovered from the same ankerite bed but gives no more precise information on the exact horizon.

Identification

The ornament of the specimens collected from 020 is similar to that of R. pulchellum figured in Bisat and Hudson (1943, pl.xxviii, fig.1), but the 020 forms are more widely umbilicate. The umbilical margin is also distinctive as it forms an acute angle with an undercut inner slope, not seen in *R. pulchellum*. *R. pulchellum* in Staffordshire and in the section at Storris House, Otley, also occurs slightly higher in the succession than the horizon of the kaolinised ash bands. The holotype of *R. umbilicatum* (figured in Stephens *et al.* 1953) is more similar to the specimens in question. The holotype was obtained from a bed containing *R. circumplicatile* group (*ibid.* p.98), so that it is possible from stratigraphical considerations that the 020 specimens could be referable to *R. umbilicatum*.

Bisat and Hudson (1943, p.421-422) describe *R. umbilicatum* as a widely umbilicate form with a slight lingua and radial and slightly roughened striations. This describes the form found at 020 except for the additional feature of the interpolated striations. As the form is otherwise similar to the holotype of *R. umbilicatum* in which the umbilical rim also appears to be angular, it is concluded that the specimens can most usefully be termed *R.* aff. *umbilicatum*.

Reticuloceras aff. *pulchellum* (Foord)

For synonymy of *R. pulchellum* see the description of the form from the *R. todmordenense* subzone (p.40).

Localities: Dingle Brook, loc. 018.

Traveller's Rest, Upper Manifold, loc. 010.

Preservation of material

Poorly preserved specimens were obtained from the impure limestone in the Dingle Brook, and better preserved, numerous specimens crushed in shale from up to 1.20 m above the limestone and ash band ?5. The latter specimens were used in the description of the form. A single specimen of R. aff. pulchellum crushed in shale was obtained from loc. 010, 1.80 cm above ash band 5.

Description

Specimens collected were of a fairly uniform size, ranging only from 9-14 mm lingual diameter, so that the information available is somewhat restricted.

Specimen no.	Lingual diameter	Projn. L.	Striae/mm L.	Depth Hy. sinus	Umbilicus
1	10 mm	0.5 mm	5	1.6 mm	3 mm
2	11.5	0.75	5	-	3
3	14.0	0.75	6	-	4.5 approx

The development of the lingua is slight, although the hyponomic sinus appears to be relatively deep. The ribs are radial from the umbilicus and are delicately crenulate. Subordinate spiral striations are seen on the flank and lingua in the smaller specimens, but appear to be absent at 14 mm diameter. All specimens are involute. The ribs bifurcate at the umbilical margin, but there is no formation of nodes or umbilical plications, only a very slight thickening of the primary in comparison with the weaker ribs on bifurcation. Bifurcation of the primaries is regular, and a single striation of equal strength to the bifurcating ribs is interpolated between sets of bifurcating primaries.

Identification

The specimens compare in most respects with the description of R. pulchellum and R. aff. pulchellum in Bisat and Hudson (1943). Subordinate spirals occur on the specimen figured (ibid. pl.xxviii, fig.1) as in the specimens from the Dingle Brook and the pattern of the ornament is similar to that seen in figs. 6 and 7 (*ibid.*) although the hyponomic sinus does not appear to be as deep as in Bisat and Hudson's specimens. The material described here is also similar to that collected from the "*R. pulchellum*" horizon at Storris House, Otley, recorded by Stephens *et al.* 1953, and is thus identified as *R.* aff. *pulchellum*.

Discussion

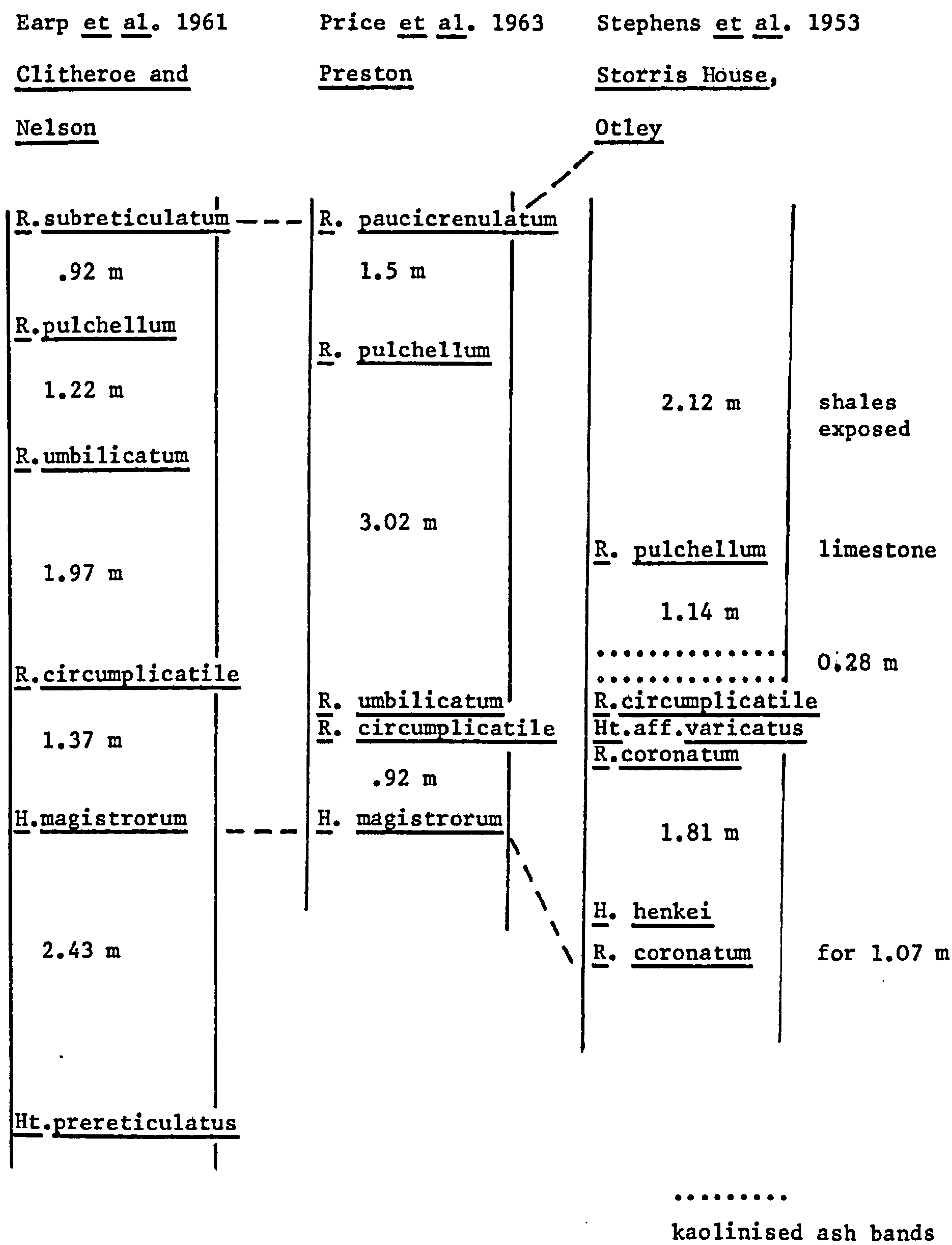
R. aff. *pulchellum* has been included in the *R. circumplicatile* horizon because there is no break of unfossiliferous shale between occurrences of *R. circumplicatile* and *R.* aff. *pulchellum*, and at one locality *R.* aff. *pulchellum* appears to occur to the exclusion of *R. circumplicatile* (see below).

In the original description of *R. pulchellum*, Bisat and Hudson (1943) referred the holotype to a position probably in the *R. circumplicatile* (then *inconstans*) zone. Similar specimens were obtained from near Ashop Bridge, 3.02 m (10') above *R. coronatum*, and from Roughlee, Lancashire where *R.* aff. *pulchellum* occurred with *R. umbilicatum*. The relationship of *R.* aff. *pulchellum* to *R. circumplicatile* was not known specifically from these sections, although it might be inferred from the occurrence of the other *Reticuloceras* forms, and it is the section at Storris House, Otley and the re-recorded section from Roughlee (Earp *et al.* 1961, p.192) which best demonstrate the position of *R.* aff. *pulchellum* to that of *R. circumplicatile* (Figure 1.E). *R.* aff. *pulchellum* is used here in preference to *R. pulchellum* because specimens identical with *R. pulchellum* s.s. have only been recovered from $R1a_2$ (p.42).

An apparent anomaly arises in the distribution of *R. circumplicatile* and *R.* aff. *pulchellum* in the Dingle Brook section.

FIGURE 1.E

COMPARISON OF THE R. CIRCUMPLICATILE SUBZONE FAUNA IN THE SECTIONS IN THE CLITHEROE AND NELSON AREA, PRESTON AREA, AND AT STORRIS HOUSE, OTLEY



The ash bands at the *R. circumplicatile* horizon, which in view of their probable volcanic ash origin have been accepted as marking time planes, are exposed in this section. Despite the apparent absence of *R. circumplicatile*, the ash bands are specifically identified by their position in the measured section which contains other distinctive R1/H2 goniatites. The uppermost ash band of the two which occur is thought to be band 5, since it tends to be the thinnest of the three uppermost (and more persistent) bands elsewhere. In an impure limestone immediately below band 5, and in shales up to 1.2 m above the limestone, *R.* aff. *pulchellum* is extremely abundant. Elsewhere (eg. loc. 010), *R. circumplicatile* occurs immediately above and below band 5, and *R.* aff. *pulchellum* occurs only higher in the succession. *R. circumplicatile* has not been found in collections from the Dingle Brook section, although Evans *et al.* (1968, p.56) record *R. circumplicatile* group and *R. circumplicatile*. In their account, the shales containing *R. circumplicatile* pass downwards into "pyritic siltstone", suggesting one of the ash bands, and a comparison of measurements of the section by Evans *et al.* and the author indicates the occurrence of *R. circumplicatile* above ash band 4 only. The distribution of *R.* aff. *pulchellum* in this section is unusual and suggests possible local variation of the fauna as it seems unlikely that the ash bands, which may be correlated at this level over as wide an area as North Staffordshire, and as far as Ashover and Otley, Yorkshire, should not mark time planes.

THE RETICULOCERAS TODMORDENENSE SUBZONE $R1a_2$

Introduction

In the area of North Staffordshire, the *R. todmordenense* subzone is usually thin and, as in the Ashover boreholes, consists of a single marine band containing a complex fauna and a leaf of unfossiliferous shales, variable in thickness, separating the $R1a_2$ and $R1b_i$ faunas. In the Brund Boreholes, however, there is a continuously fossiliferous sequence between recognisable $R1a_2$ and $R1b_i$ goniatites, but in other areas (particularly towards the south) an unfossiliferous shale leaf or sandstones and siderites are present, and the extent of the marine band is clearly marked.

The base of the $R1a_2$ marine band, and thus the base of the subzone, is marked by a thin unfossiliferous shale interval (30 cm at loc. 024) which is included in the *R. circumplicatile* subzone. This break of unfossiliferous shales occurs immediately beneath *R. pulchellum* ($R1a_2$) in the Upper Manifold section. At successively higher levels in the marine band other species become dominant, and the marine band may conveniently be split into three horizons containing the *R. pulchellum* fauna, the *R. paucicrenulatum* / *R. todmordenense* fauna and the *R. adpressum* Bisat and Hudson / *R. dubium* Bisat and Hudson fauna. The whole marine band has been called after *R. paucicrenulatum* because this goniatite is readily recognisable, unlike the subzonal index fossil.

Stratigraphical palaeontology

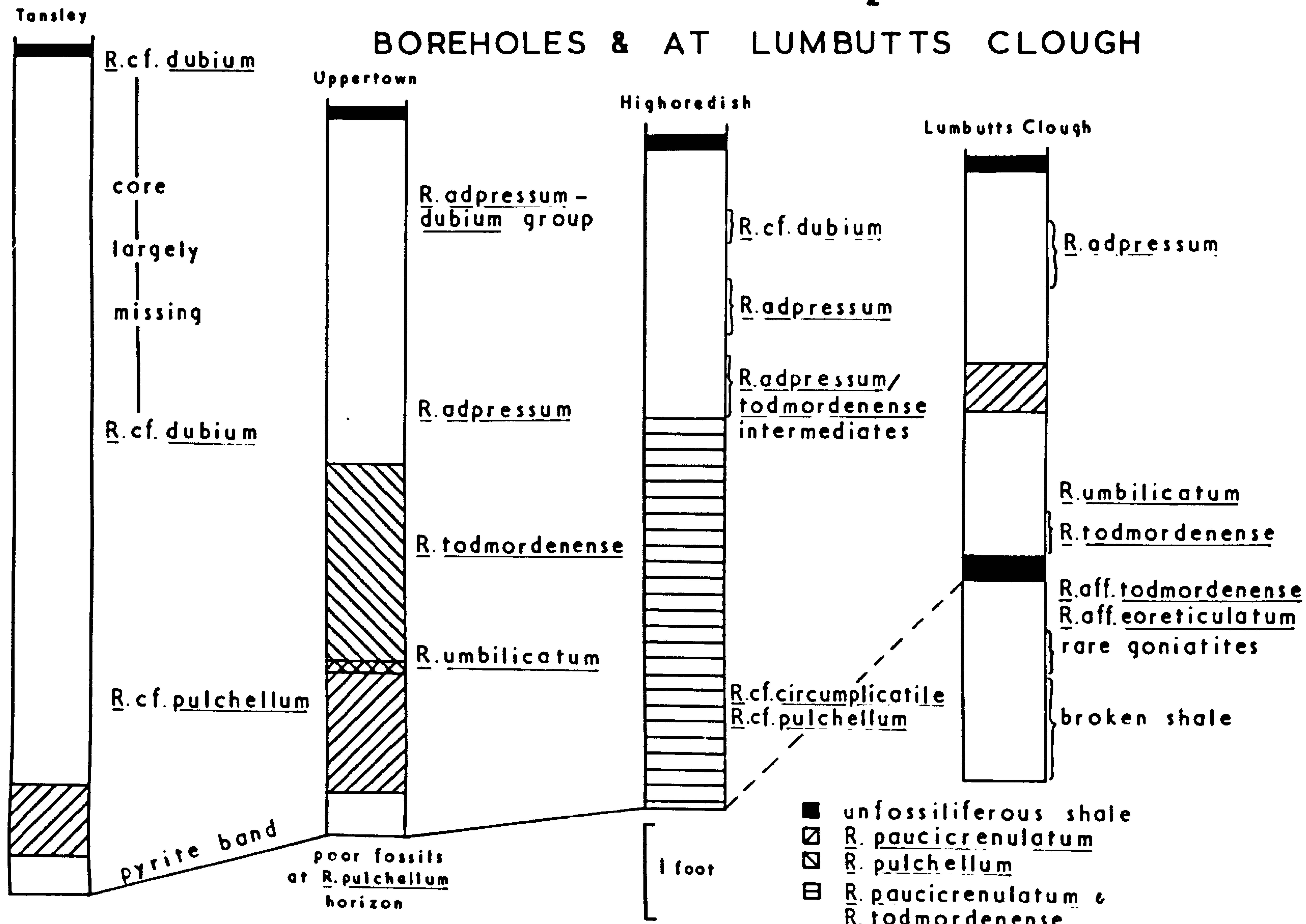
The fauna of the marine band is complex, Bisat and Hudson (1943) recognised representatives at different levels in the marine band, of a continuously evolving sequence of goniatites. The sequence of the fauna was as follows: *R. todmordenense* occurs 1.22 m

(4') from the base of the section in Lumbutt's Clough, and late derivatives of the *R. circumplicatile* group also occur at this level. *R. todmordenense* is replaced by *R. adpressum* Bisat and Hudson 32 cm (1') higher in the succession, although rare early forms of *R. adpressum* occur from 31 cm (1') to 38 cm (1'3") after the above mentioned occurrence of *R. todmordenense*. The late forms of the *R. circumplicatile* stock evolve 31 cm (1') to 41 cm (1'4") higher in the succession into *R. paucicrenulatum*, early forms of *R. paucicrenulatum* occurring in the lower part of this 4 cm (1¾") band, and typical forms in the upper.

The position of *R. paucicrenulatum* is also described in Earp *et al.* (1961, p.192) as 32 cm (1') above *R. subreticulatum* (Foord) which is closely allied to *R. todmordenense* (Ramsbottom *et al.*, 1962, p.125), although *R. subreticulatum*, or forms similar have previously been recorded at higher levels in the Kinderscoutian.

Bisat and Hudson's (1943) account of the fauna located the horizons both of the typical forms and their early and late variants within the marine band, the evolution of one form into a higher one and the overlapping ranges thus implying that the succession contained co-existing distinct forms. This is borne out by the records from the Ashover boreholes. Comparison of the Uppertown and Highoredish boreholes in the *R. todmordenense* subzone (Ramsbottom *et al.*, 1962) shows that *R. todmordenense* or similar forms occur throughout the *R. paucicrenulatum* marine band, except at the *R. adpressum*-*R. dubium* level. *R. paucicrenulatum* itself tends to be restricted to the lower part of the band (Figure 1.F). Ramsbottom (*ibid.* p.125) emphasises that boundaries between certain groups must be arbitrary in a continuously marine sequence rather than in a

Fig. I.F COMPARISON OF SECTIONS – RIa_2 IN THE ASHOVER BOREHOLES & AT LUMBUTTS CLOUGH



sequence where periodic sampling from the evolving goniatite stock has taken place. The variable nature of a "species" also leads to difficulties in naming a specimen. This feature is illustrated by material from the North Staffordshire area, and also by Ramsbottom (in Earp *et al.*, 1961, p.192) where solid specimens of *R. paucicrenulatum* are described as very variable in shell form, ranging from ellipsicone to coronate. This situation is in contrast to R2b where certain of the marine leaves of a composite marine band contain a remarkably uniform fauna of only one form or two co-existing forms (eg. the uppermost two marine leaves of the *R. bilingue* marine band), although a progression may be illustrated from one marine leaf to the next.

Previous work within the field area

Hull and Green (1866) and Morris (1967) recorded the *R. paucicrenulatum* marine band at the Combes, Ipstones, and Holdsworth recorded the same band at Ball bank, Upper Manifold valley. These identifications have been confirmed.

Holdsworth (1963a, p.146) states that, "the *R. paucicrenulatum* bullion line is not developed in the Blake Brook", but suggests (*ibid.* p.147) that *R. paucicrenulatum* might occur about 92 cm (3') above his Type Section limestone 4 of the Blake. This has now been verified. The bullion limestone (T.S. limestone 4) which yielded *R.* aff. *pulchellum* is now known to be $R1a_2$, and his conclusion that the "*R. nodosum* - *R.* aff. *nodosum* group" (from $R1a_2$ also, see p.60 of this account) and the *R. nodosum* group - *Hd. ornatum* fauna ($R1b_{ii}$, p.61) are different horizons, the latter one being the higher, is thus justified.

Holdsworth also identified R1a in the Upper Dove. The $R1a_2$ marine band has been identified in the Upper Dove a few yards upstream from Holdsworth's locality at loc. 022. The locality identified as R. paucicrenulatum (loc. 009) by Holdsworth (1966a and 1963a, loc. 179) has failed to yield any definitive Reticuloceras specimens, only R. paucicrenulatum--R. circumplicatile group. The calcite rather than ankerite bullions at the locality suggest an $R1a_2$ marine horizon rather than $R1a_1$ because calcite bullions are unknown elsewhere in the R. circumplicatile horizon, but kaolinised ash bands confirm its identity as $R1a_1$.

Correlation with other areas

The R. paucicrenulatum marine horizon is not mentioned in Stephens et al. (1953) in the Bradford and Skipton area. R. adpressum with R. cf. umbilicatum has been obtained, however, from a possibly land slipped mass (ibid. p.37, 99), so that at least some of the R. todmordenense subzone fauna is present.

To the south and west of this area, the R. paucicrenulatum marine band is well represented. It was originally described from the section at Lumbutt's Clough by Bisat and Hudson (1943) and later in the Clitheroe and Nelson area (Earp et al., 1961, p.192) and in the Preston area (Price et al., 1963, p.62). The marine band has also been noted in Edale and adjacent areas (Stevenson and Gaunt, in preparation, Hudson and Cotton, 1943) and at Roughlee, near Blackburn.

In the Kirkby Malzeard area to the north, few thicker-shelled R1 goniatites have been found. The R1a Cayton Gill shell bed fauna consists largely of brachiopods and lamellibranchs, and only a single specimen of R. circumplicatile group, which could be $R1a_1$ or $R1a_2$, has been found (Wilson and Thompson, 1965).

In the Knaresborough forest area, however, the shales below the shell bed yielded *R.* cf. *eoreticulatum* (once considered to be possibly R1) and *Reticuloceras* sp. (Hudson 1939, p.335). Bisat and Hudson (1943, p.403) considered that these goniatites could represent an "*inconstans*" group fauna which would be compatible with the record of *R.* aff. *coronatum* beneath the possible equivalent of the Cayton Gill shell bed in Stephens *et al.* (1942, p.354). Shales with *R. dubium* Bisat and Hudson at Spofforth Hags (Bisat and Hudson, 1943 p.403) overlie the Cayton Gill shell bed, suggesting that the shell bed itself is partly $R1a_2$. The record of *R.* aff. *umbilicatum* in the shales below the Addlethorpe Grit (*R. dubium*, too, underlies this sandstone horizon) also suggests an R1a fauna because *R.* aff. *umbilicatum* has been recorded from $R1a_2$ in North Staffordshire.

In Ireland, Hodson (1954, p.157) records *R. subreticulatum* and suggests that it is a representative of the *R. todmordenense* subzone, a conclusion supported by the evidence in this account. No higher *R. todmordenense* subzone species have been found. A single specimen of *R. circumplicatile* group could be from the lower part of $R1a_2$. Arenaceous sedimentation may follow the *R. subreticulatum* horizon, thus occurring within the *R. todmordenense* subzone and explaining the failure to find higher *Reticuloceras* species in Ireland.

Measurement of sections

As the thickness of the *R. paucicrenulatum* marine band is variable and the base of the fossiliferous shales ill-defined, the more objective kaolinised ashband datum plane has been chosen, from which to record the position of the goniatite fauna.

In a persistent impure limestone immediately underlying the ash band, and in the shales to the base of the fossiliferous sequence, the fauna is characterised by the occurrence of R. pulchellum. This part of the marine band has thus been called the R. pulchellum horizon. Immediately above the ash band, goniatites referable to R. todmordenense occur, followed by R. paucicrenulatum, still accompanied by R. todmordenense group. This fauna is succeeded by the highest horizon, that of R. adpressum--dubium.

Thickness variations of the subzone

In the North Staffordshire Basin area, the subzone usually consists entirely of shale, as in the area described by Bisat and Hudson (1943). Further north, where arenaceous sediments occur at this horizon, the thickness of the subzone cannot be measured with accuracy.

At Lumbutt's Clough (Bisat and Hudson, 1943, p.393), the subzone is approximately 2.4 m (8'3" minimum estimate) thick compared with 3.77 m (12'6") in the Ashover boreholes (Tansley). At Samlesbury Bottoms, Lancashire, the R. paucicrenulatum marine band is 1.82 m (6') thick, 3.02 m (10') of non-fossiliferous shales also intervening between this marine band and the R. dubium marine band which appears to be separated from the R. paucicrenulatum marine band in this section. This gives a minimum thickness of 5.42 m (18') for the subzone.

The thickness of the subzone around the North Staffordshire Basin is fairly constant as may be seen from the table below and Appendix Figure I.

	Bearda	Traveller's Rest Upper Manifold	Thorncliff
A. Non-fossiliferous shale interval to $R1b_i$	2.27 m	1.45 m	approx. 1.5 m
B. *R. paucicrenulatum* marine band	5.98 m	4.38 m	only 1.04 m exposed

Only on the margins of the basin is the subzone locally thickened by arenaceous developments, as at the localities below.

	Golf Course	Heath Hay Ravines
A. Non-fossiliferous shale interval to $R1b_i$	21 m	Total of 9 m
B. *R. paucicrenulatum* marine band	2.98 m	

Lithology and faunal variation of the *R. paucicrenulatum* marine band

This is the thickest marine band in the R1a--R2b succession, excluding the *R. circumplicatile* subzone sequence which is, however, less fossiliferous and may include a number of thicker-shelled goniatite phases alternating with less than "fully marine" phases.

Shales at the top of the *R. paucicrenulatum* marine band ie. the *R. adpressum--dubium* horizon, tend to be lighter grey in colour than the lower horizons of the marine band and do not contain bullions. Abundant impressions of the *R. adpressum--dubium* group have been found in a loose block of siderite at the Combes, Ipstones. Their occurrence is similar to the shelly horizon within the *R. gracile* marine band. Calcite bullions occur in the *R. paucicrenulatum* / *R. todmordenense* horizon in the Blake Brook, the River Dove and at

Ballbank (Upper Manifold Valley). A persistent impure limestone band occurs immediately beneath the Rla_2 kaolinised ash band defining, for the purposes of this account, the top of the R. pulchellum horizon.

At the Combes, Ipstones, where the Rla_2 marine band is well developed (locs. 038 and 039), bullions occur at several levels in the calcareous shales. Collections of bullion material have been obtained from immediately beneath the R. adpressum-dubium horizon, and at least two lower levels of limestone beds are present in the abnormally calcareous sequence.

The fauna of the Combes locality was first recorded by Hull and Green (1866, p.93) and the locality subsequently described by Morris (1967, p.22-24). Hull and Green recorded the following fauna:-

G. reticulatus Phillips

G. micronatus (?)

Orthoceras cinctum

Nautilus subsulcatus

Anthracoptera

Cardiomorpha

Ctenodonta gibbosa Fleming

Posidonia

Discina nitida Phillips

Spirorbis carbonaria McCoy, and annelid tracks

The Combes exposure of the Rla_2 marine band is particularly rich in bullions which break easily around the fossils and yield well preserved specimens. Goniatites are abundant in the bullions but tend to be concentrated on certain bedding planes. Reticuloceras occurs with abundant Homoceras; Nuculids (Pl. 1.3a), Orbiculoidea sp., an ornamented gastropod (Pl. 1.3b), small orthocones and goniatite spat

Plate 1.3

1.3a *Nuculid*

x8

Locality: the Combes, Ipstones, 039_2

"Solid" specimen in loose bullion adjacent to the exposure of the *R. paucicrenulatum* marine band.

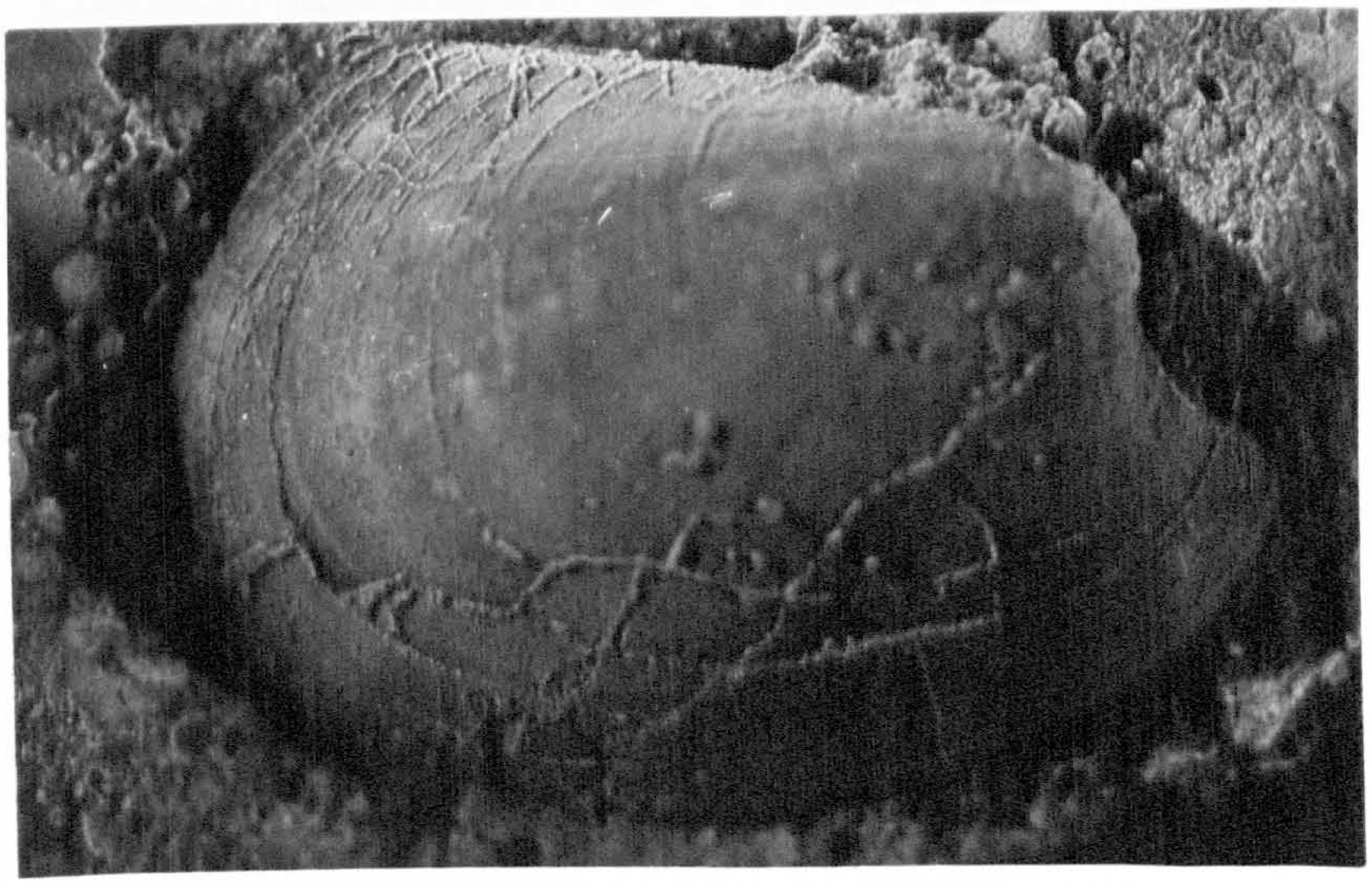
1.3b *Gastropod* sp.

x12

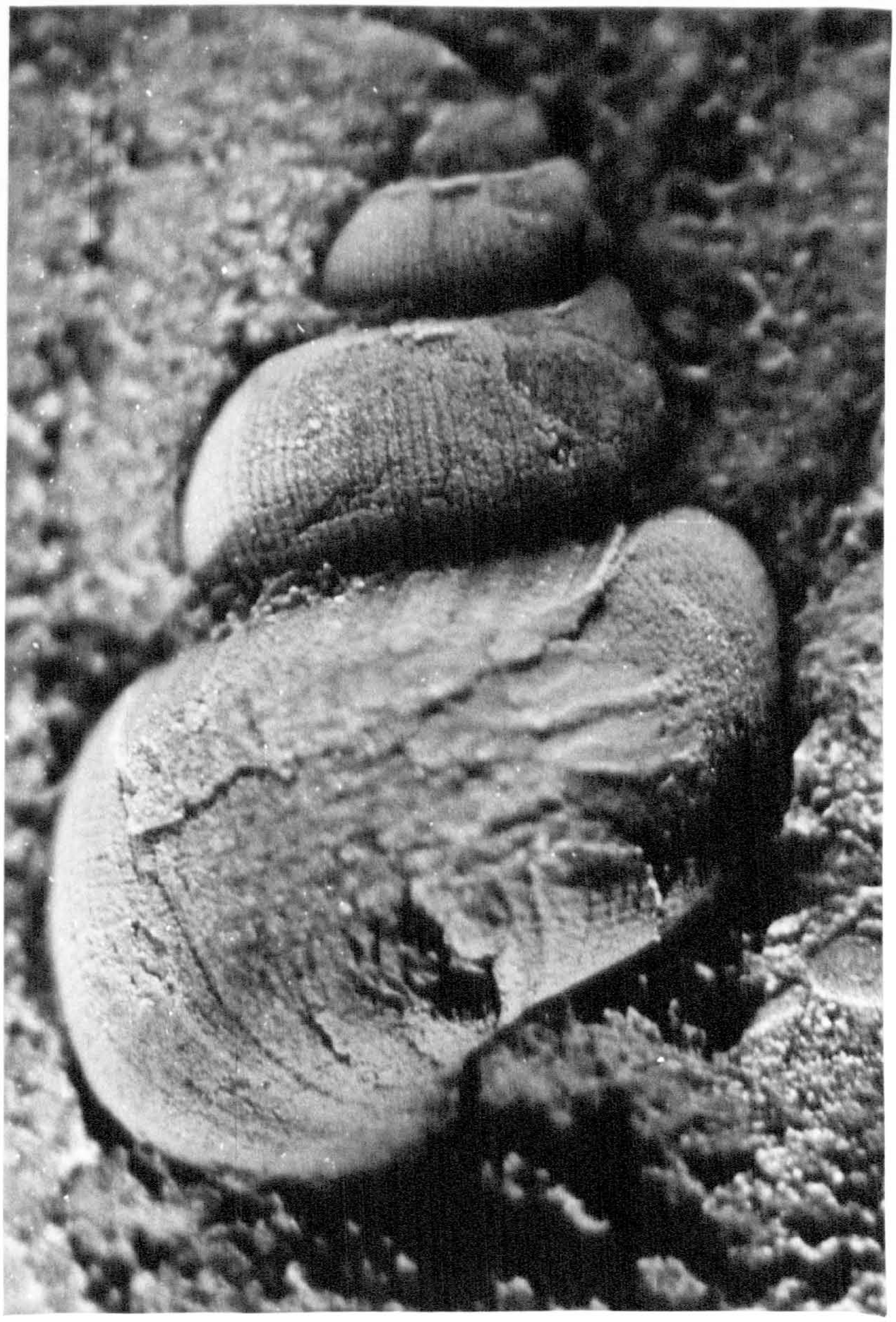
Locality: the Combes, Ipstones, 039_3

Artificial mould of external ornament of shell from impression of external ornament in loose bullion.

Pl. 1.3



a



b

have also been recorded. *Dunbarella* specimens are uncommon in the bullions and sponges and Radiolaria have not been found. *Dunbarella* becomes more common towards the top of the marine band in the *R. adpressum-dubium* horizon, and a *Dunbarella*-rich horizon occurs at the top of the band. Hull and Green (1866) also recorded annelid tracks but it is not known if these were found in the grey, generally unfossiliferous shales or in the black shales. It seems most likely that they were found in the grey shales since burrows elsewhere in the southern part of the area are common in light grey shales which contain no other fauna. Delmer (1955) does, however, record "small holes filled with pyrite" which may be annelid traces in R2 goniatite-bearing shales in Begium. *Spirorbis* specimens recorded by Morris (1967) were found on plant debris, and may have been similar to those figured by Demanet (1941, Pl. 1, fig.1).

Brachiopods have been recorded from other localities which expose the Rla_2 marine band. Evans *et al*. (1968, loc. 167a-b) recorded *Productus carbonarius* beneath *R. dubium* (probably Rla, not Rlb, since *R. adpressum-dubium* group and *R.* cf. *todmordenense* only could be found by the author). Holdsworth (1966b) recorded *Crurithyris* from the *R. nodosum* horizon (reidentified as the *R. paucicrenulatum* marine band) and Stevenson and Gaunt (in preparation) also record *Cypridina* sp. with the *R.* cf. *pulchellum* / *R.* cf. *subreticulatum* fauna in the Grindsbrook section, Edale.

Sponges are extremely abundant in bullions at some localities of the Rla_2 marine band -- notably in Shell Brook (loc. 033 and 032) and in the Manifold Valley (Holdsworth, 1966b). The sponges occur in the goniatite-bearing shales, in contrast to the Hexactinellid sponges reported by Calver (1969) which occur in the *Lingula* facies and as benthonic forms in the succeeding *Myalina* facies. Because of the unusually large size of the sponges at this horizon, and their abundance, Holdsworth (1966b) suggested that they might be benthonic. The author also considers possible a benthonic mode of life for the sponges since there are other indications of benthonic faunas and sponges are extremely abundant at this horizon.

Fauna of the R. paucicrenulatum marine band

R. aff. *dubium* *R. adpressum-dubium* group	R. ADPRESSUM-DUBIUM HORIZON
R. aff. *umbilicatum* *R. paucicrenulatum* *R.* aff. *paucicrenulatum* *R. todmordenense* *R.* cf. *pulchellum* *Homoceras henkei* Gastropod sp. Nuculid sp.	R. PAUCICRENULATUM/ TODMORDENENSE HORIZON
R. pulchellum *R.* sp. nov. *R. pulchellum* group *R. subreticulatum* *R.* of *R. circumplicatile* group *Homoceratoides* sp.	R. PULCHELLUM HORIZON

A. Description of the fauna of the Reticuloceras pulchellum (Foord) horizon

Reticuloceras pulchellum (Foord)

Glyphioceras (Beyrichoceras) pulchellum Foord 1903, p.190, pl.xlix fig.5

Reticuloceras pulchellum (Foord). Bisat and Hudson, 1943, p.422-423, pl.xxviii, fig.8, holotype refigured from Foord, 1903, pl.xxiv, fig.6, possibly R. pulchellum

Localities: Upper Manifold Valley, loc. 024, immediately below kaolinised ash band. Two specimens, crushed in shale. Oakenclough Valley, loc. 023. One specimen from decalcified limestone beneath ash band.

Description

All specimens are narrowly umbilicate, including fragments of specimens not included in the table below. No small specimens were found so that the early rib pattern is obscured in available specimens. There appears to be a regular dichotomy of the primaries in most specimens, but in specimen 024(1) interpolation of a striation is also seen to take place. The lingua is not pronounced, projecting only 0.5-1.0 mm forwards. The hyponomic sinus in the one example seen is deeper than the lingua. The striae in all specimens are delicately crenulate, and better preserved fragments compare well with the fragment of ornament of R. aff. pulchellum figured in Bisat and Hudson (1943) in pl.xxiv, fig.6. A concentric ornament is present on the lingua and diffused over the flank, although the strength in different specimens tends to be variable.

Locality and spec. no			Lingual D	Projn. Lingua	Striae/ mm L.	Depth Hy. sinus
024_1	1	Pl. 1.4a	approx. 32.0 mm	1.0 mm	4-5	3.5 mm
024_2	2	Pl. 1.4b	17.0	0.5	4 approx.	-
023	1		14.0	0.5	4-5	-

Identification and discussion

The horizon of the holotype of R. pulchellum is unfortunately unknown, and it is not clear in Bisat and Hudson (1943) from exactly which horizon the specimens of R. aff. pulchellum were obtained. R. aff. pulchellum collected from Lumbutt's Clough may have come from the R. todmordenense subzone, or that of R. circumplicatile. The former is more probable because little fossiliferous material in $R1a_1$ is exposed, and R. subreticulatum, with which R. pulchellum occurs, is also recorded from the same locality. The fauna recorded from Ashop Bridge may well be in the R. circumplicatile subzone.

R. aff. pulchellum has frequently been recorded from the R. circumplicatile subzone (Figure 1.E) and has also been noted at the R. circumplicatile horizon in North Staffordshire (p.28). The range of R. pulchellum and its variants is undoubtedly greater than the R. circumplicatile subzone, however, because at least three authors have recorded R. aff. pulchellum and R. cf. pulchellum in the R. todmordenense subzone since the publication of Bisat and Hudson's paper, although no specific mention was made of this form in $R1a_2$ in the 1943 publication. Ramsbottom et al. (1962) record R. cf. pulchellum at varying levels of the R. paucicrenulatum marine band in the Ashover boreholes (Figure 1.F). Morris (1967, p.23) records R. pulchellum and R. aff. pulchellum (a late form) from his faunal bands A and B respectively, and Holdsworth (1963a, p.141) records R. aff. pulchellum with R. todmordenense. One of the specimens figured as R.

Plate 1.4

1.4a *Reticuloceras pulchellum* (Foord)

x13.5

Locality: Upper Manifold Valley (024_1)

Impression in shale of external ornament on flank and lingua.

1.4b *Reticuloceras pulchellum* (Foord)

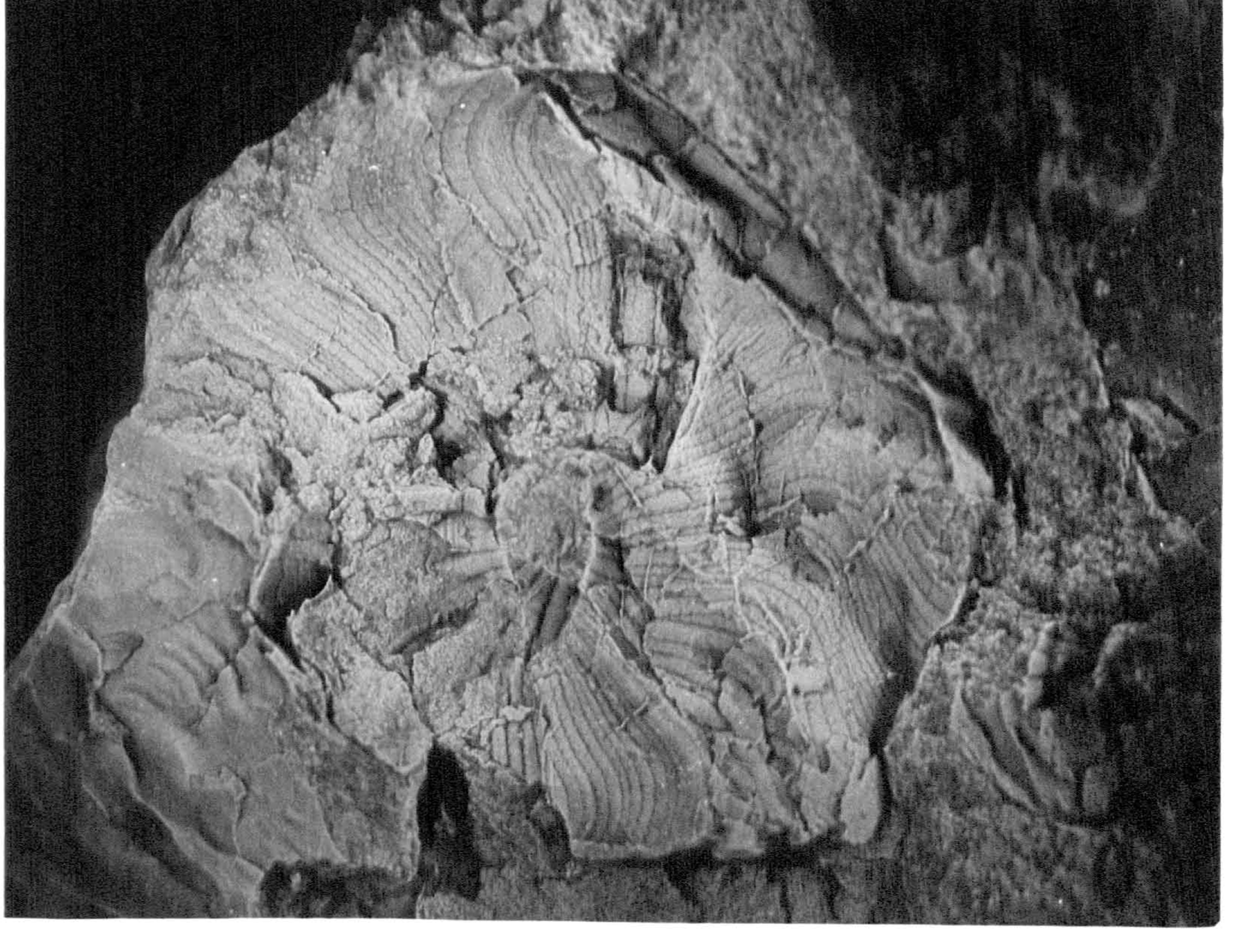
x4.5

Locality: Upper Manifold Valley (024_2)

Impression of external ornament in shale.

Pl. 1.4

a



b

cf. pulchellum (ibid. Pl. 13, fig.2) is now known to have come from the R. paucicrenulatum marine band from bullions 1.2 m above the kaolinised ash band. The specimens figured in Pl. 13, fig.1 (ibid.) came from the same marine band, possibly from the R. pulchellum horizon defined here, at the level of the ash band.

All specimens from the level of the impure limestone show a poorly developed lingua, delicately crenulate striae and a broad venter -- features all typical of R. pulchellum. The hyponomic sinus is always deeper than the lingua. Strength of the ornament is intermediate between the coarse and fine ribbed varieties of R. aff. pulchellum described by Bisat and Hudson. Synonomy with the holotype may not be justified as the early stages of ontogeny in the holotype cannot be seen, and all striae appear to emerge straight from the umbilicus at a diameter of 30 mm (approx.), although a few striations may bifurcate at a narrow angle. Specimens of comparable diameter and ornament to the holotype have been obtained from the R. pulchellum horizon and look very like the holotype, suggesting that the horizon of R. pulchellum is in fact as high as the R. todmordenense subzone. Hodson (1957, p.157) remarks on the similarity of the R. pulchellum/subreticulatum/todmordenense group, and states that it is likely that ". . . this species . . . will be found to occupy a horizon, which in the Pennines would be assigned to the todmordenense sub-zone".

Some of the apparent variability in the form of the specimens figured by Bisat and Hudson may be attributed to the specimens having been obtained from different horizons, as R. pulchellum and its variants would seem to have a long range for an R1a goniatite. As the specimens which most closely approach the holotype have been obtained from the limestone immediately below the $R1a_2$ ash band, it is concluded that these are in fact R. pulchellum, in a position close to that of the holotype.

Reticuloceras sp. nov. of R. pulchellum group

Localities: Traveller's Rest, Upper Manifold Valley, loc. 024.
The Combes, near Ipstones, loc. 038.
Brund borehole no. 1.

Material

External impressions of conch, crushed in shale. Material is poorly preserved bt distinctive.

Description

This is an involute form with delicate, closely-set radial striae and a weak lingua. A specimen from the Combes (Pl. 1.5a) has 9 striae/mm at a diameter of approximately 20 mm. The striae emerge radially from the umbilicus. A concentric ornament is developed over the flank and lingua and is accentuated by the juxtaposition of corresponding crenulations on closely adjacent radial striae. The hyponomic sinus is relatively well developed.

Locality and spec. no.	Lingual D.	Projn L.	Striae/ mm L.	Sinus	Umbilicus
024 (3)	10.0 mm	0.4 mm	9-10	-	2.0 mm approx.
024 (4)	13.5	0.5	14	3.8 mm	2.5

Comparison with other R1a species

The radial ornament is too closely spaced and the lingua insufficiently well developed for this form to compare with R. todmordenense. R. subreticulatum is also too coarsely ornamented. The more finely ornamented specimens of R. aff. pulchellum described

Plate 1.5

1.5a *Reticuloceras* sp. nov. of *R*. *pulchellum* group

x8

Locality: The Combes, Ipstones, $O3b_1$

Specimen in shale, preserved in relief, showing external ornament on lingua and venter.

1.5b *Reticuloceras* sp. of *R*. *circumplicatile* group

x9

Locality: Upper Manifold Valley (024_5)

Impression of external ornament of flank and weak lingua in shale.

Pl. 1.5

a

b

by Bisat and Hudson (1943) are the closest forms, thus the specimens from the Upper Manifold are thought to have most affinity with *R. pulchellum*, although the strength of the ornament differs considerably from *R. pulchellum* described in this account. The form is distinctive enough to merit the erection of a new species, but material is as yet inadequate to provide a sound description and a holotype.

Reticuloceras subreticulatum (Foord)

Glyphioceras (Beyrichoceras) subreticulatum Foord, 1903, p.184, pl.xlix, figs.6a-b, 7a-d

Reticuloceras subreticulatum (Foord). Bisat and Hudson, 1943, p.423-424, pl.xxvi, fig.3. Specimen chosen as lectotype, refigured from Foord, 1903, pl.xlix, figs.7a-d.

R. subreticulatum (Foord). Earp *et al.*, 1961, pl.xi, fig.2.

R. subreticulatum (Foord). Hodson, 1954, pl.xi, fig.1 and 1a.

Locality: Blake Brook, loc. 027.

Material

A single specimen, half crushed, from the impure limestone beneath the $R1a_2$ kaolinised ash band.

Description

The ornament of the specimen is of approximately the same strength as that of *R. pulchellum*. The ribs bifurcate regularly with no interpolation of striations as far as may be seen. The ribs occur at 4-5 per mm on the lingua at 20 mm diameter. The lingua is slight, projecting only 0.5 mm. One constriction is seen in the quarter whorl of the specimen; and in this respect, and the form of the ornament, the specimen compares well with that figured by Hodson (1954) etc., and is thus identified as R. subreticulatum.

Reticuloceras of R. circumplicatile group

Localities: Upper Manifold Valley, loc. 024

Bearda, loc. 031

Material

All specimens crushed in shale, and fragmentary.

Description

Because the material collected is poor, the description of this form is incomplete. The radial ribs are virtually non-crenulate, showing only slight indentations on the lingua, which is poorly developed (Pl. 1.5b). The hyponomic sinus is shallower than in R. pulchellum and the form is more coarsely ribbed than the more coarsely ornamented forms of R. aff. pulchellum described by Bisat and Hudson (1943, p.423). The form appears to bear no comparison with other $R1a_2$ species, but some fragments suggest affinity with R. circumplicatile from the interpolation of 2-3 striations between umbilical plications which bifurcate, and a slight development of a concentric umbilical ornament. The horizon of the form described is, however, too high for R. circumplicatile s.s. and the ornament too widely spaced.

Diameter	Projn. L.	Striae/mm L.	Umbilicus
11.5 mm approx.	0.5 mm	2-3	2 mm approx.

Discussion

In the Uppertown borehole (Ramsbottom *et al.*, 1962, p.93-94) a thicker-shelled goniatite phase occurs at 0.8 m (2'7") to 0.94 m (3'1") beneath the $R1a_2$ ash band (393'10" to 394'6½"). This "marine band" is 1.97 m (6'6") above a ¼" band of pyrite at 401'8" in the *R. circumplicatile* subzone. The pyrite band is probably the topmost ash band of the $R1a_1$ subzone. The above thicker-shelled goniatite phase is separated from the $R1a_2$ thicker-shelled goniatite phases by a spat phase, but its position is closely comparable to the horizon from which the above described specimens from North Staffordshire were obtained. The specimens (loc. 024) were obtained from 0.46-0.96 m (1'6"-3'1½") below the $R1a_2$ ash band and 3.19 m (10'6½") above the highest $R1a_1$ ash band.

Reticuloceras specimens from the above horizon in the Uppertown borehole were not specifically identified, but both crenulate and non-crenulate forms occur (Ramsbottom *et al.*, 1962, p.126). These may correspond to the *Reticuloceras* specimens of the *R. circumplicatile* group described above, and to *R.* aff. *pulchellum*.

Homoceratoides sp.

Material

Half crushed specimens in impure limestone with *R. pulchellum* below the ash band. Loc. 032, Upper Shell Brook.

Description

A pronounced lingua is formed by the inflexion of the ribs, which are clearly defined and box-shaped at 30 mm diameter. One secondary rib (occasionally two) is interpolated between the primaries to within 3-7 mm from the position of the umbilical edge.

Because the umbilical edge is not actually seen, it is not known if the primary ribs bifurcate or not, but the specimens' similarity to Ht. aff. divaricatus (Hind) (p. 91) indicate that this is likely, and that the specimens in question are also Homoceratoides.

This may be the same form as that recorded as (?)Homoceratoides sp. (Morris 1967, p.23) in faunal band A of the section in the Combes, approximately equivalent to the R. pulchellum horizon of this account. It may also be noted that these specimens of Homoceratoides occur with good specimens of R. pulchellum, and that the holotype of R. pulchellum from Ireland is associated with a fragment showing a Homoceratoides ornament.

B. Description of the fauna of the Reticuloceras paucicrenulatum Bisat and Hudson / Reticuloceras todmordenense Bisat and Hudson horizon

R. todmordenense tends to occur most commonly at the base and R. paucicrenulatum higher in the marine band, but the two forms can occur together throughout the horizon. R. aff. pulchellum is also recorded at varying intervals within the horizon, and fragments of feebly-crenulate goniatites (possibly R. adpressum) occur in the higher part of the horizon with R. paucicrenulatum.

The total thickness of the horizon (between the Rla_2 ash band and the base of the R. adpressum-dubium horizon) is 3.33 m at Bearda. Approximately 1.22 m of this succession is exposed at Thorncliff (020) and at Ballbank (loc. 025 and 026).

Reticuloceras paucicrenulatum Bisat and Hudson

Reticuloceras paucicrenulatum Bisat and Hudson, 1943, p.427-428.

R. paucicrenulatum Bisat and Hudson. Earp *et al*., 1961, pl.xi, fig.3.

R. paucicrenulatum Bisat and Hudson. Holdsworth, 1963a, p.139-140, 142-144, pl.14, fig.2.

Description

R. paucicrenulatum is characterised by an evolute conch with strong primary nodes at the umbilical edge. The nodes degenerate by bifurcation into two strong ribs, pronounced on internal casts. A single strong striation is interpolated between the pairs of ribs, and the radial ornament is bent sharply into a pronounced lingua. *R. paucicrenulatum* s.s. is characterised by a definite concentric ornament at the umbilical edge, but forms attributed only to *R. paucicrenulatum* group can lack this feature. All forms are evolute, but show a rapid development of the more involute adult stage at about 13 mm diameter in most specimens. The adult stage lacks the sharp twist in the ribs as they emerge from the umbilicus, the ornament being truly radial. The ribs emerge from the umbilicus without the development of an umbilical node and are barely crenulate. A spiral ornament can be developed on the lingua only. Some more evolute forms of *R. paucicrenulatum* group still retain the *R. paucicrenulatum* typical adolescent ornament at approximately 20 mm diameter. These more evolute forms (Plate 1.6a) predominate lower in the band, typical forms accompanied by *R. adpressum* occurring at higher levels. In the highest part of the horizon, more delicately ornamented forms occur (Plate 1.6b) which still show the typical *R. paucicrenulatum* (evolute stage) rib interpolation pattern. Too much significance should not be attached to these variants at different levels in the horizon as Ramsbottom (in Earp *et al*., 1961, p.192) noted that

Plate 1.6

1.6a *R.* aff. *paucicrenulatum*

x12

Locality: Thorncliff stream (020_1)

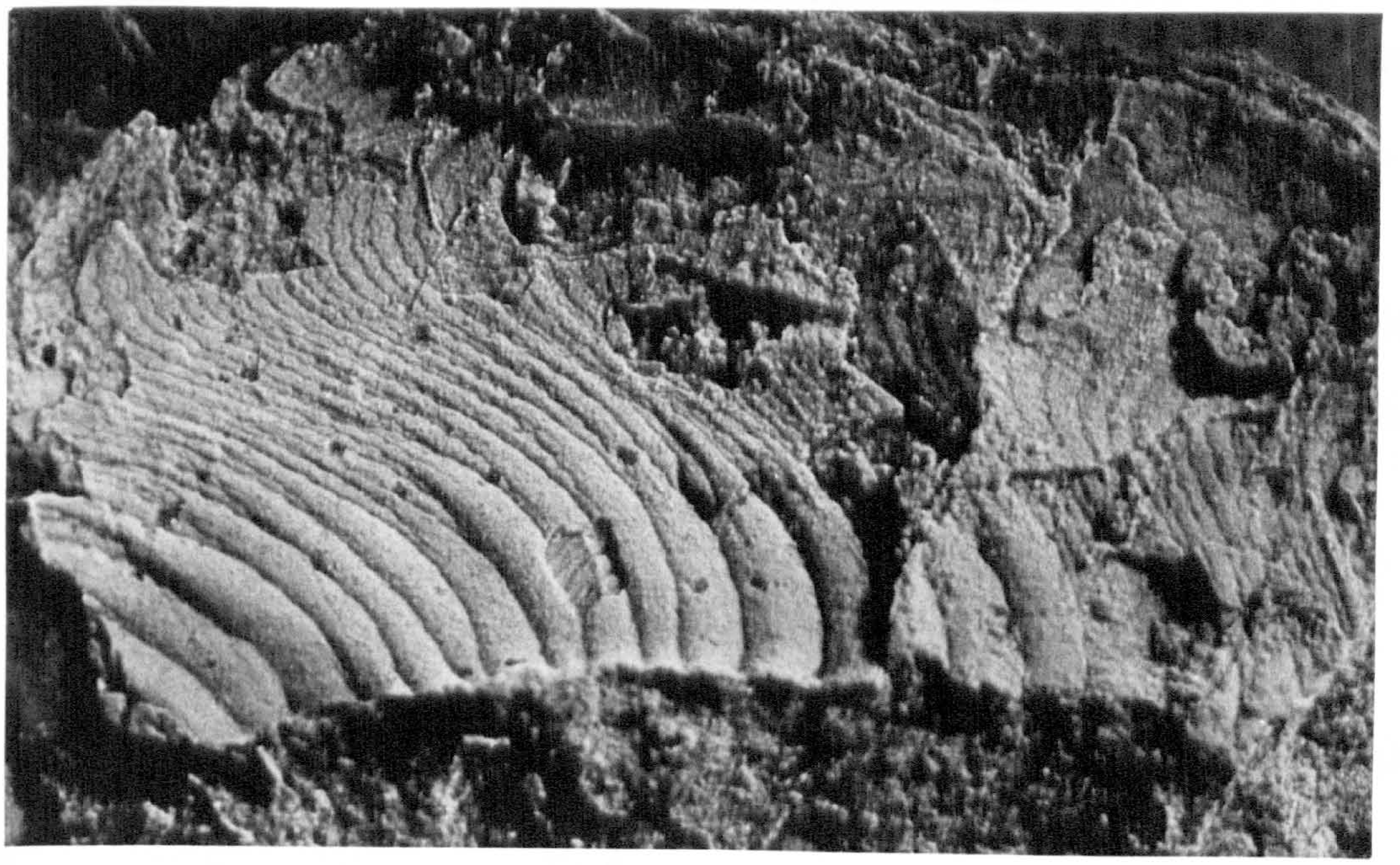
Impression of evolute form in shale.

1.6b *R.* aff. *paucicrenulatum*

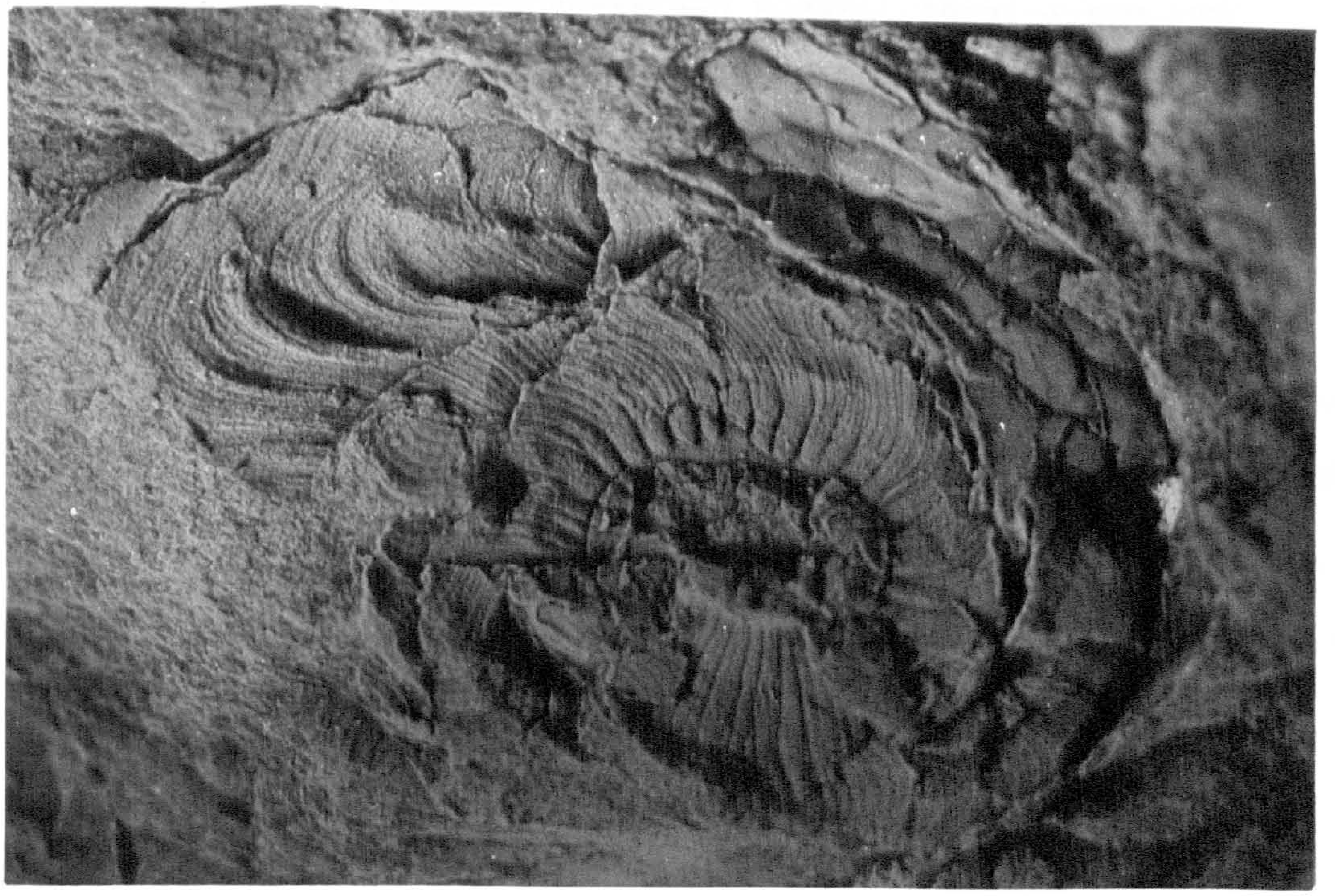
x6.5

as above, (020_2)

Pl. 1.6



a



b

considerable variation in the shell-shape of R. paucicrenulatum occurred at a single level in the marine band at Roughlee, Lancashire.

Immediately beneath the R. adpressum-dubium horizon at The Combes, widely umbilicate Reticuloceras forms occur which are similar to R. paucicrenulatum, but lack an interpolated striation between the primaries, or have only an occasional, irregularly interpolated striation. Similar forms have also been noted crushed in shale at the top of the R. paucicrenulatum/todmordenense horizon at Bearda. These forms may be referable to R. umbilicatum which has been recorded beneath R. dubium. Alexander (in Bisat and Hudson 1943, p.391) also recorded R. aff. umbilicatum at a locality in North Staffordshire (Manifold Valley, Thick Withens Farm, near Ballbank) which is almost certainly $R1a_2$ (p. 60).

Reticuloceras todmordenense Bisat and Hudson

Reticuloceras todmordenense Bisat and Hudson, 1943, p.419-420, pl.XXIII, figs.1-5.

Description

Specimens used in the description are shale impressions from the Bearda locality (loc. 031), at a horizon up to 0.68 m above the $R1a_2$ ash band. All specimens are narrowly umbilicate and have ribs radial to the umbilicus. The ribs bifurcate and one striation is interpolated between them. Faint spirals can occur on the lingua but are absent on the flank in the more finely ribbed specimens. They occur faintly on the flank in the more coarsely ribbed specimens.

Spec. no.	Lingual D.	Projn. L.	Striae/mm L.	Umbilicus
2	8.5 mm	0.5–0.75 mm	5	2.0–2.5 mm
3	9.0	0.75	5	2.0
6	9.0	0.5–0.75	7	-
7	18.0	1.5	6	-
1	12.0	0.5–0.75	4–5	
5	9.0 mm approx.	0.5–0.75	4–5	
I.G.S. specimens				
63070	10.5	0.4	4–5	Bisat and Hudson, 1943, pl.XXIII fig.5
63069	11.0	0.8	6–7	fig.4

Identification

Fragments of larger specimens which occur with the specimens above show a reticulate ornament and projection of the lingua similar to the holotype of R. todmordenense. Irregular bifurcation of the ribs was mentioned in the description of R. todmordenense by Bisat and Hudson (1943), but not the interpolation of secondary striae. This feature may, however, be seen in one of the paratypes (ibid. Pl.XXIII, fig.3), as in the specimens described here.

Most of these have the radial ornament spaced at 5 per mm, and closely resemble the paratypes in the strength of the ornament (Plate 1.7a). Some specimens show faint spirals on the lingua as in Bisat and Hudson (1943, Pl.XXIII, fig.2), whereas others lack this ornament. The close correspondence of these forms with the paratypes establishes their identity as R. todmordenense.

Plate 1.7

1.7a *Reticuloceras todmordenense* Bisat and Hudson

x9

Locality: Bearda (031_1)

Impression of external ornament in shale.

1.7b *Reticuloceras* (?) *todmordenense*

x17

Locality: Oakenclough (023_4)

Fragment of lingua from rotten limestone preserved in relief. The lingua appears to be slightly too pronounced for *R. pulchellum*, although the ornament is similar.

Plate 1.8

1.8a *R.* aff. *pulchellum*

x9

Locality: Bearda (031_8)

Impression of external ornament in shale.

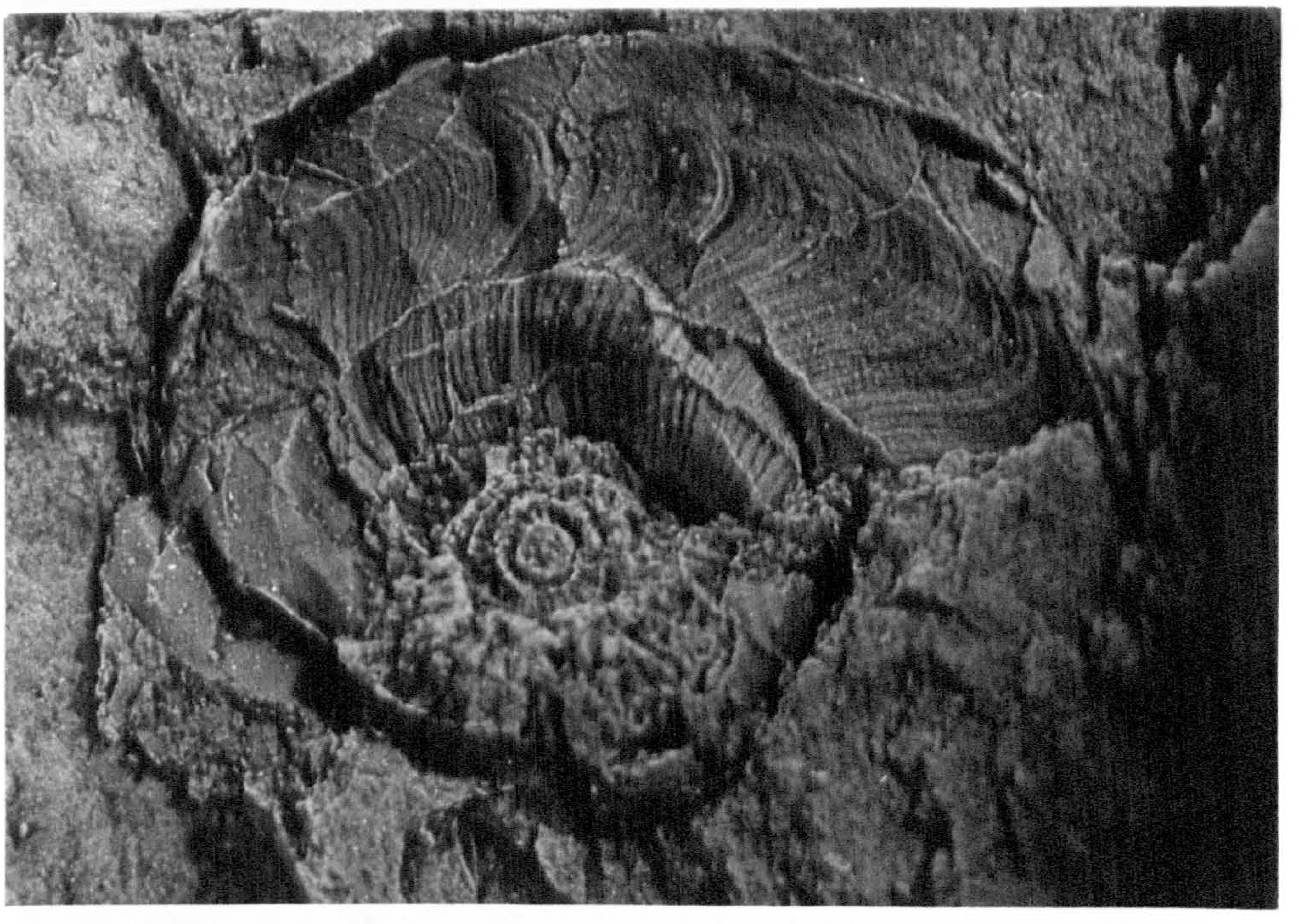
1.8b *Homoceras henkei* H. Schmidt

x6

Locality: The Combes, Ipstones (039_1)

"Solid" specimen in bullion limestone with goniatite spat.

Pl. 1.7

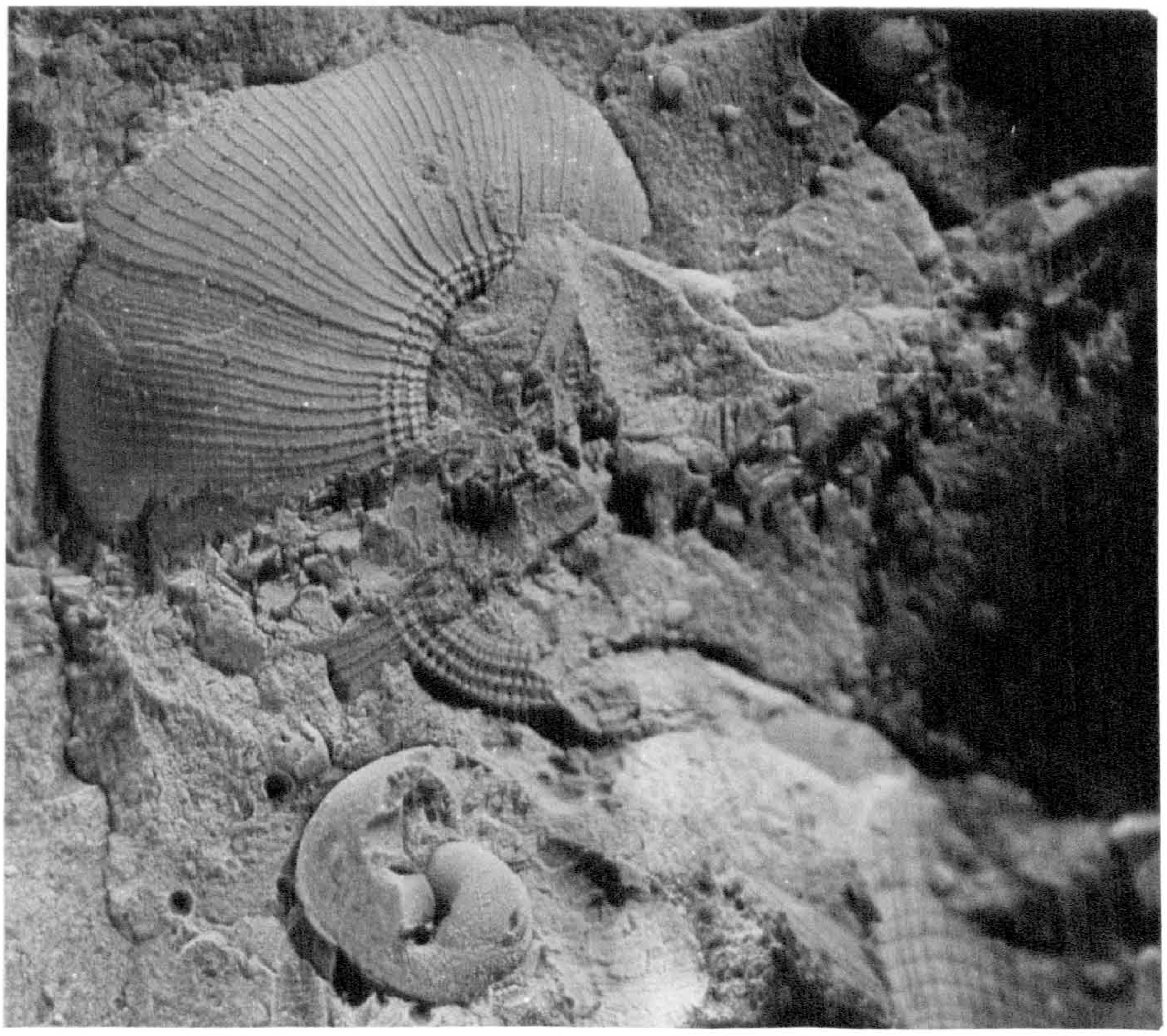


a

b

Pl. 1. 8

a



b

Some specimens eg. 1 and 5, compare less well with the paratypes of *R. todmordenense* and may be more closely allied to *R. pulchellum*. It may be noted that *R.* cf. *pulchellum* was recorded in 0.54 m (1'9") of the Uppertown (Ashover) Borehole core (Figure 1.F) and *R. todmordenense* at only one level. Conversely, in the corresponding strata of the neighbouring Highoredish borehole, *R. todmordenense* and *R. paucicrenulatum* were recorded, but not *R.* cf. *pulchellum*, except at a lower level. The two forms exist at the same horizon, but distinction may be difficult, especially in small specimens. The lack of a typical *pulchellum* ornament in fragments of larger specimens in the material collected from Bearda suggests that these specimens are scarcely comparable with *R. pulchellum* from the underlying horizon. Specimens with a more poorly developed lingua were referred in the boreholes to *R.* cf. *pulchellum*, and this practice has been followed here also. Such specimens tend to be slightly more coarsely ribbed (Plate 1.8a) and similar to the one figured as *R.* cf. *pulchellum* by Holdsworth (1963a, Pl.13, fig.2). The other specimen figured by Holdsworth (Pl.13, fig.1) has more affinity with *R. todmordenense*.

Homoceras henkei H. Schmidt

Eumorphoceras subreticulatum (Foord). Schmidt 1925, Pl.xxv, figs.4-6.

Homoceras henkei H. Schmidt, 1933, p.456. Text figs. 70 and 71, p.453.

Homoceras henkei H. Schmidt. Bisat and Hudson, 1943, Pl.XXV, figs. 4, 5, 7 and Pl.XXX, fig.2.

Homoceras henkei H. Schmidt. Hodson 1957, Pl.C, fig.2, and Pl.E, figs.5 and 6.

Localities: The Combes, Ipstones, loc.039.

Upper Shell Brook, loc.032.

Material

"Solid" specimens from bullion limestones.

Description

Slight inflexion of the ribs is seen at 12 mm diameter (ventral), but does not become pronounced until at least 14 mm diameter. The hyponomic sinus develops at the same time as the lingua and is consistently deeper. No small specimens were available to compare the umbilical slope with that of the specimens figured by Hodson (1957), but this feature appears in larger specimens to be not quite open enough to compare exactly with the H. henkei specimens from the H. magistrorum horizon. Hodson's larger specimen, however, compares closely with that of 039_2 in the development of the lingua and hyponomic

Spec. no. and loc.	Ventral diameter	Projn. L.	Depth Hy. sinus
039_1 (Plate 1.8b)	12.0 mm	none	none
039_2	20.0	1.5 mm	1.8 mm
032	14.0	0.2	-

sinus. Twisting of the ribs around the umbilical nodes is not well enough developed for the specimens to be H. striolatum (Phillips), hence the specimens are determined as a higher form of H. henkei than those figured by Hodson (1957).

C. Description of the fauna of the Reticuloceras adpressum-dubium Bisat and Hudson horizon

Stratigraphic position of R. dubium and R. adpressum

The eponymous subzonal index, Reticuloceras dubium, occurs at the base of the subzone in the section at Samlesbury Bottoms, Lancashire, in the section through the Sabden Shales (Bisat and Hudson, 1943, p.398). The marine band containing this species lies 3.02 m (10') above the *R. paucicrenulatum* marine band and is separated from it by non-fossiliferous shales (see also Price *et al.* 1963, p.62). *R. adpressum*, however, occurs within the same marine band as *R. paucicrenulatum* but occurs above both the latter form and *R. todmordenense*. *R. adpressum* thus represents the highest form in R1a, according to earlier accounts.

In Staffordshire and adjacent areas, non-crenulate, or practically non-crenulate goniatites of the *R. adpressum-dubium* group have been collected from the shales immediately above *R. paucicrenulatum* and *R. umbilicatum*. The lowest R1b marine band ($R1b_i$) has failed at all exposures to produce specimens referable to *R. dubium*. Similarly, the Highoredish borehole produced only forms in the *R. eoreticulatum/moorei* group, although the Tansley and Uppertown Boreholes both yielded *R.* cf. *dubium* in the lowest $R1b_i$ marine band (Ramsbottom *et al.*, 1962).

The Macclesfield Memoir (Evans *et al.*, 1968) records three occurrences of *R.* cf. *dubium* (*ibid.* locs. 146g, 167b and 150). Field work indicates that these localities are within the upper part of the *R. paucicrenulatum* marine band rather than in the "*dubium*" subzone of Bisat and Hudson (1943) which was not intended to include any of the fauna of the *R. paucicrenulatum* marine band. As neither *R. dubium* nor *R.* cf. *dubium* have been found in $R1b_i$, where this marine band is seen to succeed that of *R. paucicrenulatum* other forms have been used to identify the lower part of the *R. nodosum* zone.

It is possible that *R. dubium* may simply not have been collected from the $R1b_i$ marine band in North Staffordshire, or that *R. dubium* occurs at a level poorly represented by marine shales in the area. The abundance of *R. dubium*-like forms in Staffordshire, in the Ashover boreholes and in the Brund boreholes at the top of the *R. paucicrenulatum* marine band does suggest, however, that the section at Samlesbury Bottoms is atypical.

The *R. adpressum-dubium* group

Reticuloceras adpressum Bisat and Hudson, 1943, p.420.

Reticuloceras dubium Bisat and Hudson, 1943, p.421.

Localities: Dingle Brook, near Rudyard, loc. 034.
The Combes, Ipstones, loc. 039.
Bearda, loc. 031.
Blake Brook, loc. 027.
Upper Churnet, Strines, loc. 021.

Material

In the Combes, barely reticulate forms occur in the uppermost 76 cm of shale in the *R. paucicrenulatum* marine band, and at Bearda in 46 cm of shale beneath the topmost 1.4 m of shales containing abundant and often matted *Dunbarella*. Sparse goniatites occur in the *Dunbarella* phase, but these are usually thinner-shelled types, or unidentifiable *Reticuloceras* specimens. The *R. adpressum-dubium* horizon is more silty than that of *R. paucicrenulatum*, this feature being most marked in the Combes because of the locality's proximity to areas of subsequent coarse clastic deposition. Preservation of the impressions of the external ornament of the shell at this horizon is consequently poor. A few specimens of this group have also been found in association with *R. paucicrenulatum*, but have been described in this section since the *R. adpressum-dubium* group is common only at the highest horizon.

Description

All specimens are involute, the umbilical diameter being no larger than 2.5 mm in specimens up to 13 mm diameter at the lingua. The lingua in all cases is weak, and a spiral ornament is absent. Ribs emerge radially from the umbilicus with no sign of bifurcation, a feature shared with typical specimens of R. dubium (I.G.S. specimens), in which the ribs are simple. Specimens collected from the R. adpressum-dubium horizon at 3.94-4.24 m above the Rla_2 ash band are slightly reticulate, as are those from The Combes, where the ornament is better preserved in an unusually fossiliferous sideritic band. Non-crenulate forms, however, occur at 4.24-4.56 m above the reference ash band at Bearda, and are closer to R. dubium than the specimens from slightly lower in the horizon.

Bearda	No.	Diameter	Projn. L.	Striae/mm L.	Umbilical diameter
3.94-4.24 m	1	12.0 mm	1.0 mm	6-7	2.5 mm
	2	12.0	1.2	7-8	-
4.24-4.56 m	3	11.0	1.0 approx.	7	2.5
	4	20.0	1.5	9-10	-
The Combes ,039					
	1	9.0	-	7	1.5
	2	12.0	0.75	8	Hyponomic sinus: 2.9 mm deep

Distinction between R. adpressum and R. dubium

Distinction between the two forms appears to be based partially on the strength of the ornament (Bisat and Hudson, 1943) which is much finer in R. dubium than in R. adpressum. Spacing of the striae in R. adpressum (type form) is about 6 per mm at 10-20 mm diameter, and in R. dubium 5-15 per mm on the lingua. Specimens from the

Plate 1.9

1.9a *Reticuloceras adpressum-dubium* group Bisat and Hudson

x12.5

Locality: Blake Brook (027_1). *R. paucicrenulatum* horizon.

Impression of external ornament in shale.

1.9b *Reticuloceras* aff. *dubium* Bisat and Hudson

x6.5

Locality: Bearda (031_3). *R. adpressum-dubium* horizon.

Impression of external ornament in shale.

1.9c *Reticuloceras adpressum-dubium* group Bisat and Hudson

x7

Locality: Blake Brook (027_2). *R. paucicrenulatum* horizon.

Impression of external ornament on the flank.

Plate 1.10

1.10a *R.* aff. *adpressum* Bisat and Hudson

x5

Locality: Upper Churnet (021_1)

Impression of external ornament in shale showing bifurcated ribs and deep hyponomic sinus.

1.10b *R.* of *R. eoreticulatum* group

x9.5

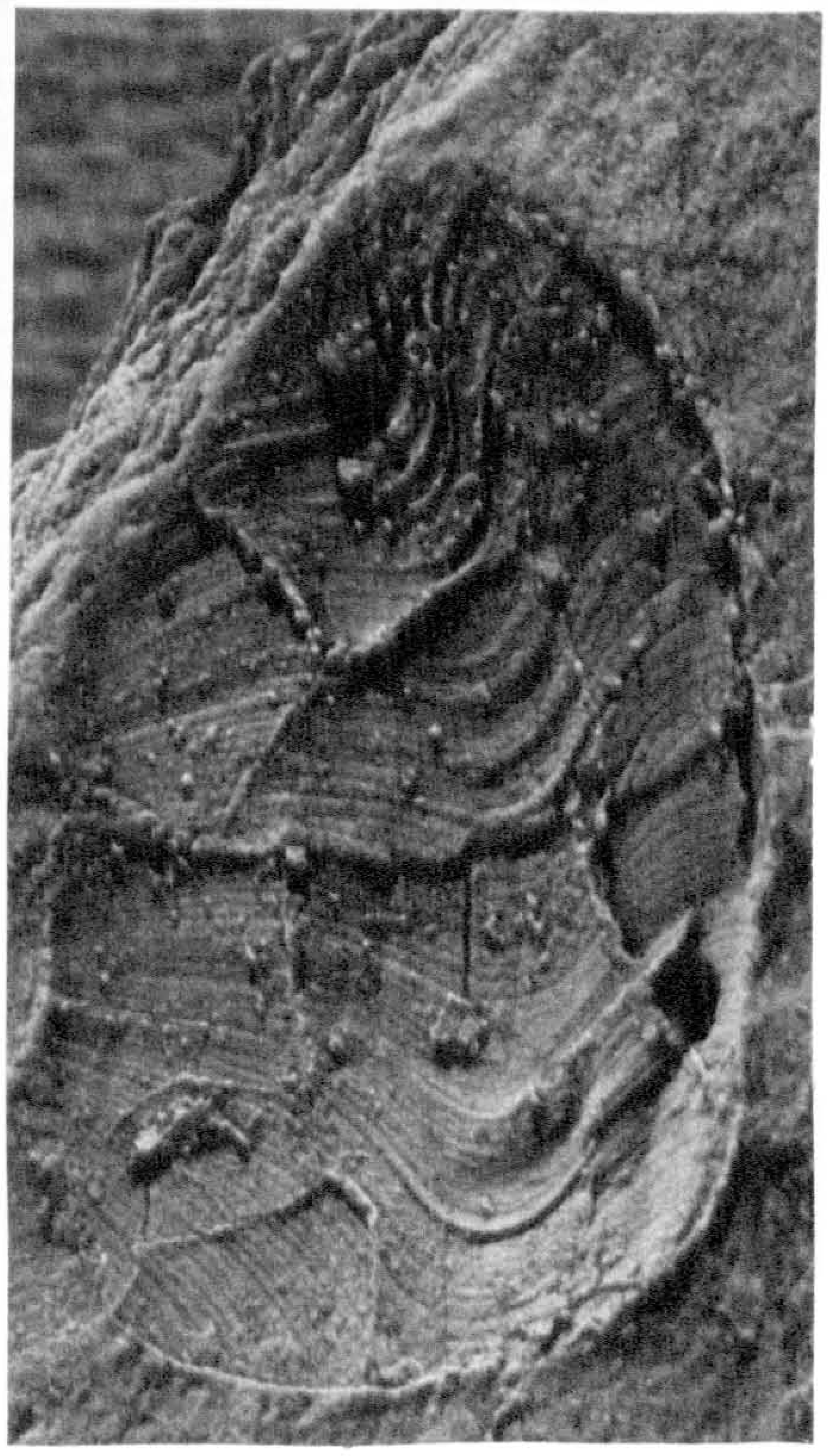
Locality: Blake Brook (043_2)

Impression in shale of external shell ornament.

Pl. 1.9

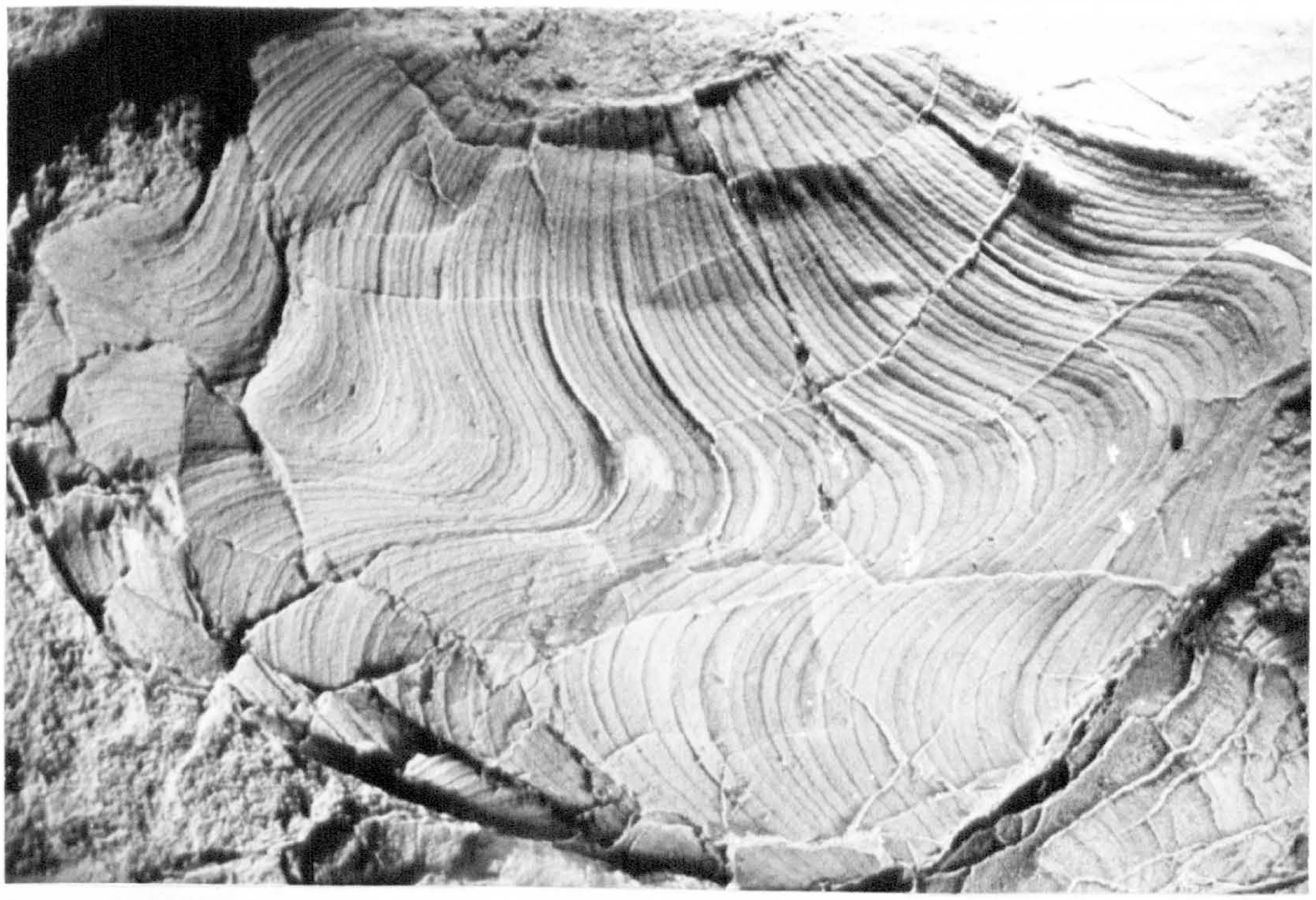
a

b

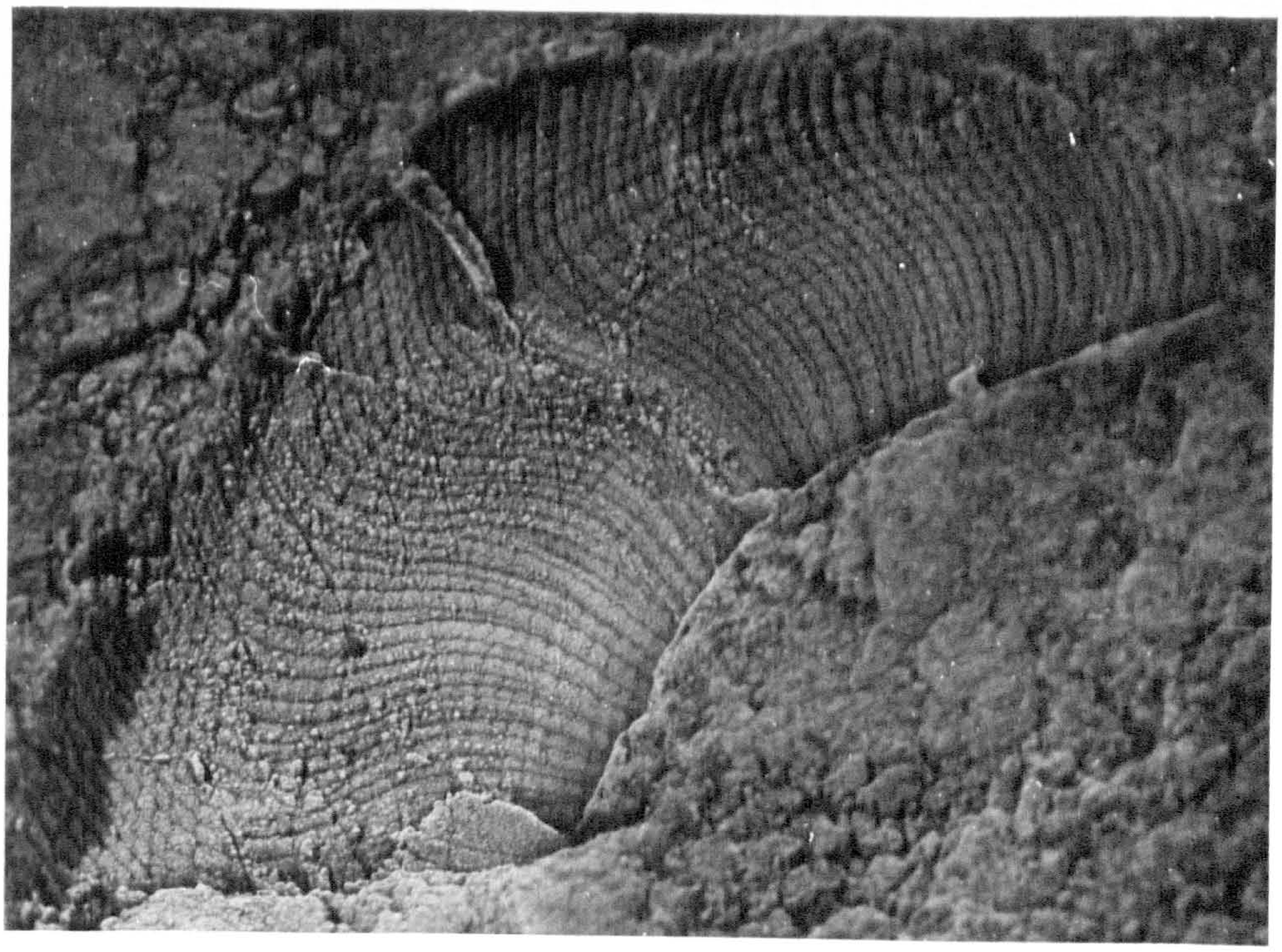


c

Pl. 1.10



a



b

upper part of the marine band appear to be too finely ornamented to be typical R. adpressum. All forms lack constrictions, although Bisat and Hudson noted constrictions in R. dubium. The hyponomic sinus in both forms is deep (as noted in the specimens from N. Staffs) but is adpressed against the lingua in R. adpressum.

Bisat and Hudson (1943, p.420) describe R. adpressum as "almost non-crenulate", compared with "non-crenulate" in R. dubium. Non-crenulate forms occur only in the uppermost 30 cm of the goniatite bearing part of the marine band at Bearda, and are closer to R. dubium than any other forms seen (Plate 1.9b). Specimens from the other localities, and below R. aff. dubium at Bearda, all tend to be slightly crenulate and are best referred to the R. adpressum-dubium group (Plate 1.9a and c). Virtually non-crenulate specimens obtained from the R. paucicrenulatum horizon, and accompanied by R. paucicrenulatum, are more coarsely ornamented than R. aff. dubium and probably referable to R. aff. adpressum (Plate 1.10a). These specimens also show definite bifurcation of the primary ribs near the umbilicus, rather than the emergence of all ribs as striae straight from the umbilicus.

THE RETICULOCERAS NODOSUM ZONE, R1b

Stratigraphy

The stratigraphy of the zone as a whole is not well known, as there appear to be no completely exposed sections where the preservation of the fauna is good. Identification of the fauna has thus often been restricted to "Reticuloceras sp." only.

Hudson and Cotton (1943) recorded the _R. nodosum_ subzone succession from the section at Swint Clough, but the succession of the "_dubium_" subzone and the position of the eponymous subzonal index fossil appear to be somewhat obscure. The Alport Borehole (_ibid._) records only _R. eoreticulatum_ group below the surface exposures of $R1b_{iii}$ (the position of the holotype of _R. nodosum_). _R. dubium_ is not mentioned in the account, and it is implied that there is only a single marine band containing _R. eoreticulatum_ between $R1b_{iii}$ and $R1a_2$. It is possible that the marine band containing _R. eoreticulatum_ group is $R1b_{ii}$, as $R1b_i$ in the Brund Boreholes (p.152) is not separated from the $R1a_2$ fauna by unfossiliferous shales. Thus if the succession were similar in Swint Clough, an $R1b_i$ fauna could have been included in the $R1a_2$ marine band.

Bisat and Hudson (1943) gave no complete section for the "_dubium_" subzone, mentioning specifically only one marine band with _R. eoreticulatum_ in the section at Roughlee (_ibid._ p.399), which was partially obscured. In another section at Samlesbury Bottoms (_ibid._ p.398), _R. dubium_ occurs directly above $R1a_2$ but it is not clear how the position of the _R. dubium_ fauna is related to that of _R. eoreticulatum_, or how many marine bands are present in the "_dubium_" subzone.

In the higher part of the R1b succession at Samlesbury Bottoms, preservation of the fauna appears to be poor, as the lower part of the R1b fauna is recorded as _Reticuloceras_ sp. in Price _et al._ (1963). The number of R1b marine bands recorded also seems inadequate to correlate with North Staffordshire.

The difficulty of assessing the complete succession in R1b is increased by the absence of detailed information on the position of the holotypes of R. moorei Bisat and Hudson and R. stubblefieldi Bisat and Hudson in relation to the other R1b faunas, and the apparently long range of R. eoreticulatum Bisat which has been recorded from the R. todmordenense subzone, as well as the "dubium" and R. nodosum subzones. The position of the holotype of R. nodosum Bisat and Hudson corresponds to $R1b_{iii}$ of this account, but the full range of this form is longer than that given in Bisat and Hudson (1943) from the evidence of the Ashover Boreholes (Ramsbottom et al., 1962), and the succession in the North Staffordshire area.

The Ashover Boreholes show five main marine bands containing thicker-shelled goniatites, compared with four with goniatites in the Swint Clough/Alport borehole succession. The $R1b_{iii}$ marine band is characterized by a matted Dunbarella horizon occurring in a spat phase, and correlating with a similar horizon in the same position at Swint Clough (Ramsbottom et al., 1962, p.124) and in North Staffordshire (loc. 056). A matted Dunbarella band recorded from the Upper Dove (Holdsworth, 1963a, loc. 313) is possibly the same horizon.

The R1b marine bands have been numbered from those of the Ashover boreholes, $R1b_{i}$ occurring at the base of the R1b sequence and $R1b_{v}$ at the top. In the Ashover records, R. cf. nodosum occurs in $R1b_{ii}$, in $R1b_{v}$ and in $R1b_{iii}$ -- which is the marine band of the holotype. R. eoreticulatum has been recorded at the base of the zone as well as from $R1b_{iii}$ (ibid. p.124). R. eoreticulatum, however, appears to be more common in the lower marine band than the other Reticuloceras forms. R. nodosum group is most frequent in $R1b_{ii}$ and $R1b_{iii}$, and Reticuloceras of the moorei/stubblefieldi group in the upper part of the zone. This succession holds, as a general rule, in North Staffordshire also.

No section in North Staffordshire shows all five successive R1b marine bands but it is fairly certain, on the basis of the fauna and measured sections (Appendix Figure I), that all five exist.

In certain areas, the marine shales with an $R1b_i$ fauna may follow an $R1a_2$ fauna with no unfossiliferous break. In Brund Borehole 1 (Appendix Figure II) the $R1a_2$ thicker-shelled goniatite fauna is succeeded by a Dunbarella band, then a less fossiliferous phase (sparse goniatites and Dunbarella) before the $R1b_i$ goniatites. If this interpretation is correct, then the Blake Brook barren $R1a_2$-$R1b_i$ interval correlates with the sparsely fossiliferous interval of the boreholes. That an R1b fauna follows almost immediately after $R1a_2$ is also suggested by the Alport Borehole (Hudson and Cotton, 1943, see p.57 of this account).

Unlike R1a, there are no particularly distinctive faunal horizons within the *R. nodosum* zone, and the evolution of the fauna appears to be comparatively slow. This suggests that the *R. nodosum* zone may represent a lesser period of time than that of R1a, despite the former's greater thickness. Coarse clastic sedimentation is more marked in R1b, and marine bands are generally clearly defined in the field by alternating unfossiliferous shales. These features are in contrast to the almost completely fossiliferous sections of the *R. circumplicatile* zone. In the Brund Boreholes, however, the R1b fossiliferous sequence is almost entirely within "marine" shales. Exact determination of the R1b marine bands, despite their usual clear lithological distinction, is more difficult than the identification of the faunal horizons in R1a. The R1b fauna is less well known because preservation tends to be poor, sections incompletely exposed, and thicker-shelled goniatites often absent, especially in areas marginal to the basin. As some forms, such as R. nodosum group, are not restricted to one marine band, lithological features and the abundance of such forms as Homoceratoides, Homoceras spiraloides Bisat and Hudson, Homoceras henkei-striolatum group and Hd. ornatum have often been used to determine the relative position in the succession of certain marine bands. Where a section showing at least two marine bands is available, fairly certain specific identification can be made, with reference to the ideal section of the Ashover Boreholes. In isolated exposures, however, the situation is rendered less clear.

Previous work within the field area

Holdsworth (1963a) recorded R. nodosum from a position thought to be 0.61-0.92 m (2-3') above R. paucicrenulatum. From measured sections at several localities (Appendix Figure I), it seems extremely unlikely that R. nodosum should occur in this position since 1.45 m of unfossiliferous shales separate the R. paucicrenulatum and lowest R1b marine band at other exposures near the Ballbank area, where the R. nodosum specimens in question were obtained.

The identification of the Ballbank horizon as that of R. nodosum was believed to be partially confirmed by the occurrence of Crurithyris at the same level -- a shelly fauna occurring in $R1b_i$ of the Ashover boreholes. A shelly fauna, however, occurs in $R1a_2$ at The Combes and other localities and a correlation of the "R. nodosum" specimens with the R. paucicrenulatum marine band is thus just as probable on this basis.

The best specimen in question is not typical of R. nodosum, because interpolated ribs do not occur regularly between sets of bifurcating primaries. It is now thought that the specimen in fact comes from the *R. paucicrenulatum* marine band because of its position, only up to 0.92 m (3') above *R. paucicrenulatum*, and its similarity to specimens obtained from the higher part of the *R. paucicrenulatum* horizon, containing *R.* aff. *umbilicatum*, at The Combes (p. 49).

R. nodosum was also recorded in the Blake Brook section (Holdsworth, 1963a, p.146). Holdsworth's T.S. limestone 2 yielded fragments of *Hd. ornatum* and *R. nodosum*, and this limestone and T.S. limestone 1 are now correlated with $R1b_{ii}$. T.S. limestone 3, which yielded crushed specimens of *Reticuloceras* and *Homoceras*, comes from a lower marine band and is equivalent to $R1b_{i}$.

Morris (1966a, 1969) records a lower R1 fauna, with *Reticuloceras* sp. and *Hd. ornatum* in the Thorncliff stream at (0058, 5832). Mapping of this area (Figure 1.C) and identification of the R1b faunal bands in this section show that Morris' locality is probably $R2b_{i}$, the marine band containing the typical fauna of *Hd. ornatum* and *R. bilingue* early form (Holdsworth, Edwards and Trewin, 1970). A low R1b fauna recorded by Morris (1966a) in The Combes is equivalent to $R1b_{i}$.

Evans *et al.* (1968) record *R. nodosum* zone fossils at various localities in the Minns, and Lask Edge. *Hd. ornatum* and *Homoceratoides* sp. (*ibid.* p.52, locs. 119 and 120) may indicate a position near the base of R1b, on account of the common occurrence of these forms in $R1b_{ii}$ within the area. The exposures may, however, be in $R1b_{v}$ as these goniatites are also abundant at this level. Locs. 139b-d (*ibid.* p.54) which yielded *Hd. ornatum* and *Homoceratoides* sp. are likely to be $R1b_{v}$ from the occurrence of *R.* cf. *reticulatum* above.

R1b exposures in the area around Rudyard (*ibid*. p.56, locs. 153, 163, 147a-c) are poor at present. No recognisable fauna was obtained from these localities.

The R1b succession at locs. 143a-c (*ibid*. p.53) yielded a fauna of the *R. stubblefieldi*/*regularum* group. This was confirmed and loc. 143b correlated with $R1b_v$ since the two $R1b_v$ ash bands (p.166) are present.

In the Heath Hay Ravines section (*ibid*. p.54), *Hd. ornatum* and *R. nodosum* were recorded at loc. 158, but the *R. stubblefieldi* band was thought to be unexposed or faulted out. This *Hd. ornatum*/*R. nodosum* fauna overlies $R1b_{iii}$, however, and the position of the marine band and the occurrence of crinoid columnals (common in the *R. stubblefieldi* {$R1b_v$} marine band) suggest that loc. 158 of the Survey is $R1b_v$. This marine band is faulted against unfossiliferous shales, the fault probably cutting out $R1b_{iv}$.

Loc. 159a and b (*ibid*. p.54) yielded *Reticuloceras* sp., but has now been identified as $R1b_{iii}$ (p. 73). Loc. 157 (*ibid*. p.55) is thought to be $R1b_i$ or $R1b_{ii}$.

In Fairboroughs Wood (*ibid*. p.57, loc. 150), *R.* cf. *dubium* was recorded. This form is now known to occur within the *R. paucicrenulatum* marine band, and is indicative of $R1a_2$. Some fragments obtained from the above locality (loc. 037), could be *R. paucicrenulatum*. Loc. 151 (*ibid*. p.57) yielded an *R. nodosum* zone fauna. This exposure is not 7.55 m (25') stratigraphically higher in the succession than loc. 150 as the dips between 151 and 150 are reversed due to faulting. The fauna of loc. 150 (loc. 078 of this account) could be $R1b_{iii}$.

Correlation with other areas

Each R. nodosum marine band fauna has been correlated with those of the Ashover Boreholes and, in the R. nodosum subzone, with the succession at Swint Clough. In areas to the north of Edale and Swint Clough, the black shale facies with thicker-shelled goniatites is replaced by a sandstone lithology containing a shelly fauna. In the Bradford and Skipton area, the Otley Shell bed occurs between R. reticulatum (R1c) and R. eoreticulatum (Stephens et al., 1942, p.356, and Stephens et al., 1953) and may represent the upper part of R1b and/or lower R1c.

In the Colsterdale area, the Ure Shell bed is an approximate equivalent to the Otley Shell bed (Wilson and Thompson, 1965, p.206). Ramsbottom (1965) shows the R. stubblefieldi marine band as a possible lateral equivalent of the Ure Shell bed.

R1b faunas are well represented in the Clitheroe and Nelson area, and in the area around Preston. R. stubblefieldi has been recorded in the Barnard Castle area (Hull, 1963, p.45) and in the Clapham and Giggleswick area (Bisat and Hudson, 1943, p.400). Hodson (1953) records the fauna of this marine band from N.W. Co. Clare, Ireland, as R. cf. stubblefieldi in association with R. regularum Bisat and Hudson. Chalard (1960) also notes a R. nodosum zone marine band in the north of France containing R. moorei and R. stubblefieldi.

From the number of records of R. stubblefieldi, the marine band containing this form appears to be the most persistent, or at least the most readily recognisable and useful, of the R1b marine bands. $R1b_{iv}$ is often represented by a Homoceras and lamellibranch fauna only, and $R1b_{ii}$ appears to be virtually unrecorded except in the Ashover Boreholes. A band with occasional Reticuloceras and

Homoceras specimens which occurs beneath *R. nodosum* in the section at Ewood Clough (Bisat and Hudson, 1943, p.194) may represent $R1b_{ii}$, as *Homoceras* is frequently more abundant at this horizon than *Reticuloceras*. *Hd. ornatum* also occurs in $R1b_{ii}$, and it is possible that the marine band recorded near Chevin Hall, Otley (Stephens *et al.* 1953, p.403) with *R. nodosum* group and *Hd. ornatum* is also $R1b_{ii}$ or $R1b_{v}$ as Bisat and Hudson (1943, p.403) also record *Homoceratoides* sp. and *Homoceras striolatum* group with *R. nodosum* group, a fauna similar to that found a short distance below the Mam Tor sandstones.

$R1b_{iii}$, the marine band from which the holotype of *R. nodosum* was obtained, also contains near the top a distinctive matted *Dunbarella* horizon. The marine band and the *Dunbarella* horizon in North Staffordshire correlate with the succession of the Ashover Boreholes and Swint Clough, but $R1b_{iii}$ does not appear to have been specifically recorded elsewhere. Its position in the Samlesbury Bottoms sections cannot be specifically identified from the records of Price *et al.* (1963).

Finally, the *R. eoreticulatum* marine band, $R1b_{i}$, occupies a somewhat ambiguous position as *R. dubium* should be the index fossil for the lowest R1b band. Yet no *R. dubium* specimens were identified with certainty from the lowest R1b faunal band in the Ashover records, nor in North Staffordshire. The problem is discussed at the end of the R1b section. Low R1b bands have been recorded from the Samlesbury Bottoms section and Holden Beck, in Bisat and Hudson (1943). Both contain *R. dubium*, now thought to be best included in $R1a_{2}$. *R. eoreticulatum*, possibly equivalent to $R1b_{i}$, was recorded from Roughlee (*ibid*. p.399, 6 m {20'} above $R1a_{i}$), and from the Alport borehole (Hudson and Cotton, 1943, p.164). The latter could possibly be $R1b_{ii}$ in age however (see above).

Thickness variations of the R. nodosum zone

Variation in thickness of the zone is more marked than in R1a, both in the area covered and over northern England generally. At Ashover, where the succession is relatively thin, the *R. nodosum* zone totals some 10.57 m (35'). This compares with approximately 14 m from $R1b_i$ to $R1b_v$ in the Thorncliff area and 15.6 m near the River Dane at Bearda. The Macclesfield Memoir (Evans *et al.* 1968) records some 30.2-42.1 m (100-140') of strata within the zone in the area of the Minns, immediately adjacent to Bearda. The lack of sandstone bodies in this area in R1b makes this apparent thickening of the succession in the Minns unlikely. The thickness of the succession in the Minns is virtually impossible to estimate due to repeated faulting. The section at Bearda is thought to be complete despite the almost vertical attitude of the beds, as four R1b marine bands are exposed, and the unexposed part of the section would account for the other one (Appendix Figure I). The similarity of the fragments of the succession seen in the Minns compared with the section at Bearda suggests that sedimentation in the two areas was similar, and the thicknesses likely to be comparable, rather than an abrupt thickening of the succession to over 30 m taking place in the Minns.

The greatest variations in the thickness of the zone occur in the southern and eastern parts of the area where protoquartzites occur in the succession. The succession is about 37 m thick (an estimated 110' in the Macclesfield Memoir) in the area of Lask edge (Heath Hay Ravines section) where lateral equivalents of siderites replace the protoquartzites of the south-east. Towards the Ipstones area, however, deltaic protoquartzites occur. This succession is known to contain one (?)R1b marine band containing *Dunbarella* only

(The Combes section, loc. 079). The fossiliferous $R1b_i$ marine band at the base of the sandstone succession in The Combes is faulted against protoquartzites and R1c marine bands are unknown. Thus a reliable estimate of the total thickness of the succession is impossible to make. The total R1b-R1c sequence, however, appears to be in the region of 100 m thick, at a rough estimate.

Within the basin, where the R1b protoquartzites are represented by a turbidite facies, the R1b succession is 55.5 m thick in the Blake Brook section. The situation is complex due to the local development of the turbidite sandstones and thicknesses are consequently variable (Ch.3). The R1b succession thins rapidly towards the Dinantian reef limestones. Thus the *R. nodosum* zone shows considerable variation in thickness over the whole area, being thickest at the margins of the basin in the deltaic sandstone facies, and in the basin in the turbidite facies. In the areas of the basin by-passed by sandstone deposition, possibly because of the existence of contemporary topographic highs, the succession thins.

THE $R1b_i$ MARINE BAND

Lithology and preservation of the fauna

The fauna of this marine band is invariably poorly preserved, and is known only from a few localities.

At Bearda (044) the total thickness of the marine band is 1.14 m, but it is split into two leaves by a shale intercalation 26 cm thick, which contains lamellibranchs only. The base of the marine band is approximately 2.3 m above the top of the $R1a_2$ fossiliferous shales.

At The Combes, Ipstones, a marine band occurs at 3.06 m above *R. dubium* ($R1a_2$). Out of a total thickness of 1.14 m of fossiliferous shales, only 7 cm contains thicker-shelled goniatites. Caneyella is abundant throughout the band, and Dunbarella occurs in a matted horizon at the top. Unlike the typical black marine shales at the other localities, the lithology is of soft, light grey, gypsiferous clay, the gypsum having been formed on recent decalicification of the rock. Preservation of the fauna is poor in the clay, and most goniatite specimens have been obtained from a lenticular impure limestone. The fauna appears to be somewhat atypical of $R1b_i$, and is discussed on the following pages.

Goniatites are rare at the Endon Golf Course locality where only a single fragment of an unidentifiable specimen has been obtained. The marine band is believed to be $R1b_i$ from its position relative to $R1a_2$ (21.8 m of protoquartzites and shales intervene between the two marine bands). A single specimen of (?)Promytilus has been obtained from the locality. A 15 cm band of poorly cemented pebbly sandstone occurs within the 0.5 m band of blue-black clay with sporadic lamellibranchs. This lithological variation from the normally fine grained sediments within the marine bands, and the paucity of the fauna may be attributed to the locality's proximity to the area of deltaic protoquartzite deposition.

Poor specimens of the fauna have also been obtained from the Upper Manifold Valley and the Blake Brook, description of the fauna having been drawn from the latter locality.

Description of Reticuloceras aff. eoreticulatum Bisat and related forms

Reticuloceras eoreticulatum Bisat

Reticuloceras eoreticulatum Bisat, 1928, p.131.

Reticuloceras eoreticulatum Bisat. Bisat and Hudson, 1943, p.418-9.

Reticuloceras eoreticulatum Bisat. Earp et al. 1961, pl.xi, fig.1 (holotype).

Reticuloceras aff. eoreticulatum Bisat

Material

Impressions of the external shell ornament in shale from loc. 043.

Description

Fragments of smaller specimens, at 10 mm diameter and less, have a weak concentric ornament on the upper flank and lingua. At larger diameters the concentric ornament is obsolete, the ornament of the conch consisting of radial crenulate striations only. The lingua is fairly well defined at 18 mm diameter, but has only a slight forward projection. The radial ornament in both large and small specimens appears to consist of bifurcating primary ribs only, umbilical nodes and interpolated striations being absent. All specimens are involute. A few fragments of more evolute forms have been found in which the concentric ornament is more pronounced, and persists up to 20 mm diameter.

Spec. no.	Diameter	Striae/mm	Projection of lingua
043_1	23 mm approx.	5	1.0 mm
043_2	18 "	5	0.9

Identification

Material is poor, but the goniatites described above are thought to be close to R. eoreticulatum Bisat. In this form, subordinate spirals are seen on specimens at 8 mm diameter, but die out later in life. They are absent in the lectotype at 13 mm diameter. The radial striations at larger diameters are "closely set, feebly crenulate and roughened", (Bisat and Hudson 1943, p.419) as in the specimens described above.

No goniatites are available at 13 mm diameter to compare with the lectotype, but the projection of the lingua (1.5 mm) is slightly greater than in the specimens at larger diameters described above. The strength of the radial ornament (5 striae/mm) is similar. The specimens are thus thought to be close to the lectotype.

The more evolute specimen (Pl. 1.10b) may have some affinity with R. umbilicatum or R. nodosum, as the spiral ornament persists. It lacks, however, the interpolated striation between the bifurcating primaries, typical of R. nodosum, and the projection of the lingua is less than in specimens thought to be similar to R. umbilicatum. The specimen has thus been assigned to R. eoreticulatum group as it shows bifurcating ribs, which form a weak lingua, in a form too evolute for R. eoreticulatum.

Reticuloceras aff. umbilicatum Bisat and Hudson

For synonymy of R. umbilicatum see the description of the form from the R. circumplicatile subzone (p. 24).

Material

Half crushed specimens in impure limestone, and impressions of the external ornament in shale from loc. 046.

Description

More coarsely ornamented forms than R. aff. eoreticulatum have been found in the marine band overlying that of R. paucicrenulatum at The Combes, Ipstones.

Spec.	Diameter	Projn. Lingua	Striae/mm L.	Umbilicus	Depth Hy. sinus
046_1	20 mm	1.0 mm	6	-	-
046_2	28	3.0	4-5	6.5 mm	4.0 mm

Fragments of smaller specimens show a coarsely ribbed stage with a concentric ornament on the lingua. Larger specimens, however, have only a faint concentric ornament in this area. The ribs are radial or slightly reflexed before the lingua on the larger specimens. Bifurcation of theribs is regular and interpolation lacking, hence this form cannot be assigned to the R. nodosum group. There is a marked similarity between this form and the R. aff. umbilicatum forms noted in the underlying R. paucicrenulatum marine band, and as the form is too coarsely ornamented for the R. eoreticulatum group, it has also been assigned to R. aff. umbilicatum. R. eoreticulatum or forms similar appear to be absent at this exposure of $R1b_i$, but it may well be that the limestone and shales which yielded the R. aff. umbilicatum specimens, found in only a small portion of themarine band, are from a lower faunal level than the R. aff. eoreticulatum fauna collected elsewhere.

Stratigraphic position of R. eoreticulatum

In Bisat and Hudson's (1943) description of R. eoreticulatum,the horizon of this species was thought to be in the R. todmordenense or R. "dubium" subzone. From measured sections, the position of the type material was thought to lie in the R. "dubium" subzone, but the occurrence of similar specimens below _R. todmordenense_ made it not impossible that the _R. eoreticulatum_ horizon lay within $R1a_2$.

In Price _et al._ (1963), the situation is further confused by the record of _R._ cf. _eoreticulatum_ within the _R. nodosum_ subzone, where the form occurs 6.05 m (20') below the R1c _Hd. ornatum/R. reticulatum_ marine band beneath the Parsonage sandstone.

In Earp _et al._ (1961, p.193) it is stated that at the type locality for _R. eoreticulatum_ at Roughlee, there is no continuous section between _R. eoreticulatum_ and _R. paucicrenulatum_. "The stratigraphic position of the former is uncertain though it is believed to lie about 30' above the latter".

Price _et al._ (1963, p.193) also record crinoid columnals from the type locality of _R. eoreticulatum_, and _H. striolatum_ early form. These have not been recorded from below the _R. nodosum_ subzone by Bisat and Hudson, but crinoid debris has been noted in $R1b_i$ in the Ashover Boreholes. As the Samlesbury Bottoms _R. eoreticulatum_ locality occurs some 9.06 m (30') above $R1a_2$, an $R1b_i$ horizon does seem unlikely. The occurrence of _H. striolatum_ early form at the type locality suggests a position high in R1b. Crinoid columnals are also common in $R1b_v$ in North Staffordshire, thus _R. eoreticulatum_ may well have been obtained from the $R1b_v$ marine band, (or at least high R1b), as also concluded by W.H.C. Ramsbottom. This would explain the difference between the $R1b_i$ specimens and the lectotype.

Most records of _R. eoreticulatum_, however, indicate that this form or forms similar may occur throughout R1b, and are most common in the lower horizons (Hudson and Cotton, 1943, Ramsbottom et al., 1962).

THE $R1b_{ii}$ MARINE BAND

Only three definite $R1b_{ii}$ marine band localities are known, and all of these have a poorly preserved fauna of R. moorei/nodosum group, accompanied by Hd. ornatum. Homoceras of the henkei/ striolatum group is extremely common and occurs to the exclusion of Reticuloceras in most of the marine band. The Blake Brook locality (recorded as R1b by Holdsworth, 1963a) has yielded forms referable to R. cf. nodosum showing umbilical plications. At the Thorncliff locality, specimens of R. cf. nodosum (Pl. 1.11a) show regular bifurcation of the primary ribs and interpolation of one striation. The concentric ornament is not pronounced (less so than in $R1b_{iii}$ specimens of R. nodosum) and occurs only weakly on the lingua. R. cf. moorei (Pl. 1.11b) shows more irregular bifurcation of the ribs and interpolation of the striations. A concentric ornament is developed on the lingua and between the radial ornament nearer the umbilicus. Rarer forms referable to R. cf. eoreticulatum occur at loc. 050 where Homoceras and Caneyella are abundant.

The fauna of this marine band is known only from poorly preserved material and could easily be confused with that of $R1b_{i}$. As in the case of $R1b_{i}$, the marine band has often been identified by its occurrence in the total sequence and its distance above $R1a_{2}$, rather than by the thicker-shelled goniatite fauna alone. A few fragments of coarsely ornamented individuals have been noted in $R1b_{ii}$, and the ornament of R. cf. moorei and R. cf. nodosum is also coarser than R. aff. eoreticulatum of $R1b_{i}$. Better material is needed, however, to distinguish between these two marine bands on the goniatite fauna alone.

Plate 1.11

1.11a *Reticuloceras* cf. *nodosum* Bisat and Hudson

x12

Locality: Thorncliff stream (051$_1$)

Impression of external ornament of shell showing bifurcation of ribs and interpolation of one striation. A discontinuous spiral ornament occurs between the radial ribs on the lingua in most specimens.

1.11b *Reticuloceras* cf. *moorei* Bisat and Hudson

x11

Locality: Thorncliff stream (051$_2$)

Impression of external ornament in shale showing irregular bifurcation and interpolation of ribs and striae.

Pl. 1.11

a

b

THE $R1b_{iii}$ MARINE BAND

Lithology and preservation of the fauna

In the Ashover Boreholes, the marine band correlated with that which contains the holotype of *R. nodosum* is split by an *Anthracoceras*/*Dimorphoceras* and spat phase. This has not been detected at the exposures in North Staffordshire, possibly as preservation is poor, and specimens have been obtained from bullion limestones only, at most exposures. A matted *Dunbarella* horizon has been found above the marine band. The $R1b_{iii}$ marine band has not been identified with certainty in the Blake Brook. It may be faulted out, or represented only by an ankerite horizon which contains specimens of thinner-shelled goniatites only. The marked change in the fauna could be attributed to the local pre-$R1b_{v}$ development of protoquartzites in the section (Chapter 3).

Calcite bullions containing a sponge fauna, *H. spiraloides* and *R. nodosum* are well developed at the locality of the holotype of *R. nodosum*. Except for the absence of *H. spiraloides*, a similar fauna has been found in the Thorncliff section (056) preserved in ankerite bullions. The same sponge -- with umbrella-shaped hemidiscs distinctly different from the typical sponge fauna of the $R1a_2$ marine band -- also occurs at the Heath Hay locality (055) with *R.* aff. *nodosum* and *H. spiraloides* in calcite bullions. This locality was recorded as R1b in Evans *et al.* (1968, loc. 159b).

Fauna of the R. nodosum marine band

Reticuloceras nodosum Bisat and Hudson

R. aff. *nodosum* Bisat and Hudson

R. eoreticulatum group

Homoceras striolatum (Phillips) early form

Homoceras spiraloides Bisat and Hudson

Orthocone nautiloids

Fish scales

Microfauna of typical spumelline radiolaria, spat, and a new sponge species.

Description of the goniatite fauna

Reticuloceras nodosum Bisat and Hudson

Reticuloceras nodosum Bisat and Hudson, 1943, p.414-415, pl. xxix, figs.5a-b.

Material

"Solid" specimen from weathered ankerite, and impressions of the external ornament of the conch in the ankerite from loc. 056 (Thorncliff section).

Description

Plications at the umbilical edge are most marked at less than 9 mm diameter (ventral). The plications bifurcate at the umbilical edge at 9 mm diameter and one secondary rib is interpolated between the sets of bifurcating primaries. The lingua is not marked at this diameter,projecting only 0.5 mm. The hyponomic sinus is v-shaped, but shallow at this stage. The umbilical edge is rounded, and four constrictions per whorl are present as in the holotype at the same diameter. The strength of the ornament on the venter is comparable with the holotype also, but the whorl height in the figured holotype appears to be somewhat greater than the specimen in question. Four variants of R. nodosum are also described by Bisat and Hudson.

Spec. no.	Ventral diameter	Umbilicus diameter	Umbilicus as % of diameter	Striae/ mm L.	Striae/mm venter
056_1	9 mm	4.1 mm	45%	3	2-3
Holotype	9	-	44%	-	3

The fourth variant is a more depressed form with striae at two/mm at the venter instead of three. Thus the specimen may have more affinity with the variant than the holotype. The umbilical width, however, is 45% of the ventral diameter, compared with 44% in the holotype, thus these forms are thought to be comparable.

A fragment of a second specimen (056_2), preserved as an impression of the external shell ornament, shows strong umbilical plications at about 16 mm diameter (ventral). These plications bifurcate at the umbilical edge and a secondary rib is interpolated. The depth of the lingua is 0.75 to 1.0 mm, slightly greater than in 056_1, and the hyponomic sinus is 0.75 mm deep. A concentric ornament is present on the flank and lingua, and one constriction in the quarter whorl seen. The ornament is, however, coarser. Two striations per mm occur on the lingua compared with three at 9 mm ventral diameter in 056_1. 056_2 is probably one of the variants of *R. nodosum* (see below).

Reticuloceras aff. *nodosum* Bisat and Hudson

Locality: Heath Hay Ravines, loc. 055.

Material

One "solid" specimen (Pl. 1.12a). Small serpenticone forms also occur, up to 3 mm in diameter at the venter.

Description

As in the specimen of R. nodosum, constrictions are well developed (two can be seen in the half whorl, Pl. 1.12a). The ribs bifurcate from plications at the umbilical edge, and one rib of equal strength to the bifurcating ribs is interpolated almost to the umbilical edge between the plications. The lingua projects 1.0 mm forwards at 13 mm ventral diameter, and a spiral ornament is diffused over the flank and lingua, becoming less well marked at the umbilical

Spec. no.	Ventral D.	Umbilical D.	Striae/mm L.	Striae/mm venter
055	13.0 mm	4.5 mm	2	2

edge. The spacing of the radial ornament is somewhat coarser than in R. nodosum, averaging 2/mm, and the umbilicus is reduced to approximately 30% of the ventral diameter. This form is similar to 056_2, and may correspond most closely to an R. nodosum variant described by Bisat and Hudson (1943, p.415) as, ". . . a slightly stouter form with a smaller umbilicus and short plications, with the ornament radial on the inner half of the flank". It may be noted in Plate 1.12a that the ribs are virtually radial in contrast to 056_1 where the ribs bend slightly forwards.

Reticuloceras eoreticulatum group

For synonomy of R. eoreticulatum see p. 68.

More delicately ornamented specimens of Reticuloceras which are not referable to the R. nodosum group also occur in $R1b_{iii}$, and are best referred to the R. eoreticulatum group. R. eoreticulatum has not been recorded in Swint Clough ($R1b_{iii}$), but was identified as an involute form in the Ashover Boreholes (Ramsbottom et al. 1962, p.12). Several specimens were found at loc. 053, and a single "solid" specimen at 056.

Spec.	Diameter (ventral)	Projn. L.	Striae/mm L.	Depth Hy. sinus
056	20 mm approx.	0.75 mm	4-5	1.5 mm

This is a finely ornamented involute form with a weak development of the spiral ornament on the lingua only. These features and the poor development of the lingua suggest similarity with R. eoreticulatum, but the spiral ornament persists longer than in the lectotype.

Homoceras striolatum (Phillips)

Goniatites striolatus Phillips, 1836, p.234, pl. xix, figs.14-18 (in Bisat and Hudson, 1943)

Goniatites obtusus Phillips (partim.), 1836, p.234, pl. xix, fig.12 (in Bisat and Hudson)

Goniatites striolatus Phillips. Brown, 1837-1849 (1847), p.28, pl.xxi, figs.9,9a,10 (in Bisat and Hudson)

Glyphioceras phillipsi Foord and Crick, 1897, p.172

Homoceras striolatum (Phillips) (partim.). Bisat, 1924, p.107, pl.x, fig.3)

Homoceras striolatum (Phillips). Bisat and Hudson, 1943, p.407, pl. xxvii, fig.1

Homoceras striolatum (Phillips) early form

Material

Homoceras occurs commonly in $R1b_{iii}$, but is less abundant than the Reticuloceras fauna -- in contrast to $R1b_{ii}$. Most specimens are crushed in shale and the umbilical ornament obscured. A single "solid" specimen was obtained from the weathered outer part of an ankerite bullion at loc. 056 and is described below.

Description

The specimen is approximately 10 mm in diameter at the venter. There is no inflexion of the ribs into a hyponomic sinus or a lingua at this diameter. Two prominent concentric rings of nodes, where the ribs are thickened, occur at the umbilical edge, and a third ring is seen on the abruptly sloping umbilical wall. One constriction is present in the quarter whorl preserved in detail (Pl. 1.12b).

Identification

Homoceras henkei and Homoceras striolatum can be distinguished from each other by the more openly sloping umbilical wall in H. henkei and stronger twisting of the striae at the umbilical margin around the concentric rings in H. striolatum. The feature of the openly sloping umbilical wall is well illustrated in a specimen of H. henkei figured by Hodson (1957, pl. E, fig.5), and a comparison of this feature with that of the specimen figured here shows a marked difference in slope between the two forms, although three concentric rings of nodes are developed in both specimens at comparable diameters. Neither specimen shows a lingua or hyponomic sinus. The striae around the umbilicus in the specimen figured here are hardly more twisted than in the specimen figured by Hodson, and this feature is certainly not as pronounced as in the specimen of H. striolatum figured by Bisat and Hudson (1943, pl. xxvii, fig.1). Thus it is concluded that the specimen in question is intermediate between H. henkei and H. striolatum, the slope of the umbilical wall suggesting affinity with H. striolatum. As earlier forms of H. striolatum have transverse striae straighter over the margin than in H. striolatum s.s., the specimen has been referred to H. striolatum early form.

Plate 1.12

1.12a *R. nodosum* Bisat and Hudson

x10

Locality: $R1b_{iii}$ marine band, Heath Hay

Ravines (055_3)

"Solid" specimen showing the external ornament.

1.12b *Homoceras striolatum* (Phillips) early form

x7

Locality: Thorncliff stream, $R1b_{iii}$ (056_3)

"Solid" specimen from weathered ankerite showing

umbilical ornament.

Plate 1.13

1.13a *R. nodosum* Bisat and Hudson

x6

Locality: Upper Churnet tributary stream (052_6)

Impression of external shell ornament in shale.

1.13b *R. nodosum* Bisat and Hudson

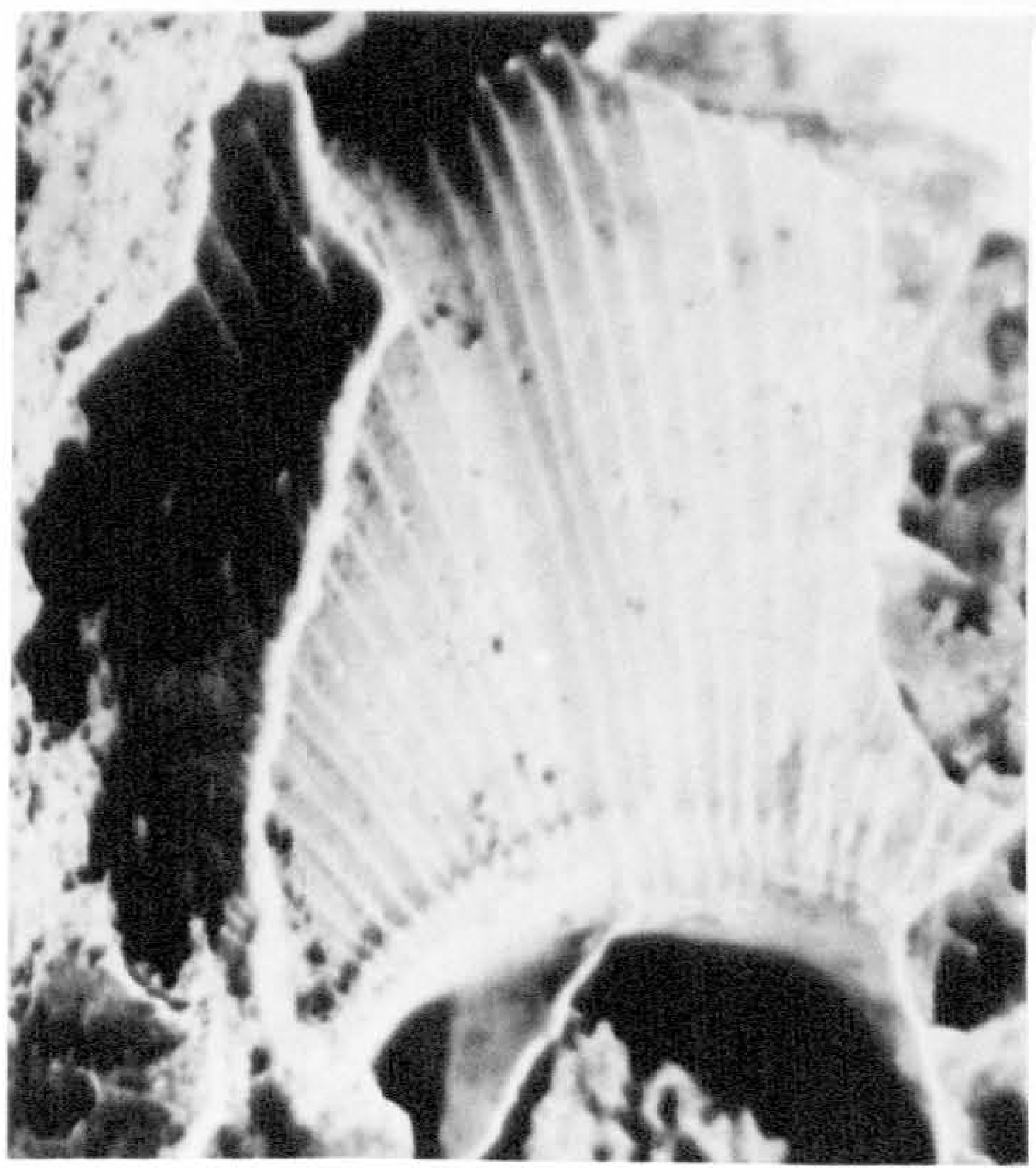
x9

as above, showing impression of ornament on

lingua and venter. (052_7)

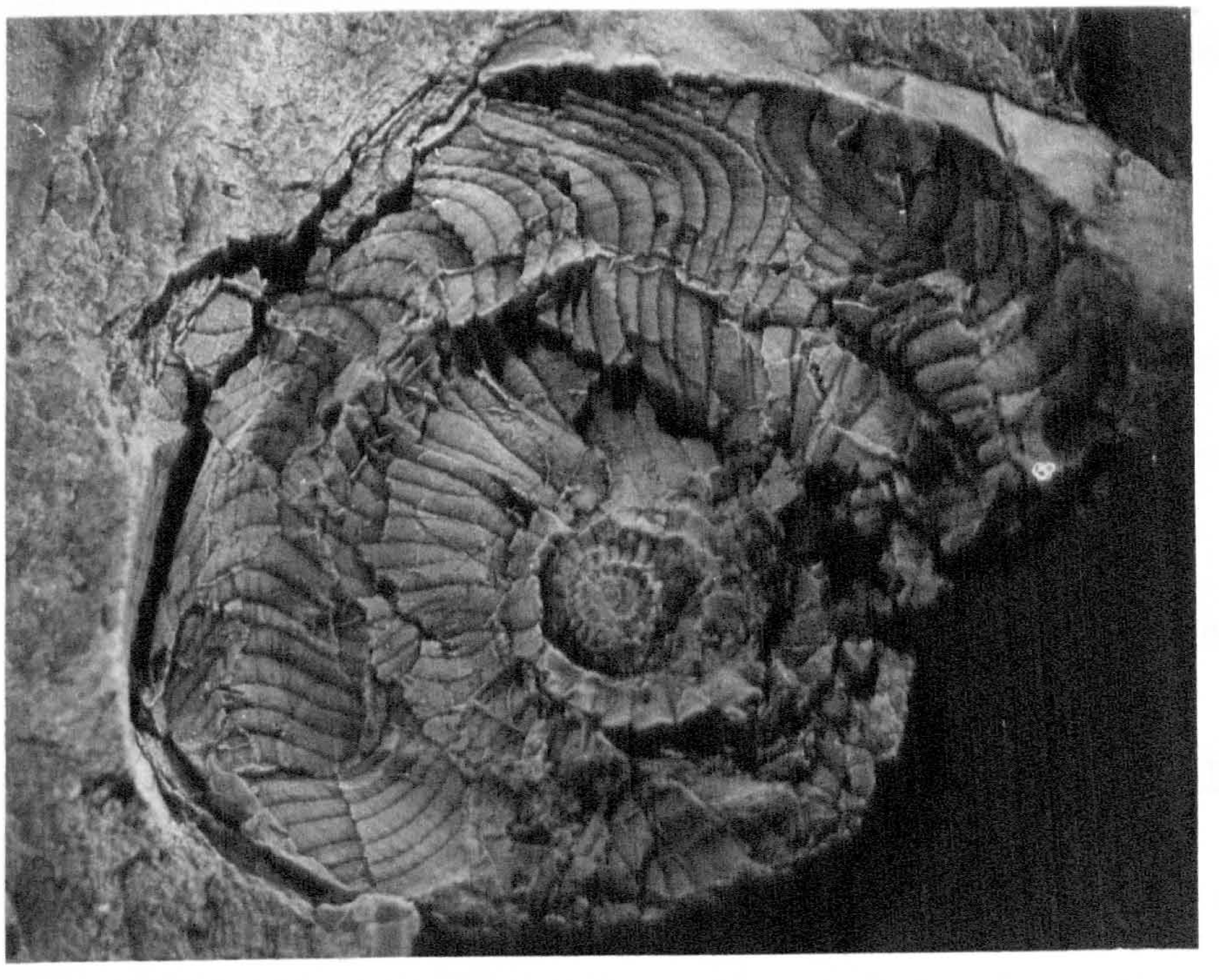
Pl. 1.12

a



b

Pl. 1.13



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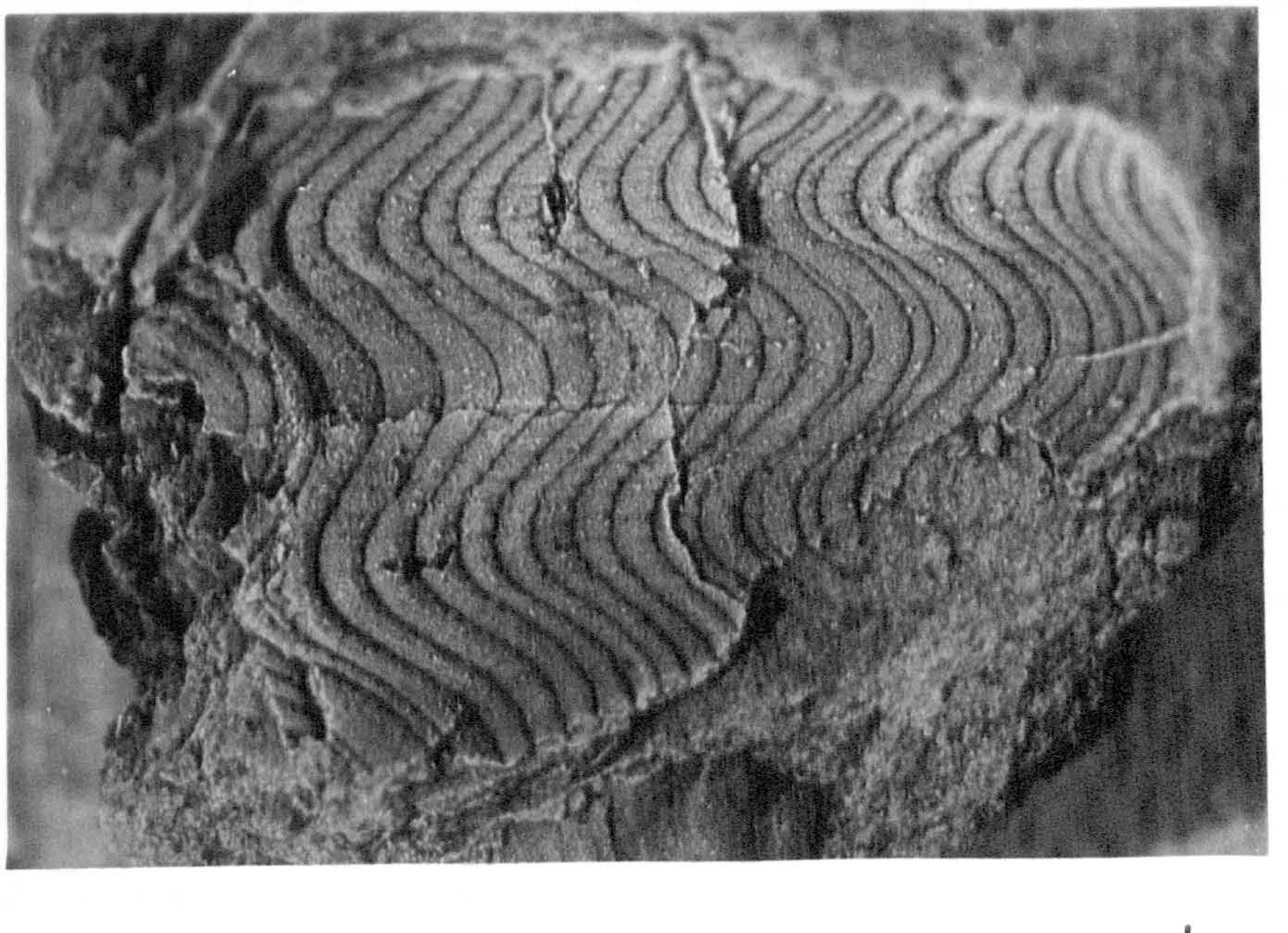


b

Homoceras spiraloides Bisat and Hudson

Homoceras spiraloides Bisat and Hudson, 1943, pl. xxx, fig.3, p.407-8.

Material

Two "solid" juvenile specimens from 055. One internal mould from Swint Clough (057), and impressions of the external shell ornament.

Description

The dimensions of the specimens compare with those tabulated by Bisat and Hudson except in the case of 055_2, which appears to have a slightly greater thickness. The umbilical edge, seen in a specimen of an internal mould, is more acute than is suggested by Bisat and Hudson. This particular specimen is from the locality of the holotype.

Specimen	Diameter (ventral)	Thickness	Umbilical diameter	Projn. L.
Bisat and	4.0 mm	2.5 mm	2.0 mm	
Hudson 1943,	5.0	3.0	2.5	
p.408	11.0	6.5	3.5	
	30.0	16.0	5.0	
055_1	7.5	4.5	2.5	0.2 mm
055_2	13.0	7.5	3.0	0.4
057	15.0	7.5	3.5	-
	19.0	10.0	4.0	-
	25.0	-	4.75	-

The umbilical ornament in the specimens described here is unlike that of the Homoceras henkei/striolatum group as it lacks the concentric ornament of umbilical nodes. This type of umbilical ornament was not noted by Bisat and Hudson in their description of H. spiraloides, and is presumably absent. The external ornament in the specimen from the type locality and in those from 055, shows delicate radial ribs which do not bifurcate. The lack of bifurcation and the delicate ornament indicate that this form is unlikely to be Reticuloceras.

Subordinate spiral striae are barely visible at 7 mm diameter, become more marked at 13 mm diameter and are pronounced on the lingua at 19 mm diameter, a feature characteristic of adult specimens of H. spiraloides. The lingua is not developed in the specimen at 7 mm diameter, the ribs forming only a slight inflexion. At 13 mm diameter, the lingua is slight, but is more pronounced than in H. striolatum at the same diameter. The lingua is, however, less well developed than in all Reticuloceras specimens. Transverse undulations occur on the outer shell ornament due to the bundling of the transverse striae, confirming the identity of the specimens as H. spiraloides.

Note on the fauna of loc. 052, Upper Churnet

This is an isolated exposure only, and its position in R1b thus difficult to determine. The fauna indicates a position equivalent to $R1b_{iii}$. R. nodosum group is too abundant for the marine band to be that of $R1b_{i}$ where no definite R. nodosum group specimens were found, and the apparent absence of Hd. ornatum and paucity of Homoceras indicate that it is unlikely to be $R1b_{ii}$. The fauna is briefly described because preservation is good and the marine band's position tentatively identified. The fauna is variable, both fine and coarsely ornamented forms occurring with intermediate examples.

R. aff. eoreticulatum: loc. 052_{3}

This is a finely ribbed involute form showing regular bifurcation of the ribs and less regular interpolation of striations. Concentric striae die out on the lingua at 12 mm diameter (lingual). At 16 mm diameter the striae occur at 6/mm, and the lingua is 1.3 mm deep.

R. aff. nodosum

Spec. no.	Diameter	Projn. L.	Striae/mm Lingua
052_1	16.0 mm	1.8 mm	2
052_2	13.0	0.9	1-2
052_4	14.0	1.0	2
052_6	14.0	0.8	2

Coarsely ribbed specimens from this locality have been assigned to *R.* aff *nodosum*. They show interpolation of secondary ribs between sets of bifurcating primaries, though in some cases bifurcation is somewhat irregular. The concentric ornament on the lingua is pronounced, but subordinate to the radial ornament (Plate 1.13a), a feature typical of *R. nodosum*. Constrictions are seen in smaller specimens which have forwardly directed umbilical nodes. A ventral impression of the external ornament (Plate 1.13b) shows a v-shaped hyponomic sinus, also seen in Bisat and Hudson's holotype of *R. nodosum*. This feature becomes marked in *R. moorei* at 20 mm diameter, but no specimens of *R. moorei* are known elsewhere in the $R1b_{iii}$ marine band, and the ornament is too coarse for typical specimens of *R. moorei*. The ornament is also somewhat coarse for *R. nodosum*, only 2 striae per mm occurring at the venter instead of three. A coarsely ornamented form of the *nodosum* group, with striae running at 2 per mm on the venter commonly occurs in the $R1b_{iii}$ marine band, and may be similar to the forms described above.

THE $R1b_{iv}$ MARINE BAND

Fauna

This marine band is poorly developed in the North Staffordshire area, and rarely contains a goniatite fauna. The marine band contains a fauna of lamellibranchs (*Caneyella* and *Dunbarella*) in the Dane area.

At Thorncliff, only the upper part of the band is exposed, and indeterminate goniatites are present. There is some evidence from the Brund Boreholes (S.E. of Longnor) that coarsely ornamented goniatites, possibly of the R. stubblefieldi group, occur in this marine band, which may be that of the holotype of R. stubblefieldi (p. 85).

Localities

River Dane, 059. Caneyella, Dunbarella.

Bearda, 058. Homoceras sp., Caneyella, Dunbarella.

Thorncliff, 060. Indeterminate goniatites.

Swythamley section, 061. Thinner-shelled goniatites only in top few centimetres exposed.

THE R1b MARINE BAND

Lithology and preservation of the fauna

Around North Staffordshire, a sparsely fossiliferous ankerite occurs near the base of the marineband, just below the level of the kaolinised ash bands (see below). The most fossiliferous part of the marine band occurs immediately above an ankerite, at the level of the ash bands where the shales are extremely dark in colour, although frequently coarser grained than the normal marine band shales, with abundant flakes of mica (possibly derived from the ash bands). At this horizon the fauna typically consists of Hd. ornatum (which tends to be more common in the darker shales of the R1b marine bands generally), crinoid remains and other thicker-shelled goniatites preserved as impressions of the external ornament. R. prereticulatum sp. nova (no.2) is most common at this horizon in the field exposures -- as in the Brund Boreholes -- R. stubblefieldi and Reticuloceras sp. nova (no.3) occurring higher in the marine band where thicker-shelled goniatites are less common and Hd. ornatum absent.

The kaolinised ash bands

The R1b$_v$ marine band at Swint Clough contains two thin, light-coloured bands of volcanic origin, consisting largely of pyrites, kaolinite and mixed-layer montmorillonite. These two bands persist in a slightly thinned sequence in the same marine band in North Staffordshire and adjacent areas, where they occur from 5-8 cm apart compared with 0.45 m in Swint Clough.

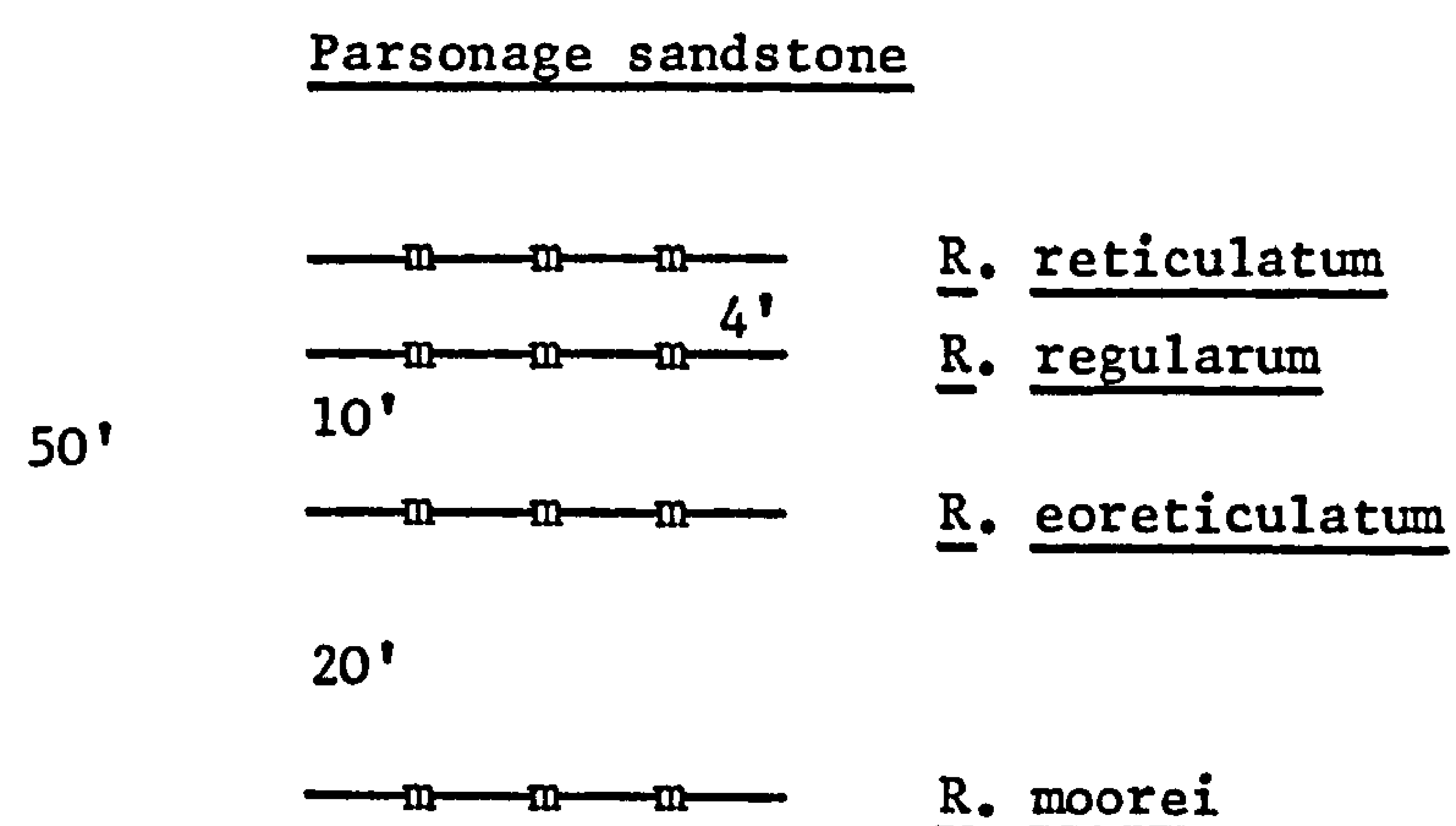
There is no indication of these two bands in the Ashover Boreholes (Ramsbottom *et al.* 1962), although the bands tend to be pyritic and bentonites (which have a similar origin to the kaolinised ash bands) recorded by Trewin (1968, 1969) were frequently noted as pyritic streaks in the borehole logs.

The thickness of the bands in R1b$_v$ is variable, ranging from a maximum of 8 mm to thin streaks only 1 mm in width. At two localities, thought to be R1b$_v$, these streaks disappear completely. Although theoretically unlikely, in view of their origin this must in fact be the case, as the typical R1b$_v$ fauna has been found at both localities. The disappearance of the ash bands is also supported by the known thinning of these bands to only 1 mm, the same phenomenon having been observed in R1a$_1$. It is impossible to see the pyritic bands where they are reduced to thin partings and conditions are unsuitable, eg. in water-logged shales. This may well be the cause of their apparent disappearance at loc. 071, although they are definitely absent at Bearda where exposure is good.

Stratigraphic position of R. moorei and R. stubblefieldi

R. moorei and *R. stubblefieldi* both occur in R1b$_v$, but there is some uncertainty over the exact horizon of the holotypes of these two species. The exact position of the holotype of *R. stubblefieldi* within the *R. nodosum* subzone is not known with certainty because the locality of the holotype fails to provide any more information on the succession. Bisat and Hudson (1943, p.389) suggest that the horizon of *R. stubblefieldi* is in fact that of the *Hd. ornatum* ($R1b_v$) marine band in Swint Clough or the preceding one ($R1b_{iv}$).

The type specimens of *R. moorei* were obtained from 15.1 m (50') beneath the Parsonage sandstone at Samlesbury Bottoms. 6.04 m (20') of the succession above *R. moorei* is obscured, and the number of marine bands beneath the *R. moorei* locality not clear. 6.04 m (20') above *R. moorei*, a marine band with *R. eoreticulatum* is exposed, followed by one with *Hd. ornatum* and *R. reticulatum* 3.02 m (10') higher in the succession.



R. regularum has been recorded 1.4 m (4') below *R. reticulatum* (Price *et al*. 1963, p.14, 16). This form may occur in the highest R1b marine band as *R. regularum* occurs with *R. stubblefieldi* at Swint Clough and in Co. Clare, Ireland (Hodson 1953). This would suggest that the *R. moorei* horizon is $R1b_{iv}$. Bisat and Hudson (1943, p.394), also record *R. moorei* below a marine band containing *R.* cf. *stubblefieldi* at Ewood Clough.

R. stubblefieldi and *R. moorei* group faunas occur frequently in $R1b_v$, but have not been noted in $R1b_{iv}$ where goniatites are rare. There is some evidence from the Brund boreholes (p.154) that coarsely ornamented forms, possibly of the *R. stubblefieldi* group, do occur in $R1b_{iv}$, suggesting that this could be the horizon of the holotype. The fauna of R1b, however, apparently evolved relatively slowly (p. 59), and it is possible that the fauna of $R1b_{iv}$ and $R1b_{v}$ is similar. The abundance of *R. stubblefieldi* in $R1b_{v}$ in North Staffordshire suggests that this is the horizon of the holotype. Conversely, only a single typical specimen of *R. moorei* occurred in $R1b_{v}$ in the Brund Boreholes, and such specimens are also rare in $R1b_{v}$ in North Staffordshire suggesting that the horizon of the holotype of this species may well be $R1b_{iv}$. Previous records of *R. moorei* show that this form or forms similar occur in $R1b_{v}$ in Swint Clough, and in the Ashover Boreholes, recorded as *R.* cf. *moorei* (Ramsbottom *et al.* 1962, p.123). The Highoredish borehole also yielded specimens of *R. eoreticulatum/ moorei* group in $R1b_{i}$ and *R. moorei* group in $R1b_{iii}$ (*ibid.* p.102). Forms similar to *R. moorei* may range over the whole of R1b, but *R. stubblefieldi* is restricted to the two topmost marine bands.

In the Macclesfield area, Evans *et al.* (1968, p.53, locs. 143b-c), recorded two marine bands containing *R.* cf. *stubblefieldi*, the upper one containing *R. regularum* as at Swint Clough ($R1b_{v}$) and the lower one containing *R.* cf. *moorei*. The lower Macclesfield band is the equivalent of Staffordshire's $R1b_{v}$, so that it is possible that *R. stubblefieldi*-like forms range higher than $R1b_{v}$, particularly as the correlation of $R1b_{v}$ with the *Hd. ornatum* ($R1b_{v}$) band of Swint Clough is again substantiated by the occurrence of the kaolinised ash bands.

Ramsbottom (Ramsbottom *et al.* 1962, p.123) notes an *R. nodosum* group fauna above the equivalent of $R1b_{v}$, separated from $R1b_{v}$ by a *Dunbarella* and spat phase, so that it is possible that the higher of the two Macclesfield Memoir *R. stubblefieldi* could be the equivalent of this marine phase and still be pre-R1c.

Identification of R. moorei and R. stubblefieldi

Identification of "solid" specimens is based upon the evolute nature of *R. stubblefieldi* compared with the more involute and compressed *R. moorei*. Recognition of the crushed specimens in shale is more difficult because the pattern of the rib interpolation was not described by Bisat and Hudson (1943). The holotype of *R. stubblefieldi* shows irregular, infrequent interpolation of striations between sets of bifurcating primaries. The ornament of *R. moorei* is more irregular than that of *R. stubblefieldi*, showing occasional trifurcation of the primaries as well as bifurcation, and more frequent, though still irregular; interpolation of a secondary rib. The distance from the umbilicus to which secondary striae are interpolated at different diameters, and the distance of the point of bifurcation of the primary ribs from the umbilical edge, appear in both forms to be similar. Interpolation and bifurcation of the ribs takes place at the umbilical edge or up to one third of the distance up the flank in both *R. moorei* and *R. stubblefieldi* at comparable diameters.

In the specimens of the holotypes of *R. moorei* and *R. stubblefieldi*, concentric striations are diffused over the flank, become accentuated on the lingua and less so on the venter. The direction of the ribs is also similar, being at first radial or bent slightly backwards in *R. stubblefieldi* (Bisat and Hudson 1943, p.414) and radial in *R. moorei*, ". . . with little or no backward bowing of the striae on the flank" (*ibid*. p.413).

Owing to the similarity of the ornament, distinction of *R. moorei* from *R. stubblefieldi*, except in well preserved specimens, is based largely on the degree of involution of the conch. Ramsbottom (in Ramsbottom *et al*. 1962, p.123) distinguished crushed specimens of *R.*

moorei from R. stubblefieldi by referring more widely umbilicate forms to the latter and involute forms to R. moorei.

In practice, the more widely umbilicate forms are generally more coarsely ornamented although Bisat and Hudson (1943, p.413) state that in R. moorei coarser variants may occur, and that specimens with a finer ornament than R. stubblefieldi occur with the latter, exhibiting affinity with R. moorei, but having a weaker concentric ornament.

Fauna of the $R1b_v$ marine band

The fauna of this marine band is identical to that of the Hd. ornatum band in Swint Clough. This locality was recorded by Bisat and Hudson (1943, p.389) who identified R. aff. moorei, R. cf. regularum, R. cf. stubblefieldi and Hd. ornatum. Hudson and Cotton (1943, p.155) also included H. striolatum early form, R. davisii and Homoceratoides sp. Representatives of all these forms were found as well as crinoid remains.

In North Staffordshire, the fauna is characterised by an abundance of a form described here as Reticuloceras prereticulatum sp. nov. accompanied by Ht. aff. divaricatus. More evolute and strongly ornamented forms occur higher in the marine band, and are referable to R. stubblefieldi. Specimens from the Brund boreholes showed a similar fauna, and also yielded a barely reticulate form from the top of the marine band (p.156). Crinoid columnals occur commonly at locs. 072, 070 and 067.

List of the fauna

R. prereticulatum sp. nov. (no.2)

R. stubblefieldi Bisat and Hudson

R. sp. nova (no.3, see Appendix to Palaeontology)

R. moorei Bisat and Hudson

Homoceratoides aff. *divaricatus* (Hind)

Crinoid remains

Caneyella

Homoceras sp.

Description of the fauna

Reticuloceras prereticulatum sp. nov.

Localities: Thorncliff stream, loc. 072

Swythamley, loc. 071

Bearda, loc. 067

Material

The form occurs most commonly near the base of the marine band. All specimens are crushed in shale and show the external ornament of the shell. Holotype: 071_{3c} paratypes: $071_{3a \text{ and } b}$ and 071_7

Description

Fragments of the ornament from individuals less than 15 mm in diameter show regular bifurcation of the ribs at the umbilicus at an extremely narrow angle. In larger specimens, the ribs often appear to radiate from the umbilicus, but there is a tendency for a rib, weak at first, to diverge from a stronger one at approximately 2 mm from the umbilicus. The weaker rib becomes equal in strength to its paired rib further from the umbilicus (see spec. $071_{3a \text{ and } b}$). *R. prereticulatum* is more involute than *R. moorei* and *R. stubblefieldi* at all stages of growth. Fragments both more finely and coarsely ornamented, otherwise similar to *R. prereticulatum*, have also been noted.

Spec. no.	Diameter	Striae/mm L.	Projection L.
072_4	15.0 mm	4	0.75-1.0 mm
071_{3b}	16.0	4-5	2.0
171_{3a}	18.0	5	2.7
171_{3c}	20.0	5	3.0
067	22.0	6-7	3.2

Reticuloceras stubblefieldi Bisat and Hudson

Reticuloceras stubblefieldi Bisat and Hudson, 1943, p.415-416, pl. xxix, fig.1.

Reticuloceras cf. *stubblefieldi* Bisat and Hudson. Hodson 1953, pl. xi, fig.3.

Locality: Swythamley, loc. 071.

Material

Fragments of coarsely ribbed forms possibly referable to *R. stubblefieldi* were obtained from $R1b_v$ in Brund boreholes 1, 2 and 3. Identifiable material is generally scarce, and has only been obtained in a relatively well preserved state (impressions of the external ornament in shale) from one locality. *R. stubblefieldi* occurs most commonly above the basal 30 cm of the band where *R. prereticulatum* is most common.

Description

The specimens tend to be slightly variable in the strength of the ornament but all are widely umbilicate and coarsely ornamented. As can be seen from Plate 1.15a (specimen 071_5), the radial ornament is simpler than that of *R. moorei*, consisting of bifurcating ribs only. Interpolations are occasionally seen on other specimens, and occur periodically in the holotype, near to constrictions. All forms are more coarsely ornamented than *R. moorei*, and tend to have a more

Spec. no.	Diameter	Projn. L.	Striae/mm L.
071_6	28 mm approx.	-	1-2
071_5	25 "	2.0 mm	1-2
071_2	13	0.5	2
071_4	35 approx	-	2

pronounced concentric ornament at larger diameters. Specimen 071_5 still shows a strong concentric ornament on the lingua at 25 mm diameter, and concentric plications on the flank in the areas between the radial ribs are well marked. This feature and the coarse radial ornament is retained at 35 mm diameter. Specimen 071_5 appears to be almost identical with the holotype, and 071_4 appears to be a later growth stage of the same form. The other specimens have been referred to _R._ aff. _stubblefieldi_. Specimen 071_2 (Plate 1.14b) is probably a younger growth stage of _R._ _stubblefieldi_, and 071_6 a more coarsely ribbed variant.

Reticuloceras moorei Bisat and Hudson

Reticuloceras moorei Bisat and Hudson, 1943, p.413-4.

Reticuloceras moorei Bisat and Hudson. Price _et al._, 1963, pl. 3, fig.1 (holotype).

Material

Impression of the external ornament of the shell in shale from loc. 071.

Description

About one third of the whorl of the specimen (071, Pl.1.16a) is preserved. Faint spirals are present on the flank and near the umbilicus at a diameter of approximately 15 mm; these become less well marked at 20 mm diameter -- a feature characteristic of _R._ _moorei_ according to Bisat and Hudson. The radial ornament consists of primary ribs which may bifurcate or occasionally trifurcate. One or two striations are interpolated between the sets of primaries. The lingua is relatively shallow, somewhat similar to that of R. nodosum

Approximate lingual D.	Projn. Lingua	Striae/mm L.
20.0 mm	1.5-2.0 mm	3-4
15.0	1.5	3

and curving into a well marked hyponomic sinus. The strength of the ornament (3 striae per mm on the lingua) is the same as that described for R. moorei by Bisat and Hudson. The specimen also compares with the holotype in other features such as the form of the spiral ornament, the organisation of the radial ornament and degree of involution of the conch. The specimen is thus thought to be R. moorei. Some specimens of R. stubblefieldi group are similar in the strength of the ornament to this specimen of R. moorei, but the forms can be distinguished by the organisation of the radial ornament. That of the R. stubblefieldi group is more regular than that of R. moorei, lacking trifurcating ribs. Only one striation, if any, is interpolated between the primary ribs of R. stubblefieldi.

Homoceratoides divaricatus (Hind)

Glyphioceras divaricatum Hind, 1905, p.144, pl. vi, fig.6.

Pericyclus divaricatum (Hind), 1918, p.448, pl. xvi, figs.2-6.

Homoceratoides divaricatum (Hind). Bisat 1924, p.113-114.

Homoceratoides divaricatus (Hind). Hodson 1953, p.157-158.

Homoceratoides aff. divaricatus

Localities: Thorncliff stream section, loc. 072

Bearda, loc. 067

Swythamley, loc. 071

Swint Clough, loc. 073

Material

All specimens are crushed in shale, and have been obtained largely from loc. 072.

Description

The umbilicus in adolescent specimens (10-13 mm diameter) is narrow, attaining only 2.5 mm in diameter. The ribs are poorly defined, and slightly twisted on passing over the umbilical rim. They bifurcate regularly at only a few millimetres from the umbilical edge.

In gerontic specimens, the ribs are sharply defined, 0.2-0.3 mm thick. They form a broad lingua projecting 2.0 mm forwards at approximately 38 mm diameter. The umbilicus is narrow or may even be closed, and the ribs are twisted around it (Pl. 1.16b). Instead of an even distribution, the ribs occur in groups of four on the flank due either to bifurcation of the primary ribs near the umbilicus and interpolation of two ribs of equal strength, or trifurcation of the primaries and interpolation of one rib. Interpolation takes place high on the flank, the interpolated rib not progressing past the point of inflexion of the lingua.

Identification

The record of *Ht.* aff. *divaricatus* in $R1b_v$ in the Highoredish borehole (Ramsbottom *et al.* 1962, p.101) suggests that the $R1b_v$ *Homoceratoides* specimens described here are the same form. The description compares with that of Bisat (1924) with respect to the minute or even closed umbilicus at 38 mm diameter and small projection of the broad lingua (1 mm at 24 mm diameter). The point of bifurcation of the ribs on the flank is higher than in Hind's description, thus the Rlb_v form has been assigned to Ht. aff. divaricatus. Bisat (1924) suggested that the range of this species was from the "reticulatum" type zone (perhaps earlier) up to the Gastrioceras listeri zone. The former zone was subsequently re-defined as the eoreticulatum (now nodosum) zone, thus fragments of Ht. specimens which have been collected from Rlb_{ii} may also be assignable to Ht. aff. divaricatus.

Homoceratoides divaricatus was originally described from Foynes Island (Ireland) by Hind (1905). A specimen was figured with other goniatites of the Reticuloceras and Homoceras stages, but the horizon of the Ht. specimen not given.

Hodson (1953) found that the only occurrence on Foynes of this genus was in the horizon containing Ht. aff. prereticulatus, and there seems little doubt that the type specimen of Ht. divaricatus came from the same horizon. Ht. prereticulatus is itself variable, and the exact position of the holotype unknown. Hodson thought it likely that the two species of Homoceratoides, even if distinct, might overlap since features attributed to Ht. divaricatus also occur in Ht. prereticulatus. He states that the group as a whole stands in need of revision.

On Hodson's finings, the range of Ht. divaricatus is considerably greater than that envisaged by Bisat, and the Rlb forms may thus deviate considerably from the specimens described by Hind. Material is, however, too sporadic and fragmentary to distinguish any change up the succession, though differences may well be expected if it does range from H_2 to G.

Plate 1.14

1.14a *R. prereticulatum* sp. nov. holotype

x4

Locality: Swythamley. Specimen number (071_{3c})

Impression of external ornament in shale.

1.14b *R.* cf. *stubblefieldi* Bisat and Hudson

Locality: Swythamley. Specimen number (071_2)

Plate 1.15

1.15a *R. stubblefieldi* Bisat and Hudson

x9

Locality: Swythamley. Specimen number (071_5)

Impression of external ornament in shale.

1.15b *R. stubblefieldi* Bisat and Hudson

x8

as above, specimen number (071_4)

Plate 1.16

1.16a *R. moorei* Bisat and Hudson

x5

Locality: Swythamley. Specimen number (071_1)

Impression of external shell ornament in shale.

1.16b *Homoceratoides* aff. *divaricatus* (Hind)

x$1_{5/8}$

Locality: Thorncliff stream (072_1)

Raised external ornament in shale.

1.16c *Reticuloceras* sp. nova (no.4)

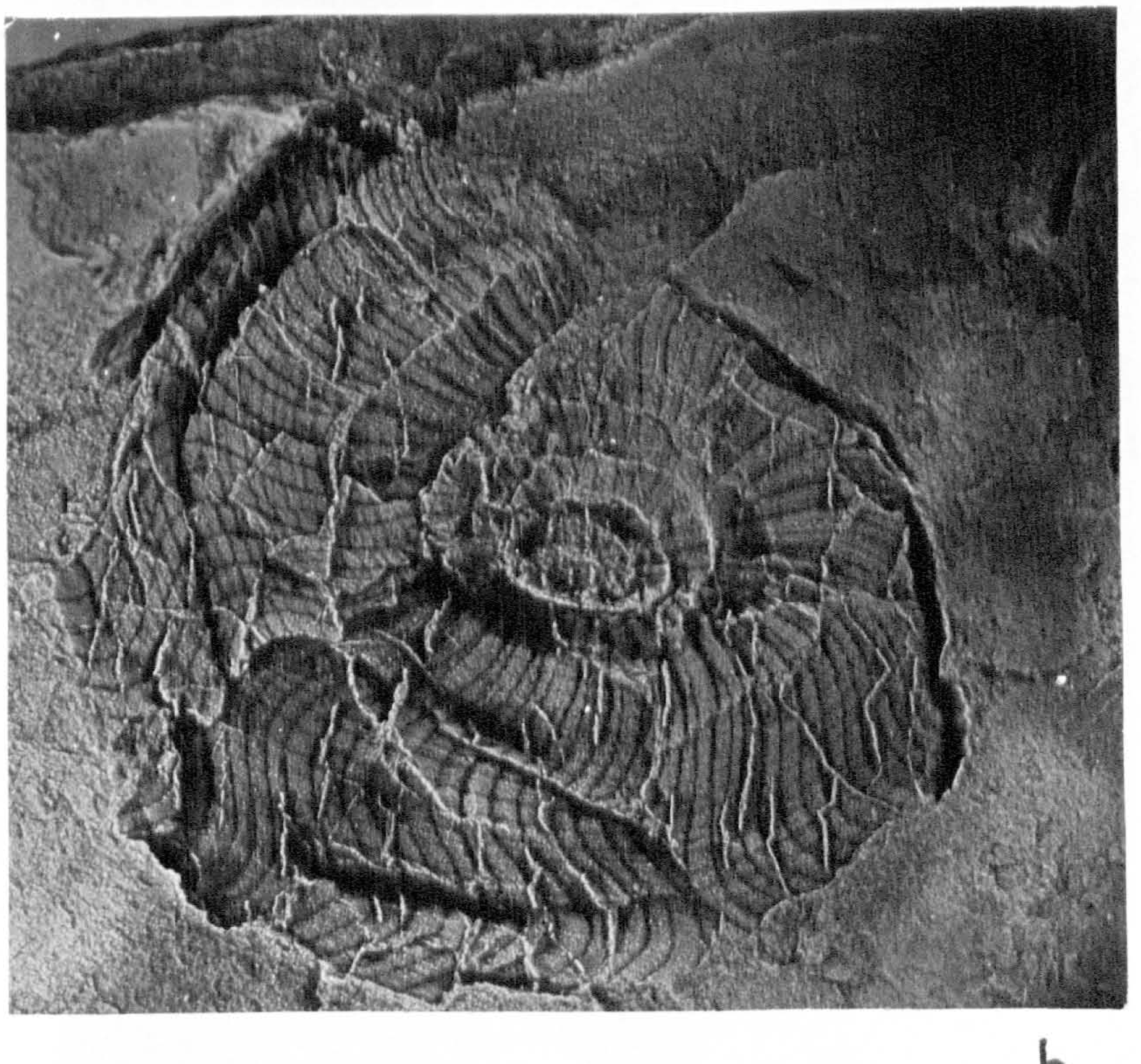
x7

Locality: Blake Brook (082_4)

External ornament of shell preserved in shale in relief.

Pl. 1.14

a



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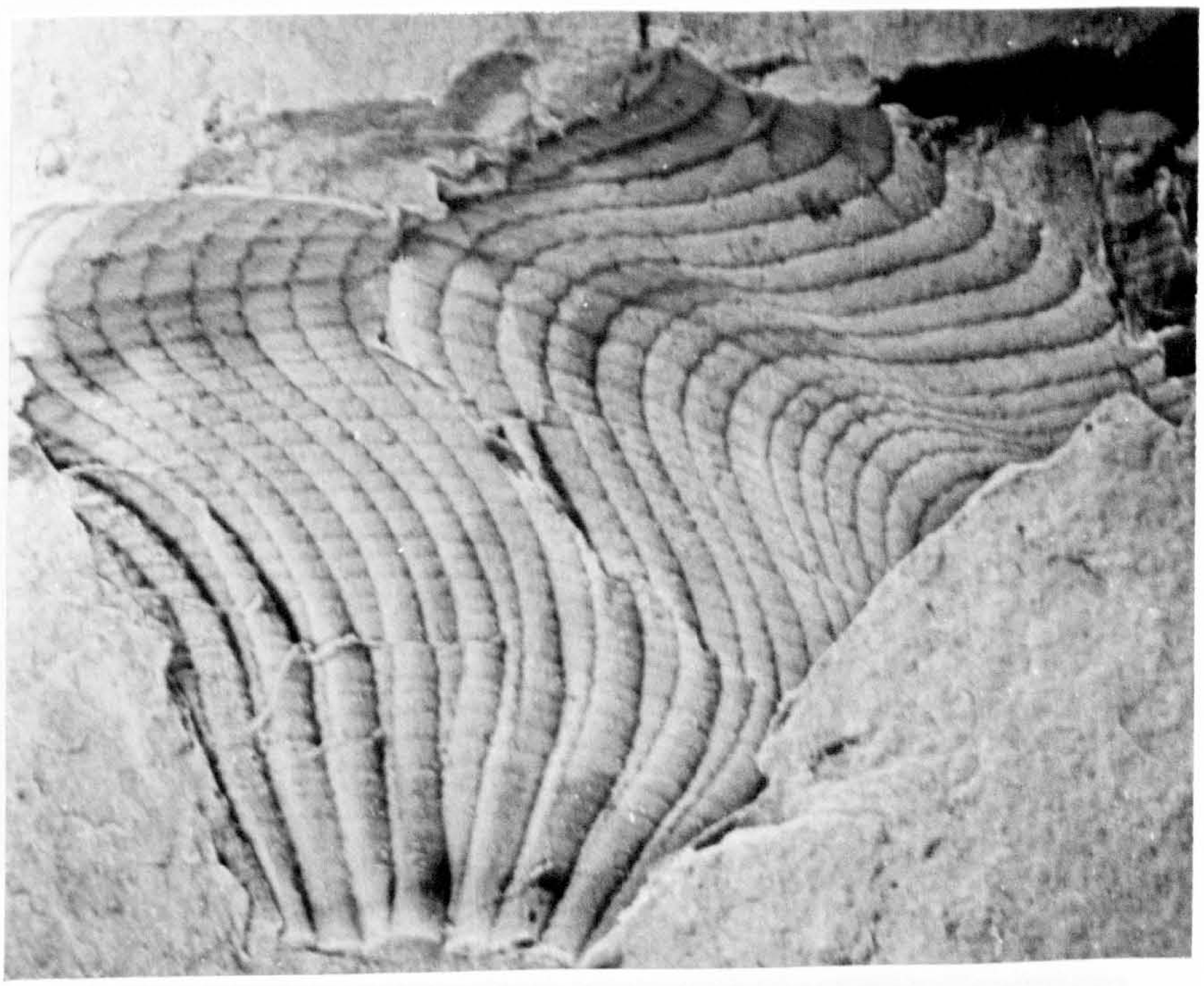
Pl. 1.15



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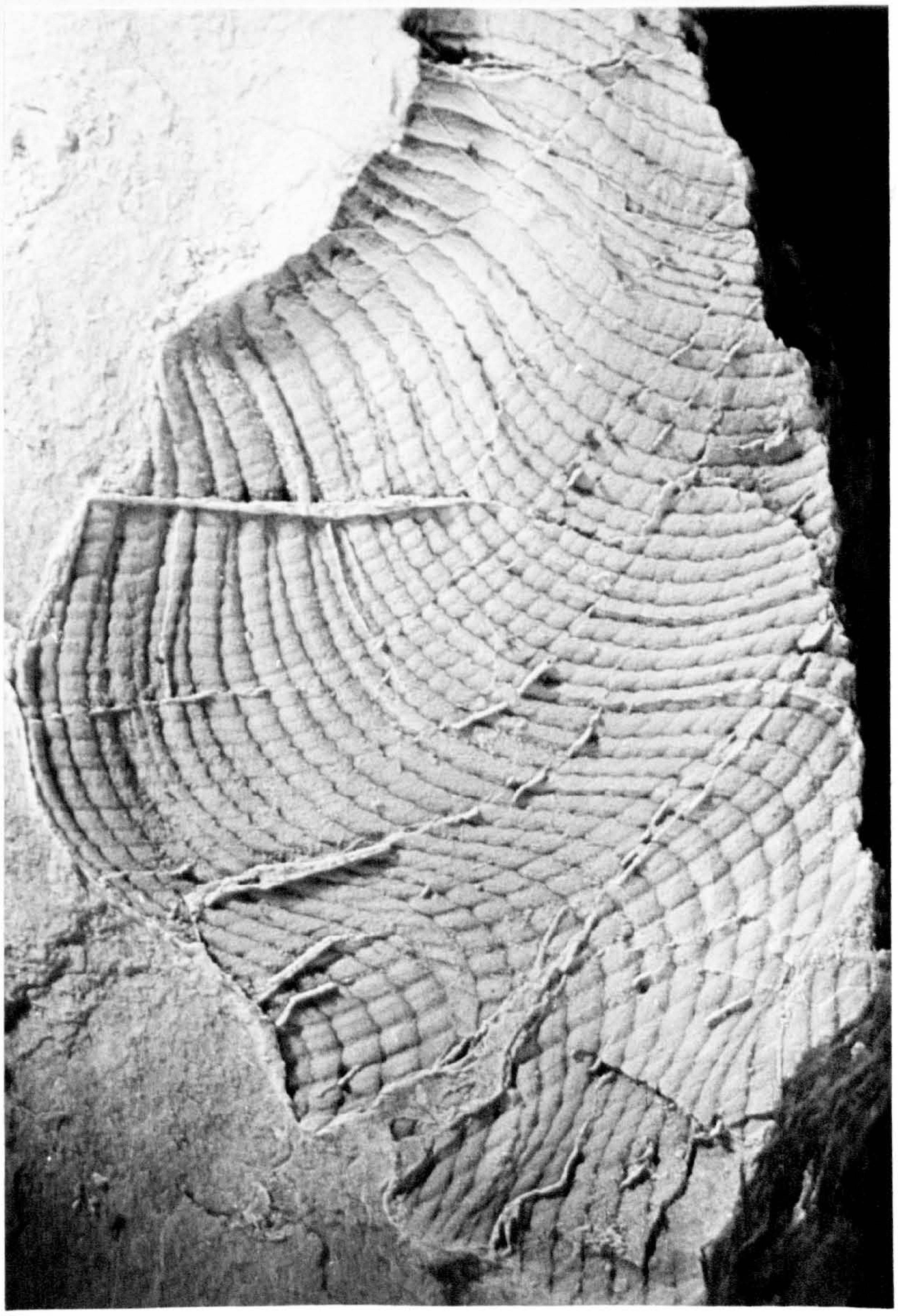
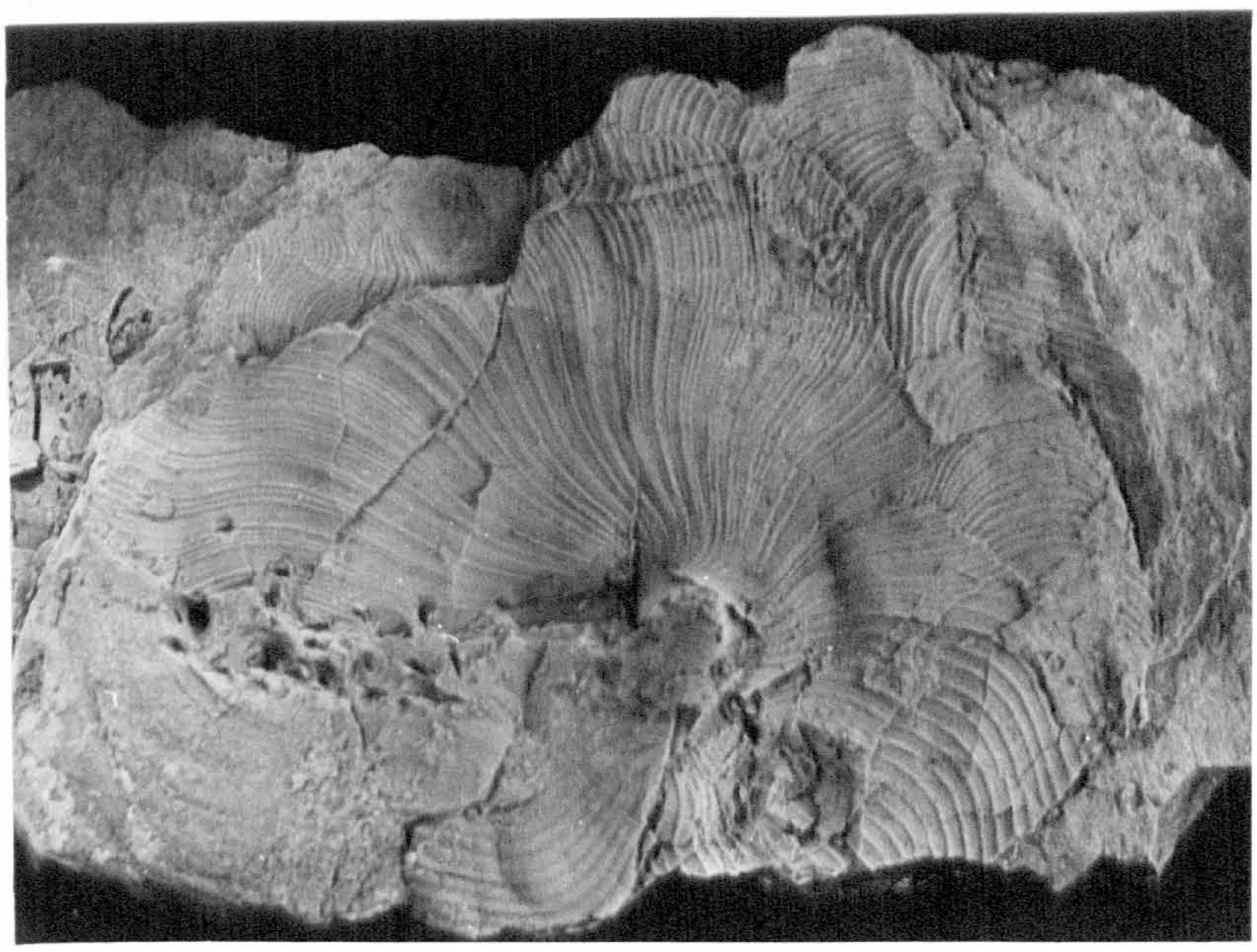


b

Pl. 1.16

a



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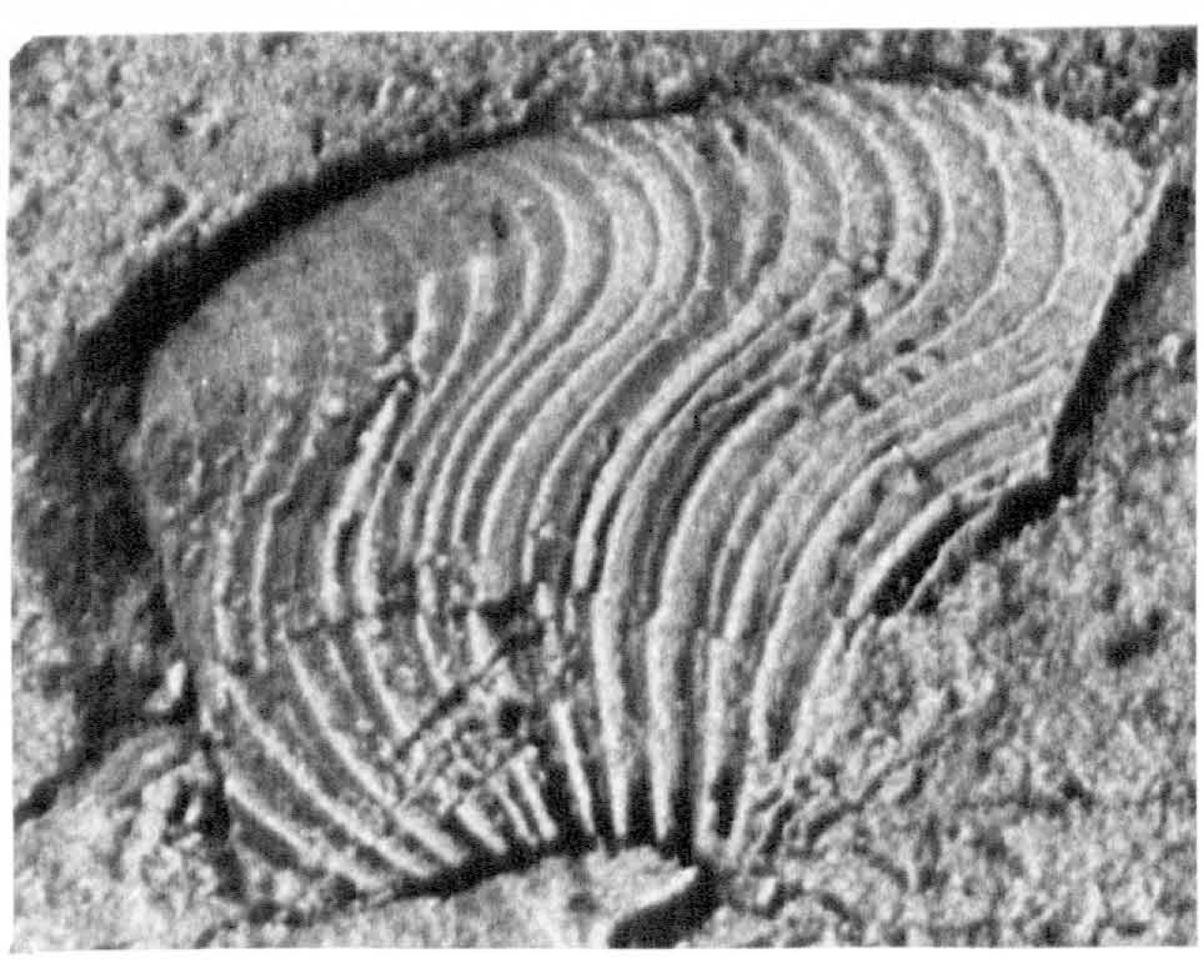


c

REVISION OF THE R. NODOSUM ZONE

The *R. nodosum* zone is currently divided into the subzones of *R. dubium* and *R. nodosum*. The *R. nodosum* fauna of $R1b_{iii}$ indicates the higher subzone, this subzone also including the faunas of $R1b_{iv}$ and $R1b_{v}$. The *R. dubium* subzone includes the faunas of $R1b_{i}$ and $R1b_{ii}$, but the eponymous subzonal index goniatite is unknown in these two marine bands in North Staffordshire. For the purpose of this account the *R. dubium* and *R. nodosum* subzones were discarded and the *R. nodosum* zone divided on the basis of the five marine bands recognised.

The stratigraphic position of *R. dubium* in North Staffordshire and the Ashover Boreholes (Ramsbottom *et al.* 1962) is immediately above *R. adpressum* or *R. paucicrenulatum*, with no break of unfossiliferous shales between the two faunas. In contrast to this situation the succession at Samlesbury Bottoms (Lancashire) is said to show an unfossiliferous shale leaf between *R. dubium* and *R. paucicrenulatum*. In Holden Beck, however, *R.* aff. *dubium* occurs only 0.61 m (2') above *R. adpressum*, and in Bottom Beck (also in the Aire Valley) *R. dubium* is associated with *R. umbilicatum* "stock" (Bisat and Hudson 1943, p.431). Although *R. umbilicatum* was not recorded in the Ashover Boreholes from immediately below the *R. adpressum-dubium* group, it has been recovered from a position below *R. paucicrenulatum* and *R. adpressum-dubium* group in the Combes. It was also recorded by Morris (1967, p.23) at the same locality. This evidence suggests that within the area of the Aire valley also, *R. dubium* may be contained within an $R1a_2$ sequence immediately above the Cayton Gill Beds ($R1a_2$).

In Namurian stratigraphical nomenclature it is convenient to define zones and subzones by the appearance of a distinctive fauna in a marine band, the base of which can be considered for practical purposes to be a synchronous time plane. The first two marine bands of R1b ($R1b_i$ and $R1b_{ii}$) do not contain *R. dubium*, which precedes $R1b_i$. The *R. dubium* subzone should therefore be discarded in name, or redefined to include the first appearance of *R. dubium*. The base of the subzone would then occur within the continuously fossiliferous sequence of the *R. paucicrenulatum* marine band. This alternative is preferable to the complete rejection of the *R. dubium* subzone because the name of the index fossil is familiar, and neither $R1b_i$ nor $R1b_{ii}$ contain distinctive goniatites which could be used as subzonal indexes.

The upper boundary of the *R. nodosum* zone may also stand in need of revision. As pointed out in Chapter 3, there appears to be some confusion over the first appearance of *R. reticulatum* and the last of the R1b goniatites, since *R. reticulatum* has been reported from what would appear to be the $R1b_v$ marine band. A revision of the goniatite fauna of the lower part of R1c is possibly needed. The R1b-R1c boundary might be better defined by the appearance of goniatites more distinctive than *R.* aff. *reticulatum*.

THE RETICULOCERAS RETICULATUM ZONE, R1c

Stratigraphy

Reticuloceras reticulatum was recorded near the base of the Mam Tor sandstones in Swint Clough by Bisat and Hudson (1943, p.389) but, as suggested in Chapter 3, this fauna may be very close to that of $R1b_v$. *Reticuloceras* cf. *reticulatum* s.s. was also recorded by Bisat and Hudson at the base of the sandstones at Mam Tor, and below the

Parsonage sandstone, Caley Crags Grit and Todmorden Grit. A second and higher fauna of Reticuloceras reticulatum was recorded from above the Caley Crags grit in the Carlton and Yeadon boreholes, and correlated with an R. reticulatum marine band above the Parsonage sandstone at Samlesbury, and one about 24 m (80') above the base of the Mam Tor sandstones in Swint Clough.

In the Keighley Borehole (Bisat and Hudson 1943, p.434) a third marine band occurs some 36 m (120') above the second. The goniatites were unfortunately unidentifiable but the band has been correlated with a fossiliferous marine band exposure at Todmorden (Heeley Clough) which occurs approximately 37.5 m (125') above the lower Spittle Clough marine band (the second R. reticulatum marine band).

Exposures at Hebden Water (High Green Wood) and Crimsworth Dean (Outwood) yielded an R. reticulatum fauna from which Bisat and Hudson described R. reticulatum and its variants. The fauna is accompanied by H. striolatum s.s. Bisat and Hudson (1943) placed this R. reticulatum s.s. marine band between the Todmorden Grit and the base of the Crimsworth Dean Grit (Addingham Edge Grit).

> The fauna suggests that the band is above that characterised by H. striolatum near type {the second R. reticulatum marine band} and below that with R. reticulatum late form -- the former immediately above the Caley Crags Grit, the latter below the Main Brimham Grit. The only faunas so far recorded from horizons which are probably between these two bands are those mentioned above at 323' in the Keighley Boring and at 925' O.D. in Heeley Clough and it is

suggested that this horizon is that of the R. reticulatum s.s. fauna of Outwood and High Green Wood.

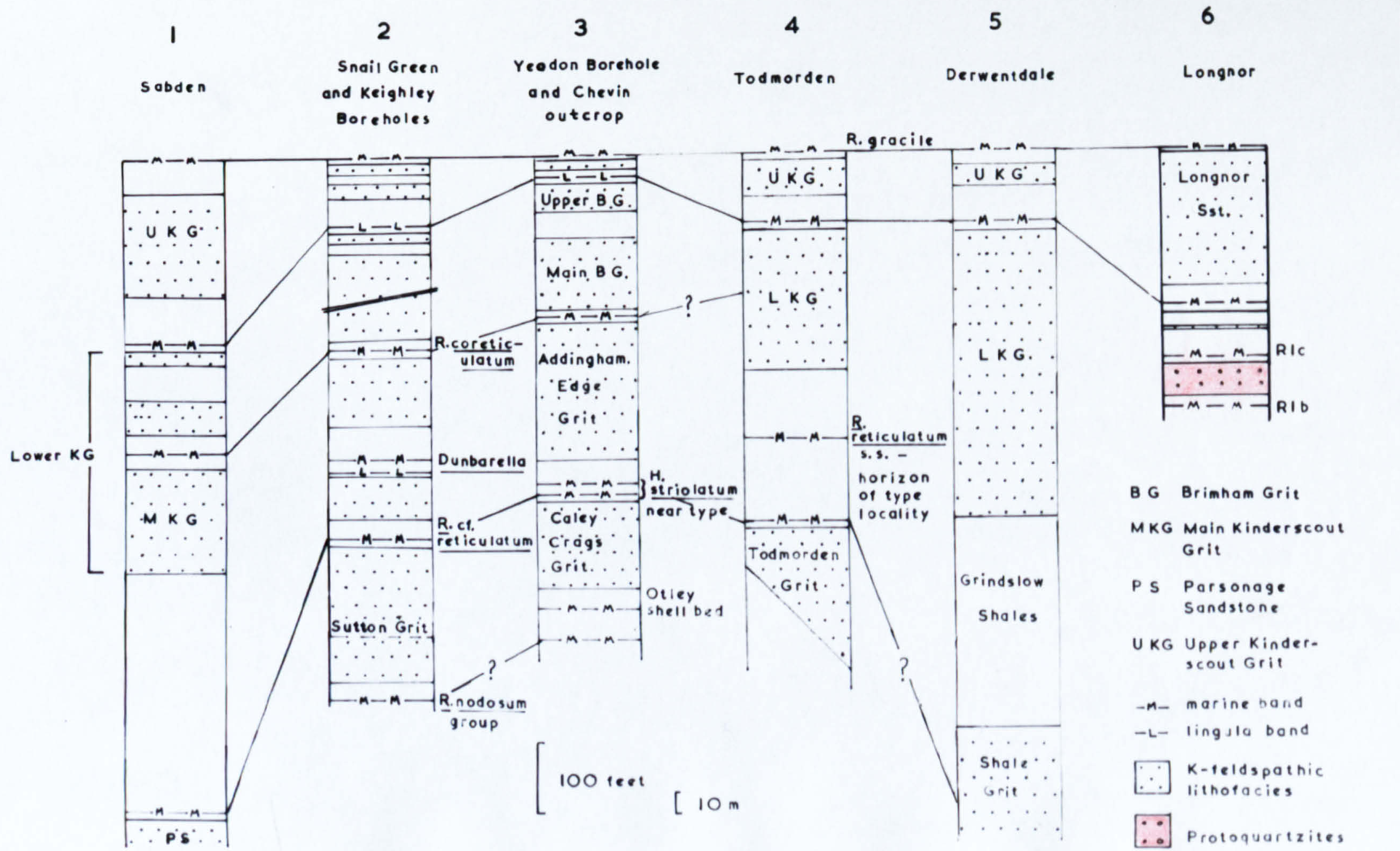
Thus at least three Reticuloceras reticulatum horizons have been recognised in the lower part of Rlc, the typical form having been obtained from what appears to be the marine band preceding that of R. reticulatum (late form) and R. coreticulatum Bisat and Hudson (Fig. 1.G). The first marine band may possibly have been confused with Rlb_v.

R. reticulatum s.s. late form has also been recorded from a marine band above the Addingham Edge Grit, and below the Brimham Grit in the Keighley and Yeadon boreholes. The R. reticulatum late form fauna occurs at the base of the band, but the upper part of the marine shales contain R. coreticulatum, and mark the base of the R. coreticulatum subzone. The R. coreticulatum fauna consists of this Reticuloceras species, Hd. ornatum and rare Homoceras. Apart from this fauna, only a single higher marine band within this subzone, yielding a fauna of gastropods, Lingula and lamellibranchs, was recognised by Bisat and Hudson.

The fauna of the R. coreticulatum/R. reticulatum late form marine band is complex. At Todmorden (Paul Clough and Heeley Clough) there are, ". . . at least four closely spaced faunal horizons, and it can be shown that R. reticulatum s.s. late form occurs in the lower part of the shale below R. coreticulatum and E. ornatum {now Hd. ornatum}. The same succession holds good in Heeley Clough and in the Keighley boring." (ibid. p.436). Bisat and Hudson continue by saying that from several other exposures (Oxenhope, Stanley and Haworth), ". . . R. co-reticulatum and occasionally E. ornatum but not Reticuloceras reticulatum s.s. late form have been collected." These

Figure I. G

CORRELATION OF MARINE BANDS IN RIc



exposures have been correlated, however, with the Todmorden and Keighley marine bands with _R. reticulatum_ s.s. late form and _R. coreticulatum_. The absence of the lower _R. reticulatum_ s.s. late form at some of the localities may possibly be due to lateral variation in the sedimentary environment, the onset of conditions favourable for goniatite population occurring later in some areas than in others, as is seen in the _R. gracile_ succession in the local development of the lower _R. retiforme_ sp. nova marine leaf.

Since Bisat and Hudson's (1943) publication, it has been discovered that the higher _R. coreticulatum_ subzone marine band with the _Lingula_ and gastropod fauna can be replaced laterally by a goniatite fauna in the marine band now known as Butterly. This band in the Holmfirth and Glossop area divides the Upper leaf of the Kinderscout Grit (the equivalent of the Longnor sandstone) from the lower Main Kinderscout Grit of that area (Fig. 1.G).

Butterly has also been recorded as a _Lingula_ band in the Keighley borehole and correlated with a band containing _R. reticulatum_ late form in the Carlton Moor Borehole (Stephens _et al._ 1953, p.36). The marine band has also been recorded in the Brandfield area (near Strines, N.W. of Hollingdale Plantation at 214, 923), but a collection from that locality yielded largely a gastropod fauna, and a single fragment of a non-crenulate goniatite (the same as that obtained from the _R._ sp. nova (no.4) marine band in Brund borehole no.3 at 37').

Despite the thickness of the marine shales recorded in the Charlestown borehole (Stevenson and Gaunt, in preparation), _R._ sp. nov. (R1c) was recorded only from the base of the 8.1 m (27') sequence. No trace of _R. coreticulatum_ was found, and it is suggested that this fauna may not be represented in the area at all, the development of the Kinderscout Grits having made conditions locally unsuitable for goniatite population. Collinson (1969) also postulates a transgressive phase, to account for the sedimentary structures of a part of the Main Kinderscout Grit, which may represent the R. coreticulatum transgression without the establishment of the typical black shale facies.

The succession in Staffordshire cannot be correlated with accuracy with the succession in northern England because the Brund Boreholes and field exposures in North Staffordshire show only two R1c marine bands with goniatites. R. sp. nova occurs in the Blake Brook section and is probably equivalent to Butterly, but the lower R1c marine band could be equivalent to any one of the pre-Butterly bands. It is unlikely, however, to represent the R. cf. reticulatum fauna frequently recorded beneath the Mam Tor sandstones since the fauna of this horizon is too close to that of $R1b_v$ in the Swint Clough section (Chapter 3). Nor is it likely to correlate with the first R1c marine band in the Ashover Boreholes as $R1b_v$ in the Tansley Borehole is separated from $R1b_v$ by only a few inches of unfossiliferous shale. The paucity of R1c goniatites in North Staffordshire may well be only because of poor preservation. At some localities, R. sp. nova occurs only in a rotten, impure limestone and is entirely absent, or recorded by only pale brown indeterminate patches, in the shales.

Lithology of the Staffordshire R1c marine bands

The R. sp. nov. marine band characteristically consists of soft light grey shales. A thin impure limestone is occasionally developed, from which specimens of R. sp. nov. have been obtained in the Manifold Valley. In the Blake section, the marine band is overlain at 0.9 m by a layer of calcareous nodules and at approximately 2.0 m by shales with irregular brown patches. It is therefore possible that a higher fauna, unrepresented in North Staffordshire, does occur above *R.* sp. nov.

Bullions are unknown in the *R.* sp. nov. marine band, but have been found in an R1c marine band in the Heath Hay Ravines section (*R. reticulatum* group fauna). The goniatite population, however, remains sparse.

Previous work in North Staffordshire

R. reticulatum was mentioned from the Blake Brook section by Holdsworth (1963a) but this fauna is now known to represent that of $R1b_v$ in the light of additional evidence from the Brund Boreholes and collections from the Blake. *R.* cf. *reticulatum* was also recorded from the Upper Dove Valley by Bisat and Hudson (1943, p.391) and the exposure noted by Holdsworth (1963a, loc. 065 in this account). This fauna was correlated with that now known to be $R1b_v$ in the Blake. The Upper Dove fauna is extremely poorly preserved, but the occurrence of abundant *Dunbarella* and thicker-shelled goniatites suggests an $R1b_v$ fauna, rather than R1c, as no thicker-shelled goniatites or *Dunbarella* specimens are known from field or borehole collections from lower R1c within the area. Apart from the record of *R.* sp. nov. by Holdsworth (1963a) and records by Evans *et al.* (1968) from the Minns area, there appear to be no previous authentic identifications of the rather sparse R1c faunas in North Staffordshire.

List of localities

082 -- Blake Brook. *R.* sp. nova

083 -- Blake Brook, bullion horizon. No thicker-shelled goniatites, lower R1c.

085 -- Manifold Valley, impure limestone, *Planolites*.

086 -- Ballbank, Impure limestone with *R.* sp. nov.

091 -- Heath Hay Ravines, R. reticulatum group.

095, 098 -- Thorncliff stream and its tributaries, R. reticulatum group.

THE RETICULOCERAS SPECIES NOVA MARINE BAND

Reticuloceras species nova

Reticuloceras mut. nova. Holdsworth 1963a.

Locality: Blake Brook, loc. 082.

Material

Crushed specimens in shale ornament, preserved in relief.

Description

Juvenile specimens show delicate ribs which bifurcate at varying distances from the umbilicus (Plate 1.16c). There is no development of a node at the umbilical edge. Roughening of the ribs occurs on the lingua at all stages of growth. This may be seen only

Spec. no.	Lingual Diameter	Projn. Lingua	Striae/mm L.
082_1	20.0 mm	2.5 mm	6-8
082_2	14.0	1.9	5-6
082_3	10.0	1.4	5

in well preserved specimens where the shell is still preserved, rather than the impression of the external ornament in shale. At smaller diameters, the lingua is only slightly raised, but after approximately 10 mm lingual diameter the lingua becomes raised into a low but distinct ridge, distinguishing R. sp. nova from other R1c goniatites.

By 1963, goniatites from Butterly had been recognised by W.H.C. Ramsbottom from N. Derbyshire between Hayfield and Glossop. These are probably similar to R. sp. nova described here. R. sp. nova was originally discovered in the Blake Brook section by Holdsworth (1963a), where it was recognised as the highest faunal band beneath the Longnor sandstone.

Other occurrences of R1c faunas in North Staffordshire

In the R1c marine bands of the Minns area, thicker-shelled goniatites are uncommon and poorly preserved but Evans *et al.* 1968 recorded R. cf. *reticulatum*. In this area and in the Swythamley section, certain marine bands have been assigned to R1c because of their position relative to K-feldspathic sandstones and R1b.

An R1c fauna was reported from the Heath Hay Ravines section by W.B. Evans *et al.* (1968, loc. 160, p.55) and also recorded by the author at loc. 091. This is 9 m below R. *gracile*, and although the section is largely unexposed, the Longnor sandstone appears to be absent. The R. *reticulatum* group fauna is underlain at 7 m by a band containing a fish and lamellibranch fauna which may be R1c or R1b. The R1c fauna at loc. 091 contains a delicately ornamented form of R. *reticulatum* which suggests -- though the position of the marine band with respect to R. sp. nova is unknown -- that in fact the 091 locality underlies R. sp. nova.

An R1c marine band has also been recorded in the Thorncliff area, but its precise position is unknown due to the poor preservation of the fauna and general absence of goniatites in R1c. Localities 095 and 098, which both immediately underlie the R1c protoquartzite, are thought to expose the same marine band, although a fauna has been collected from only 095. Some of the fragments collected could be referable to R. sp. nova but others are delicately crenulate and are more similar to R. *reticulatum* group. The marine band is probably lower in R1c than Butterly (Chapter 3).

- THE MARSDENIAN STAGE, R2 -

THE SUBDIVISIONS OF THE MARSDENIAN, R2

Bisat's original subdivision of the Marsdenian was based upon the "mutations" alpha, beta and gamma, corresponding to *R. gracile*, *R. bilingue* and *R. superbilingue*.

Bisat (1924, p.51) denoted only a "zone" of R2, presumably of equal status to the "zones" of *R. reticulatum* and *R. inconstans* (subsequently modified). Three variants of the "mutation" *R. gracile* were recognised, as well as early and typical forms of *R. bilingue* in two distinct marine bands, and *R. superbilingue* in the highest marine band of the sequence. Wright *et al.* (1927) added a further "mutation" to Bisat's succession (see also Wright 1926). This "mutation" was named *R. reticulatum* early mut. gamma, or *R. metabilingue* Wright, and was recorded from two marine bands, the upper one having a preponderance of *R. metabilingue* over *R. bilingue* late form with which it occurred (*ibid.* 1927, p.115). This "mutation" was included in Bisat's 1928 paper, where it was also indicated that *Gastrioceras cancellatum* Bisat and other *Gastrioceras* species also occurred with *R. superbilingue*.

In Stephens *et al.* (1953), two *R. bilingue* late form marine bands were also recorded from a position overlying the Woodhouse Grit, and in Price *et al.* (1963) two bands containing *R. metabilingue* were recorded from the same relative positions above the Helmshore grit (these two grits are equivalent).

Two paratypes and the holotype of *R. metabilingue* Wright were obtained from the upper of these two marine bands, described in the 1927 Memoir of the Rossendale area, and two other paratypes from the lower marine band, which rests directly on the Helmshore Grit in the Preston area (Price *et al.* 1963). A specimen from the latter locality was figured by Wright (1926, pl.XII, fig. 2) as *R. metabilingue*, as well as a specimen from the higher marine band. These two marine bands have now been shown by W.H.C. Ramsbottom to contain different faunas, the higher of the two marine bands containing *R. metabilingue* Wright, and the lower one containing a new species, *R. eometabilingue* Bisat and Ramsbottom (in Ramsbottom 1969). The chosen holotype of *R. eometabilingue* was originally figured by Wright (1926, see above, and Wright 1927, Pl.6, fig. 2) as a paratype of *R. metabilingue*.

The upper part of the Marsdenian succession is now known to contain four faunas ie. those of *Donetzoceras sigma* (Wright), *R. superbilingue*, *R. metabilingue* and *R. eometabilingue* in descending order. The *R. eometabilingue* marine band is the equivalent of the *R. bilingue* late form marine band; these two goniatites occur together at the same level. The relative abundance of these forms varies, *R. eometabilingue* occurring commonly in Staffordshire (eg. at Star Wood, Oakamoor), but *R. bilingue* late form occurring to the exclusion of *R. eometabilingue* in the Colne Mills Borehole (Ramsbottom, personal communication).

In the lower part of the Marsdenian, Hudson (1945b) states that there is considerable confusion over the terms "early" and "late" (see p.110 for the *R. gracile* fauna) in the *R. gracile* and *R. bilingue* zones. In the text, Hudson distinguishes the R2b marine band faunas as set out below.

($R2b_{iii}$)	R. metabilingue (now R. eometabilingue and R. bilingue late form (dominant)	BILINGUE LATE FORM M.B.
	WOODHOUSE GRIT	
($R2b_{ii}$)	R. bilingue, and/or R. bilingue late form	BILINGUE S.S. MARINE BAND
($R2b_{i}$)	R. bilingue and/or R. bilingue early form plus "E. proteum" (now Hd. ornatum)	BILINGUE EARLY FORM M.B.

The record of R. bilingue in $R2b_i$ and $R2b_{ii}$ is probably because Bisat (1924) stated that either his R. bilingue or his R. bilingue early form might be "G. bilingue" of Salter. As yet, several forms are included in the concept "R. bilingue". The R. bilingue fauna is defined in this account (p.148).

Confusion arises in Hudson's paper over the form R. wrighti Hudson. Ramsbottom (in manuscript) considers that Hudson intended R. wrighti as a name for R. bilingue late form from $R2b_{iii}$. The present author, however, suspects that the R. bilingue "late form" for which the name was intended may not have been $R2b_{iii}$ type, but the "late form" mentioned by Hudson from $R2b_{ii}$ or possibly for both. Delicately ornamented Reticuloceras bilingue group forms do occur in the upper part of the $R2b_{ii}$ marine band, and are described in this account (p.149).

Whatever Hudson did intend, the holotype chosen for R. wrighti Hudson was that figured by Bisat (1924, Pl. VII, fig.2) as "mutation beta", but which in fact came from a lower horizon in $R2b_i$ (Ramsbottom, in manuscript). Bisat (1932b) refers to R. bilingue late form as a widely distributed goniatite in Yorkshire, the form frequently occurring in small nodules the size of walnuts. This horizon was thought to overlie the "beta plus proteum" band, now known to be $R2b_i$, because Hd. ornatum ("proteum") occurs with R. bilingue early form at Pule Hill, and in North Staffordshire. It appears that Bisat in his 1932b paper on R. bilingue late form confused goniatites from the horizon above the "beta plus proteum" band with R. bilingue late form from $R2b_{iii}$, although the holotype for R. bilingue late form (I.G.S. 50270) was in fact taken from $R2b_{iii}$ (Ramsbottom, manuscript).

The nodular band containing "late mut. beta Bisat" (Bisat 1932b) caused some confusion, as Bromehead et al. (1933) found that in the neighbourhood of Howel's Head, Yorkshire, only 9 m (30') of strata intervene between the R. gracile marine band and the nodular beta band. There is no possibility of a non-sequence in these shales, and it was concluded that as "late mut. beta" occurred in place of R. bilingue early form, the subdivisions of R. bilingue did not necessarily form a time sequence. This was reinforced by the apparent re-occurrence of R. bilingue late form in the marine band overlying the Helmshore Grit ($R2b_{iii}$). It is now known that R. wrighti is equivalent to forms which occur at the top of the R. bilingue early form marine sequence, frequently in a nodular band. "R. wrighti" is retained here for this involute form with a pronounced lingual groove (raised in "solid" specimens) and "R. bilingue late form", (also delicately ornamented), for the goniatite which occurs with R. eometabilingue in $R2b_{iii}$.

NOTE ON TERMS USED IN THIS ACCOUNT

The term "marine band" is ingrained in Namurian literature and is used here in the conventional sense, ie. to refer to black fossiliferous shales and limestones containing goniatites, between shales, sandstones, etc. which apparently lack a fauna.

Totally unfossiliferous shales are rare in the succession where sandstones and ironstones are absent, eg. in R1a in the basin area, and the concept of a "marine band", containing its own distinctive *Reticuloceras* fauna is less useful. Hence it was found more practical to apply the term "horizon" for the range of a particular distinctive goniatite (p. 14). Within the Marsdenian, however, conventional marine bands, characterised by their particular goniatites are frequently expanded into several layers of "marine" shales separated by "non-marine" shales, and in some cases sandstones. The terms "marine" and "non-marine" are not intended here to refer to the degree of salinity of the water at the time of deposition of the sediments, but merely to the presence or absence of the characteristic type of marine band fauna.

There seems to be no indication in the literature that the marine bands can be split by unfossiliferous shales, although W.H.C. Ramsbottom recognises that *R. bilingue* early form occurs in a thick sequence of alternating marine and non-marine sediments. In North Staffordshire it has been found necessary to distinguish between various horizons of the marine sequence, and where it can be demonstrated that a simple marine band passes laterally into a composite marine band, these split fossiliferous sediments have been referred to as "marine leaves". The intervening shales are referred to as non-marine leaves. Three marine leaves are known in the case of the *R. bilingue* marine band, but the total number is unknown in the case of the *R. bilingue* early form marine band. The marine intercalation of *Reticuloceras* sp. nova ($R2b_i$) could be a marine leaf of either the *R. bilingue* early form or *R. bilingue* s.s. sequence.

A difficulty arises in the case of the *R. gracile* marine band because the lowest marine leaf (*R. retiforme*, first appearance) has not been demonstrated to amalgamate with the *R. gracile* marine band. The term "leaf" for this marine intercalation has, however, been retained since the fauna is closely connected with the *R. gracile* group and is separated from it at one point by only 3.13 m of shales, which suggests that amalgamation of this leaf with the marine band might take place at no great distance.

In the description of the fauna, the qualification of "*mutation*" has been avoided as several of the "mutations" already have specific names, and the various "early" and "late mutations" appear to have served largely to confuse Marsdenian stratigraphy, rather than clarify it. There is also a considerably greater difference between some of Bisat's "early" and "late mutations" than there is between some of the R1b forms with their own specific names. The name "*bilingue*" is thus used instead of "mutation *beta*", and "*wrighti*" employed for the form from the "nodular *beta* band". "*R. gracile*" is retained for Bisat's typical form of "mutation *alpha*", but *R. gracilingue* and *R. graciloides*, suggested by Ramsbottom, (in manuscript) have been used for Bisat's "early" and "late mutations" of *R. gracile*, instead of the earlier names. *R. bilingue* early and late forms may well justify the use of new specific names, as do some of the variants of the *R. bilingue* marine band.

THE R2a-R2b$_{ii}$ MARSDENIAN FAUNAS

The succession has been studied up to and including the *R. bilingue* marine band (R2b$_{ii}$) since this is a distinctive and well developed level, and, in the north of the area where field work commenced, it also indicated a level above which a marked change in the type of coarser clastic sedimentation took place. This is not consistent over the whole basin, however, due to the diachronous nature of these younger sandstone bodies.

The *R. gracile* zone, R2a, is undivided in most previous accounts, though divided into the two subzones of *R. gracile* and *R.* aff. *gracile* by Hudson (1945b), with little justification. *R. gracile* and its variants have generally been considered to occur in a simple marine band, containing the whole of the *R. gracile* fauna. In North Staffordshire, several metres of unfossiliferous sediments intervene between the two main *R. gracile* leaves, defined in this account as the upper and lower main leaves (p.112). In addition to these, two other marine leaves occur, containing a new species (p.115) of the *R. gracile* group, *R. retiforme*.

Bisat mentioned no other variants from the *R. bilingue* band, other than *R. bilingue* s.s., thus subsequent authors have tended to refer only to *R. bilingue* from this marine band. The fauna of $R2b_{ii}$ has been split here into five. *R. bilingue* Bisat corresponds only to his figured specimen of pl.III, fig.9 (1924). Other forms are *R. bilingue* s.l. and *R.* sp. of *R. bilingue* group (which may merit a specific name) from the first marine leaf, and another form which occurs in the second and third marine leaves.

R. bilingue s.l. also occurs in $R2b_i$, these and $R2b_{ii}$ examples being indistinguishable from each other. The fauna of $R2b_i$ is not well known, as there appear to be no complete sections across the marine sequence, which is split into a number of marine leaves.

THE RETICULOCERAS GRACILE ZONE, R2a

Occurrence and distribution of Reticuloceras gracile Bisat and its variants

Bisat's original description of *Reticuloceras reticulatum* (Phillips) and its later variants included three variants of *R. gracile* (or mutation *alpha*), ie. early, typical and late, but it was uncertain whether these terms had any stratigraphic significance. Wright et al. (1927, p.114) also commented on the relationship of late mut. alpha and mut. alpha, as they found that this typical form appeared to occupy a position higher than late mut. alpha, although at Pule Hill late alpha occurs close below the lowest R. bilingue (early form) beds.

Hudson (1945b) stated that the terminology for faunas of each zone in R2 was confused, because it was not clear whether, ". . . the 'early' or the 'late' designates forms stratigraphically or phylogenetically earlier". In the case of the R. gracile fauna the suffixes have been taken to indicate the stratigraphic order as implied by Bisat. He commented, however, that "It is not impossible that both early and late mut. alpha are merely local variants of typical mut. alpha." Some difficulties over the order of the fauna have subsequently been resolved as Hudson (1945b) indicated that "late mut. alpha" has often been recorded from the lower part of the marine band because it was erroneously thought to overlie R. gracile. Stephens et al. (1942) found three "mutations" of alpha in the Rombald's Moor area, plus a fourth widely umbilicate form. More than one type of variant was found in the same marine band, and it was concluded that (ibid., p.359) the individual distribution of the different types might be local, and not of stratigraphical significance. This was in contrast to the implication by Hudson that "early", "typical" and "late mutations" occurred in that order.

Deans (1934) found in a borehole section at Snail Green, Rombald's Moor, that the R. gracile marine band was separated into two leaves by shales containing ostracods, but no goniatites. Detailed collection across the fossiliferous shales revealed not only changes in the faunal phase (in the sense of Ramsbottom et al., 1962), but also changes in the form of R. gracile at various levels in the marine band, recognised by W.S. Bisat.

This information and the recognition of distinct changes in the goniatite fauna across the R. bilingue s.s. marine band, make it improbable that the various forms of R. gracile are quite devoid of stratigraphic significance and have only a local distribution. Where exposures in North Staffordshire and adjacent areas have permitted, collection has been made across the whole of the R. gracile marine sequence exposed, in order to determine whether or not a predictable and significant change in the fauna across the marine band does exist.

THE RETICULOCERAS GRACILE MARINE BAND, R2a

Previous work in the field area

Alkyns (1923) first recorded the red R. gracile limestone at Star Wood as a red band containing numerous fossils (p. 6). Bisat (1924) obtained R. gracile (?)late mutation from this locality, which was re-recorded by Hester (1932). The R. gracile limestone of Felthouse Wood (p.122) was also mentioned in his account. Morris (1966a) re-recorded the Star Wood locality and also found loose bullions with R. gracile in the Thorncliff stream. The Blake Brook locality for R. gracile (loc. 101) was recorded as $R2b_i$ by Holdsworth (1963a). R. gracile has subsequently been noted in the Upper Churnet (E.A. Francis, 1967) and in the Minns and Lask Edge area (Evans et al., 1968).

Preservation of the fauna

This is usually good because the shales split easily along the bedding planes, enabling whole specimens to be recovered. The predominant ornament of the forms in the lower main leaf of the band (see below) is coarse and well preserved, but even the delicate ornament of the forms of the upper and lower leaves is often preserved in detail. Some of the best preserved specimens have been obtained from the bullion limestones of the lower main leaf and the red limestone exposed at Star Wood from which several specimens have been figured.

Terminology used in measurement of sections of the R. gracile marine band: nature of the band

The *R. gracile* marine band is rarely represented by a single continuously fossiliferous marine shale unit. The band is composite, being frequently split into a number of leaves of fossiliferous shales, each having its own distinctive fauna. Variation in thickness and lithology in the composite marine band is extreme and is discussed in another section (Chapter 5; see also Appendix Figure VI).

The *R. gracile* band is known to contain three "mutations" which occur in what has been called the "main leaf" of the *R. gracile* marine band. The main leaf itself, however, is generally split into two by unfossiliferous shales, the two leaves thus formed having been distinguished from each other by the qualifications "upper" and "lower". The upper main leaf generally contains a fauna of *R. graciloides* Ramsbottom (late mut. *alpha*), and the lower main leaf a fauna dominantly composed of *R. gracilingue* Ramsbottom (early mut. *alpha*) with rarer specimens of *R. gracile* Bisat. The strongly evolute form mentioned by Stephens *et al.* (1942) occurs at the base of the upper main leaf.

A previously undescribed variant of the *R. gracile* fauna has also been recognised in the composite marine band. Unlike any other known *Reticuloceras* form, this particular species is known to occur twice in the succession, in marine leaves which occur above and below the main leaves. These leaves are called the upper and lower _R._ _retiforme_ leaves. On occasion, the upper _R._ _retiforme_ leaf is incorporated into the upper main leaf, with no break of unfossiliferous shales. Thus the upper main leaf contains an _R._ _retiforme_ "horizon", in the sense in which the term is used in the _R._ _paucicrenulatum_ marine band.

UPPER RETIFORME LEAF	_R._ _retiforme_ sp. nova	
UPPER MAIN LEAF	_R._ _graciloides_ Ramsbottom MS., sp. nov.	(_R._ _gracile_, late form; late mut. _alpha_)
	_R._ _latelirifer_ sp. nova	
LOWER MAIN LEAF	_R._ _gracile_ Bisat	
	_R._ _gracilingue_ Ramsbottom MS., sp. nov.	(_R._ _gracile_, early form; early mut. _alpha_)
LOWER RETIFORME LEAF	_R._ _retiforme_ sp. nova (first appearance)	

The development of the lower _R._ _retiforme_ leaf, also, is not constant over the whole area. Where the Longnor sandstone is present, the lower main _R._ _gracile_ leaf with _R._ _gracilingue_ alone directly overlies the sandstone with no development of the _R._ _retiforme_ leaf. In the south of the area, however, where the Longnor sandstone is absent, the lower _R._ _retiforme_ leaf is well developed, and is separated from _R._ _gracilingue_ by a thin shale sequence or by several metres of sandstones. The sequence of fossiliferous leaves, however, applies over most of the area covered; any modifications of terminology necessitated by local modification of the sequence are given where applicable.

Fauna of the R. gracile marine band

R. graciloides Ramsbottom, M.S. sp. nova

R. latelirifer sp. nova

R. gracile Bisat

R. gracilingue Ramsbottom M.S. sp. nova

R. retiforme sp. nova

Parametacoceras pulcher (Crick)

Previously used criteria for distinguishing R. gracilingue sp. nova, R. gracile and R. graciloides sp. nova

A full description of R. graciloides is given in Bisat (1924, p.116-117). A specimen is also figured in the Preston Memoir (Price et al. 1963) and briefly described as a more evolute form than R. gracile Bisat, having strong umbilical plications in the early stages and a closely set cancellate ornament similar to R. gracile in the adult stages.

R. gracile is distinguished by its more delicate ornament (Bisat 1924, p.115-116). R. gracilingue is intermediate between the type form (Reticuloceras reticulatum) and R. gracile, implying a phylogenetic relationship. The delicate test ornament develops later in life in R. gracilingue.

Ramsbottom et al. (1962, p.121) state that the "early mutation" (R. gracilingue) differs from R. gracile ". . . in that the shell is more evolute, and has strong umbilical ribs persisting into the adult stage (15-20 mm), but the old age ornament resembles that of R. gracile.". In a fuller account (Ramsbottom, manuscript) where new names for two of Bisat's "mutations" are suggested, Ramsbottom describes *R. gracile* as a relatively evolute form. Plications at the umbilical edge die out at an early stage and a closely set cancellate ornament is developed over the whole of the flank at 12 mm diameter, in contrast to *R. gracilingue* where only traces of the spirals are seen between the plications, and a closely set cancellate ornament is developed only on the upper part of the flank. The ornament on the lingua of *R. gracilingue* is finer than that in *R. graciloides*.

Description of the fauna

Reticuloceras retiforme species nova

Localities:

Upper *R. retiforme* leaf, Star Wood Oakamoor (*retiforme* horizon in the main leaf) 115
Near Thorncliff section, 119 (*retiforme* horizon in the upper leaf)
Pule Hill, Marsden, above *R. graciloides*
Upper Shell Brook, 109
River Dane Borehole no.14
Upper Churnet, 101 and 106

Lower *R. retiforme* leaf, Near Thorncliff section, 118
Parkhouse Wood, S.E. of Leek, 114

Lithology and preservation of the fauna

The shales of the lower *R. retiforme* leaf are similar in character to those of the upper leaf appearing lighter grey in colour than typical black marine shales, and also more micaceous. Near Thorncliff (118) the lower leaf is a minimum of 0.9 m thick. Goniatites are rare in the lower 0.76 m of the leaf but become more common in the upper 16 cm where the shales are slightly darker grey in colour, fissile and more typically "marine" in nature. Spat is virtually absent in the lower more silty part of the leaf, but occurs sparingly in the darker shales, where thinner-shelled goniatites also occur. These goniatites are absent in the lower part of the leaf. Small thicker-shelled goniatites are also absent in the more silty mudstones, all specimens found having attained a diameter of at least 20 mm. Smaller specimens (10 mm lingual diameter) occur commonly in the overlying darker shales, together with larger ones.

In Parkhouse Wood, the shales of the lower leaf are similar to those of the top of the same leaf at 118, but the whole leaf is reduced to approximately 30 cm in thickness. As well as spat, fish remains occur (as at 118) as spines, odd scales and mats of scales. In contrast to the black marine shale conditions of the basin, where paired valves of lamellibranchs are commonly encountered, only single valves of lamellibranchs have been found, and at 114 only large specimens of thinner-shelled goniatites (up to 22 mm in diameter) occur in contrast to the smaller sizes in most other Marsdenian marine bands described in this account. No concretions were available to provide, on etched surfaces, more information about the microfauna, but it seems probable that Radiolaria are absent, as is the case in concretions in similar conditions marginal to the basin at the base of the lower main R. gracile leaf. Apart from the silty nature of the lower part of the leaf at 118, the single valves of lamellibranchs suggest more turbulent waters. Heptonstall (1964) also found a preponderance of larger goniatites, which he calculated had a greater swimming velocity, in nearer shore supposedly more turbulent waters. The limited size range of goniatites in this marine leaf may, therefore, indicate conditions rather more turbulent than those of the black shale environment of deposition.

The lithology and fauna of the upper R. retiforme leaf, where differentiated from the upper main leaf, is similar to that of the lower R. retiforme leaf. In Upper Shell Brook (129) the upper leaf is 3 m (minimum estimate, the section may be faulted) above the main leaf. In other areas within the basin, it occurs only 0.5 m above the main leaf, and at Pule Hill at 2.12 m above R. graciloides, separated from it by shales containing thinner-shelled goniatites and sparse Reticuloceras. Specimens from the River Dane Borehole no.14 (obtained from Professor F.W. Cope) may be from the upper or lower leaf. From the depth of their occurrence in the borehole, the borehole's position with respect to the topography, and the collection of only these forms from the core, it seems likely that the main R. gracile leaf was not reached, and the specimens were thus obtained from the upper R. retiforme leaf.

Where the upper R. retiforme leaf is incorporated into the main R. gracile leaf, as at Star Wood Oakamoor, the preservation of the fauna is similar to that of the main leaf -- in this particular case in red limestone. A thin layer of black shales which overlies the red limestone does, however, contain R. retiforme alone. At other localities the lithology and fauna is similar to that of the lower leaf. The shales are fissile and light grey. Goniatite spat occur but are never abundant, and goniatites are large, most specimens reaching 20 mm or more in diameter. Average diameter of whole specimens collected from 114 (7 specimens) was 23 mm, compared with 24 mm (6 whole specimens) from 118.

The preservation of the fauna in the upper and lower leaves in the typical lithology is identical, the goniatites occurring as delicate impressions of the external ornament of the conch or as a flattened conch with the ornament preserved in relief. At first sight, the goniatites closely resemble Anthracoceras, the conch giving the impression of a thinner-shelled nature. The ornament of the shell is, however, delicately reticulate (Plate 1.17a).

Description

The initial pattern of the radial ornament at the umbilical margin is present only up to 9.5 mm lingual diameter. Stronger primary ribs have striae interpolated between them, possibly up to four. The pattern is difficult to distinguish, but bifurcation of the primaries can take place at an extremely narrow angle. At this diameter there is little trace of the spiral ornament and at 12 mm diameter, only a few spirals (3-4) appear on the lingua. The radial striations at these diameters are only very slightly crenulate on the flank, but are markedly crenulate on the lingua. In bullion material (Plate 1.17b) slight crenulation may be seen at smaller diameters. At 14 mm diameter, spirals develop over the flank and the radial ornament is consequently delicately crenulate. In adult specimens (15-25 mm diameter), the spirals become well marked over the whole of the flank, causing a distinctly reticulate ornament. There is at this

Upper R. retiforme leaf

Specimen no.	Lingual Diam.	Projn. L.	Striae/mm L.	Umbilical D.
104_3	22.0 mm	2.5 mm	-	-
104_3	23.0	2.6	-	-
109_c	23.0	2.6	6-7	-
Pule $Hill_1$	34.0	3.1	5 approx.	8.0 mm
Pule $Hill_2$	17.0	1.8	9	2.0
106_1	10.5	1.0	10 approx.	-
106_2	7.0	0.9	12 approx.	-
106_3	14.0	1.4	9-10	4.0 approx.

Lower R. retiforme leaf

	Specimen no.	Lingual Diam.	Projn. L.	Striae/mm L.	Umbilical D.
*	114_1	22.0 mm	2.4 mm	-	4.2 mm
	114_2	12.0	1.4	11	-
	118_1	8.0	1.0	16	2.0
	118_2	20.0	2.3	12	2.5
	118_3	25.0	2.8	-	2.0
	118_4	39.0	4.1	-	4.0

stage a striking resemblance to *Hd. ornatum*, as the spiral ornament is just subordinate to the radial on the flank, and becomes dominant on the lingua. The ornament is similar in relative strength to that seen in the specimens figured by Bisat (1924, pl.II, figs. 3 and 4, *R. gracile*). At larger diameters, there is also a tendency for the regular development of folds in the flank to occur, causing crowding of the radial striae in impressions of the ornament.

All specimens of *R. retiforme* have been described together because specimens obtained from the two leaves appear to be indistinguishable at any stage of growth. A comparison of the tables of specimens from the upper and lower leaves suggests that forms from the lower leaf might be more finely ornamented than those from the lower, but as the density of the striations on the lingua is difficult to measure due to periodic crowding of the radial ornament and the development of a strong concentric ornament, this cannot be regarded as a diagnostic feature. In practice, the ornament of forms from the lower leaf appears to be identical with that of forms from the upper leaf, so that distinction between the faunas of the two marine leaves may be made only on their position relative to the main *R. gracile* horizon. Thus the same name is applied to the forms from two different marine leaves.

* Holotype: 114, Goniatite 22 mm in diameter crushed in shale from lower leaf. Paratypes: 118_1, 118_2, 118_3, 118_4. Crushed in shale.

Plate 1.17

1.17a *R. retiforme* sp. nova holotype

x5¼

Locality: Parkhouse Wood, (114₁), lower

R. retiforme leaf

External shell ornament in shale preserved in relief.

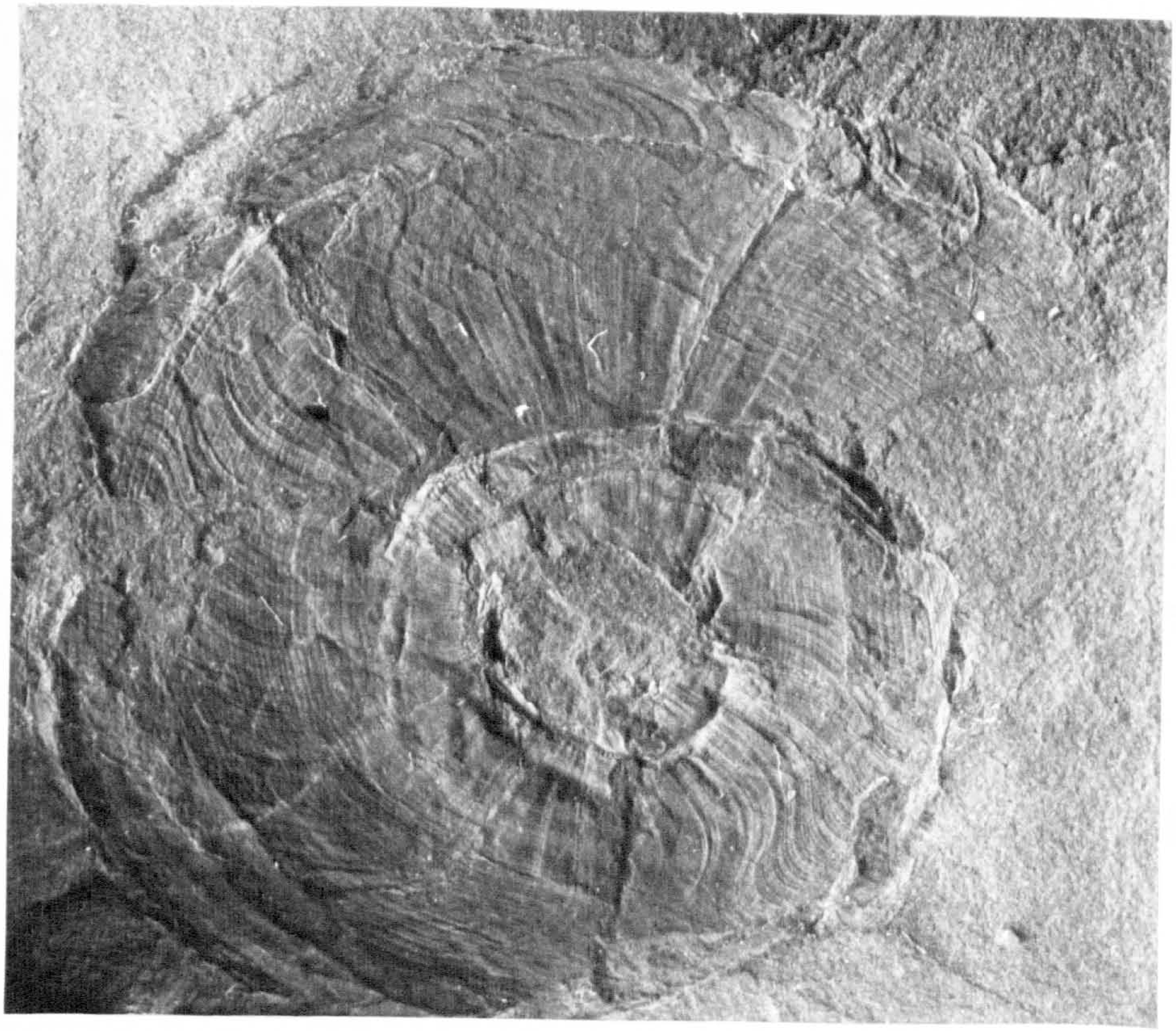
1.17b *R. retiforme*

x14

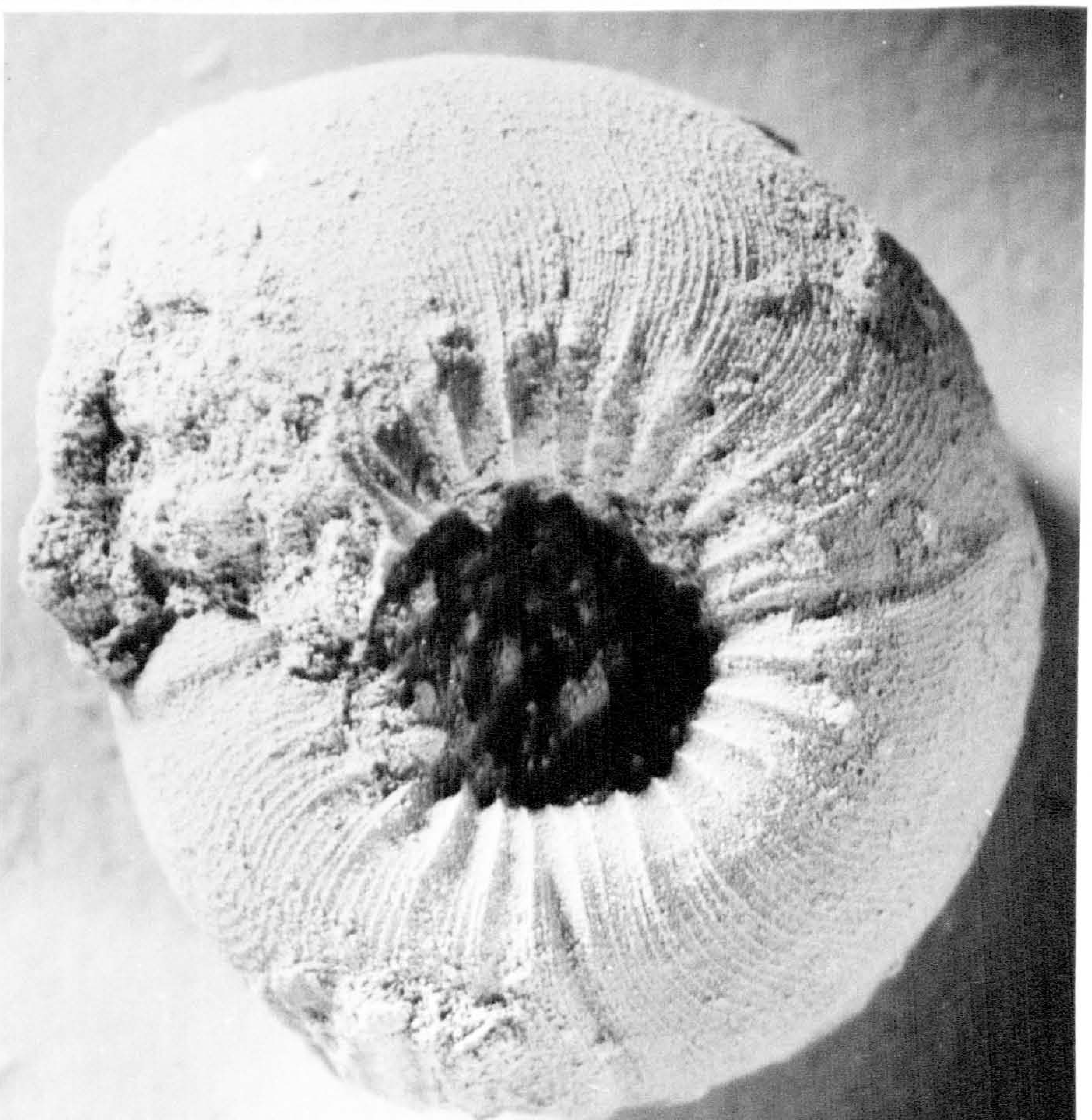
Locality: Star Wood, Oakamoor, 115₁

"Solid" specimen from *R. gracile* shell bed.

Pl. 1.17



a



b

Two "solid" specimens of *R. retiforme* have been obtained from the red limestone at Star Wood, Oakamoor, and display the rib interpolation pattern better than the specimens crushed in shale. Primary plications degenerate into primary striations which bifurcate or, more rarely, trifurcate (Plate 1.17b). Four to five striae are interpolated between the primary striae, to within varying distances from the umbilical edge, producing the typical *R. gracile* group radial ornament. The forward projection of the lingua is remarkably slight, and this feature, together with the degeneration of the primary plications into striations, suggests that it may have been this form which Alkyns (1923) called "*Gastrioceras* cf. *listeri* Mart".

Spec. no.	Ventral D.	Projn. L.	Striae/mm L.	Umbilical D.
115_1	8.5 mm	0.8	9	2.5
115_2	13.0	0.9	7-8	3.2

Bisat (1933, p.257) also commented on a "markedly *Gastrioceras*-like specimen", obtained from the same locality. No raised lingual area occurs in the "solid" specimens, nor does it occur in the crushed specimens in the shales.

Comparison of R. retiforme with other forms of the gracile group

From a comparison of the three other forms of the group previously described (*R. gracilingue*, *R. gracile* and *R. graciloides* p. 114) with the material described above, it is evident that *R. retiforme* compares most closely with *R. gracile*. *R. retiforme* is more involute than either *R. gracilingue* or *R. graciloides*. A closely-set cancellate ornament is developed over the flank at a relatively early age, the umbilical plications being short-lived. This feature is typical of *R. gracile*. The ornament in *R. retiforme* is, however, distinctly finer than that of *R. gracile*. Forms from the upper- and lowermost leaves of the composite marine band have thus been given the specific name of R. retiforme to distinguish them from other goniatites of the R. gracile group.

Occurrence of R. retiforme in the R. gracile succession

The recurrence of R. retiforme is unique in the genus Reticuloceras, although the repeated occurrence of Hd. ornatum in the R1b-R2b$_i$ succession could be a similar case.* There may be some variation in the form of Hd. ornatum up the succession, but this has not been noted by the author because of the fragmentary nature of the material collected. The variation of Hudsonoceras between two closely adjacent horizons does not, however, appear to be great. Hd. ornatum appears to be associated with particularly black carbonaceous shales, indicating a degree of facies control. It is speculated that the appearance of R. retiforme may also be controlled by the environment, as there is a great deal of similarity in the lithologies of the upper and lower R. retiforme leaves. The goniatites are also of predominantly large size, this, amongst other factors, possibly indicating nearer-shore conditions than normal (p.116). The apparently thinner-shelled and involute nature of the conch also suggest that R. retiforme may well have been adapted to conditions normally tolerated by thinner-shelled goniatites, but generally avoided by Reticuloceras.

If the environment did exert some degree of control on the distribution of R. retiforme in the succession, this form could either have colonised the area from a central and independent stock (a case presumably paralleled by Hd. ornatum), or R. retiforme could have arisen locally within the north of England area as two independent but identical expressions of the R. gracile gene pool, when the right conditions presented themselves.

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* see errata

The lower _retiforme_ leaf is known only at two exposures, both in the south of the area covered, in situations marginal to the area of periodic deltaic environments. The position of the leaf is clear at locs. 118-119 where the leaf lies 3.13 m below _R. gracilingue_, and is separated from it by shales which are barren or contain only fish scales and spines or trace fossils (worm casts). In a section at Parkhouse Wood, however, the situation has changed drastically, and the position of the fauna at loc. 114 could only be inferred by additional evidence. Loc. 114 (lower _retiforme_ leaf only) underlies some 33-39 m of protoquartzites. No marine band can be seen to overlie the protoquartzite succession, but I.G.S. specimens no.30804-30808 (red limestone containing _R. gracile_) were obtained from Felthouse Wood, which is the area overlying the protoquartzites in the section in question. The lithology of the red limestone compares exactly with that of the red _R. gracile_ limestone at Star Wood, Oakamoor, which directly overlies a protoquartzite unit, clearly leaving no room for the development of a lower _retiforme_ leaf. It appears that a drastic change in the rate of sedimentation has taken place between locs. 114 and 118, 3.13 m of shales having been expanded to 33-39 m of protoquartzites, beneath which the lower _retiforme_ leaf occurs {Appendix Figure VI}.

To the north of the area, the lower _retiforme_ leaf is unknown. It may be that the contemporaneous marine deposits have coalesced with the main _R. gracile_ horizon, a phenomenon known in the case of the upper _retiforme_ horizon (locs. 119 and 115). But no specimens of _R. retiforme_ have been recovered in field collections or boreholes (Brund 5) from the base of the lower main leaf. The proximity of _R. gracilingue_ to the top of the Longnor sandstone suggests that marine sediments equivalent to the lower _retiforme_ leaf are simply not developed in the northern part of the area. They may conceivably be represented by shales containing the quasi-marine phases which intervene between the R. sp. nov. (R1c) marine band and the base of the Longnor sandstone, but this is thought unlikely. It is more probable that the marine fauna of the lower retiforme leaf is simply not represented at all, as conditions of deposition of the Longnor sandstone within the northern area could have affected the area of goniatite population at the time of deposition of the retiforme leaf which appears, from its lithology, to represent a weaker transgression than that of the main R. gracile horizons. If this apparent lateral variation of marine band and sandstone is borne in mind, it may well help any future investigations into the nature of the extent of the faunas of the R. reticulatum zone in the area of deposition of the Kinderscout Grits, where variations in thickness and lithology, comparable to those encountered in the situation described above, could well take place.

Reticuloceras gracilingue Ramsbottom MS., species nova

Reticuloceras gracile Bisat, early form (early mut. alpha). Bisat 1924, p.116

R. gracilingue. W.H.C. Ramsbottom, in manuscript.

Material

Largely crushed in shale, but well preserved impressions of the external ornament from loc. 109. Bullion material from 104 and 108 shows the finer detail of the ornament best.

Description

In the early stages of growth, this form is strongly evolute and has pronounced umbilical plications, which in some cases bi- or trifurcate at a narrow angle to give rise to primary striae of greater strength on the flank than the interpolated striations (Plate 1.18a and b). On the lingua they are of equal strength. At 10 mm lingual diameter, bifurcation takes place at an extremely narrow angle. The pattern of interpolation is complex and irregular. It can be seen most clearly in bullion material where the external ornament of the shell is well preserved. In such specimens, numerous striae are interpolated between the sets of bifurcating primaries, and occasionally in the angle between them. At least four striations are interpolated between the plications (there may be up to six) in specimens from 10 to 14 mm diameter (specimens 104_1, 108_1 and Plate 1.19a). Interpolation at these diameters takes place to within 1.0-1.5 mm of the umbilical edge. Faint spirals appear on the flank at the forward flexure of the striations into the lingua and are accentuated on the lingua itself. This feature is seen in well preserved shale impressions of the external ornament at 11.0-13.0 mm lingual diameter. The concentric ornament is never as well marked as in *R. gracile*, being discontinuous on the lower part of the flank and only pronounced on the upper part of the flank and lingua as noted on p.115. At larger diameters the concentric ornament tends to deteriorate and remain only on the lingua.

Spec. no.	Lingual Diam.	Projn. L.	Striae/mm L.	Umbilical D.
109_1	8.5 mm	0.75 mm	4	-
109_8	10.0	-	5	-
109_2	11.0	1.7	7-8	-
108_1	11.0	2.2	5-6	4.8
109_{10}	12.0	2.2	6	4.5
109_5	12.0	2.9	4-5	3.0
109_3	13.0	2.2	9-10	6.0
109_{11}	15.0	-	8	-

Plate 1.18

1.18a *R. gracilingue* Ramsbottom MS., sp. nova

x8

Locality: Upper Churnet Valley, (104$_1$),

Lower main *gracile* leaf

Impression of external shell ornament in shale showing coarse ornament near umbilicus and delicate ornament on the lingua.

1.18b *R. gracilingue*

x5

Locality: Upper Shell Brook (109$_{12}$). Lower main *gracile* leaf.

Adult form showing more involute conch.

Plate 1.19

1.19a *R. gracilingue*

x13.5

Locality: Star Wood, (Oakamoor) (shell bed, 115$_7$)

Small "solid" specimen showing degeneration of primary ribs into two or three striations and interpolation of several striations to within 1 mm of the umbilicus. Actual ventral diameter 9 mm.

1.19b *R. gracile* Bisat

x7

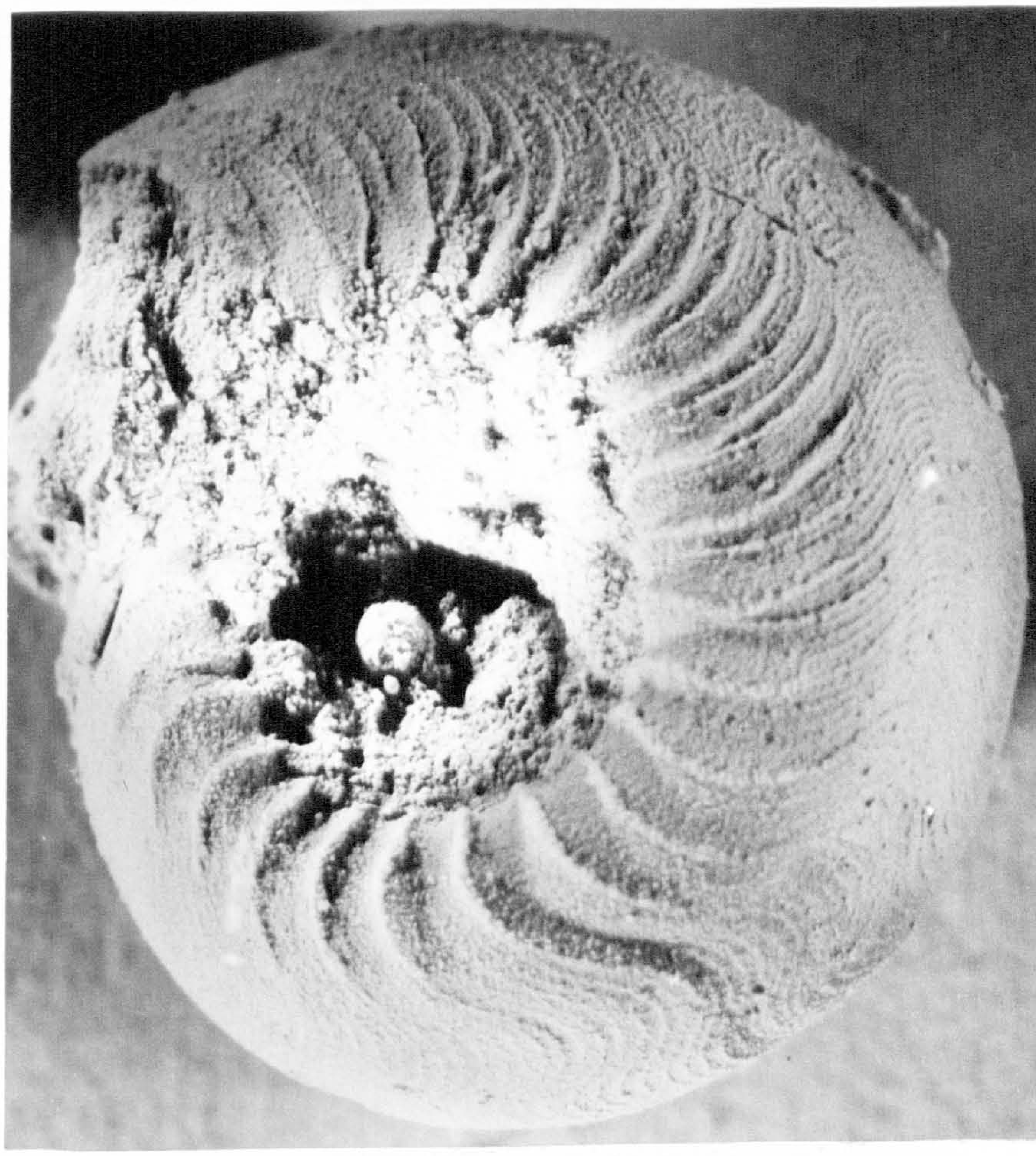
Locality: Upper Shell Brook (109$_{13}$). Lower main *gracile* leaf

Impression of external ornament in shale.

Pl. 1.18

a

b



a

Pl. 1.19

b

Spec. no.	Lingual Diam.	Projn. L.	Striae/mm L.	Umbilical D.
109_4	15.0 mm	3.5 mm	5	4.0
109_{12}	17.0	2.5	9	-
109_7	17.0	3.0	11-12	-

As can be seen from the preceding table, there is some variation of the strength of the radial ornament within specimens taken from the lower main leaf which cannot be solely accounted for by distortion of the material. More coarsely ribbed specimens appear to have fewer interpolations and a less well developed concentric ornament on the upper part of the flank. It is possible that there is a gradation from more delicately ornamented forms to those with a coarser ornament across the band, but this has not been verified.

Reticuloceras gracile Bisat

Reticuloceras gracile Bisat (Reticuloceras reticulatum mut. alpha).
Bisat 1924, p.115. Pl. II, fig.3,4,6.

Material

Two specimens crushed in shale from loc. 109.

Description

The development of the ornament in this form is similar to that of R. retiforme, up to six striations being interpolated between primary ribs which may bifurcate or trifurcate (Plate 1.19b). R. gracile is more involute than R. gracilingue, and the ornament more closely spaced on the lingua. Striae occur at 8 per mm at 15 mm lingual diameter, compared with 4 per mm at the same diameter in R. gracilingue. A distinctly cancellate ornament is developed over the lingua and the flank where the concentric ornament is more pronounced than in R. gracilingue. Strong umbilical plications do not persist.

R. gracile is rare in Staffordshire. Only two specimens have been recovered from the lower main gracile leaf, but several delicately crenulate specimens were noted at the top of the lower main gracile leaf in Brund Borehole 5. These specimens may correspond to R. gracile. The red limestone at Star Wood, Oakamoor has also yielded specimens identified as R. gracile, near typical. The precise position of the specimens in this case is unknown due to the condensed nature of the limestone bed.

Reticuloceras latelirifer species nova

Localities: Upper Shell Brook, loc. 109
Upper Churnet, loc. 102
Thorncliff stream section, loose blocks of shale, loc. 117
Brund Borehole no.5

Material

At exposures where a section some distance across the gracile sequence is exposed, R. latelirifer has been found to occupy a position at the base of the upper main gracile leaf. In Upper Shell Brook, impressions of the external ornament have been collected from black shales. Bullions occur at this level also, but no good "solid" specimens were found. Description of this form has been drawn largely from well preserved impressions of the external ornament in shale from the Upper Churnet.

Holotype: 102_5

Paratypes: 102_6, 102_4, 117_1

Description

R. latelirifer is named after the distinctive feature of the widely spaced ribs. The species can also be identified by its strongly evolute conch and the strong, virtually non-crenulate ribs which arise from umbilical plications. A notable feature is the divergence of the ribs, after bifurcation, at an extremely wide angle, and strong twist backwards of the member of the pair further from the aperture, ie. secondary rib 1 (S1 - see Fig. 1.H and Plate 1.20a). The other rib (S2) arising from the bifurcating umbilical plication, can itself bifurcate, giving rise in all to three ribs from the umbilical plication. An interpolated striation (I) occurs between the sets of bifurcating primary umbilical plications, and is interpolated at 13 mm diameter to within 1.25 mm from the umbilical edge, which is also the point of maximum inflexion of the radial ornament (Fig. 1.H). At this point, S1 is in close juxtaposition to S2, but diverges sharply on the lingua so that the spacing of the radial ornament is regular. A second interpolated striation occurs in some cases parallel to I.

At lingual diameters larger than 15 mm, the ribs emerge radially from the umbilicus and bifurcate at a narrow angle (Plate 1.20b), although a few specimens (102_4) still retain marked umbilical plications and twisting of the ribs on the flank at 18 mm lingual diameter. This suggests that two forms of *R. latelirifer* might be present, the more widely umbilicate one retaining umbilical plications at larger diameters due to the evolute shape and low whorl height of the conch which prevents the development of the adult radial ornament, characteristic of the more involute adult specimens.

The pattern of ornamentation of *R. latelirifer* is similar to that of *R. paucicrenulatum* where the direction of the ornament is

Figure 1.H

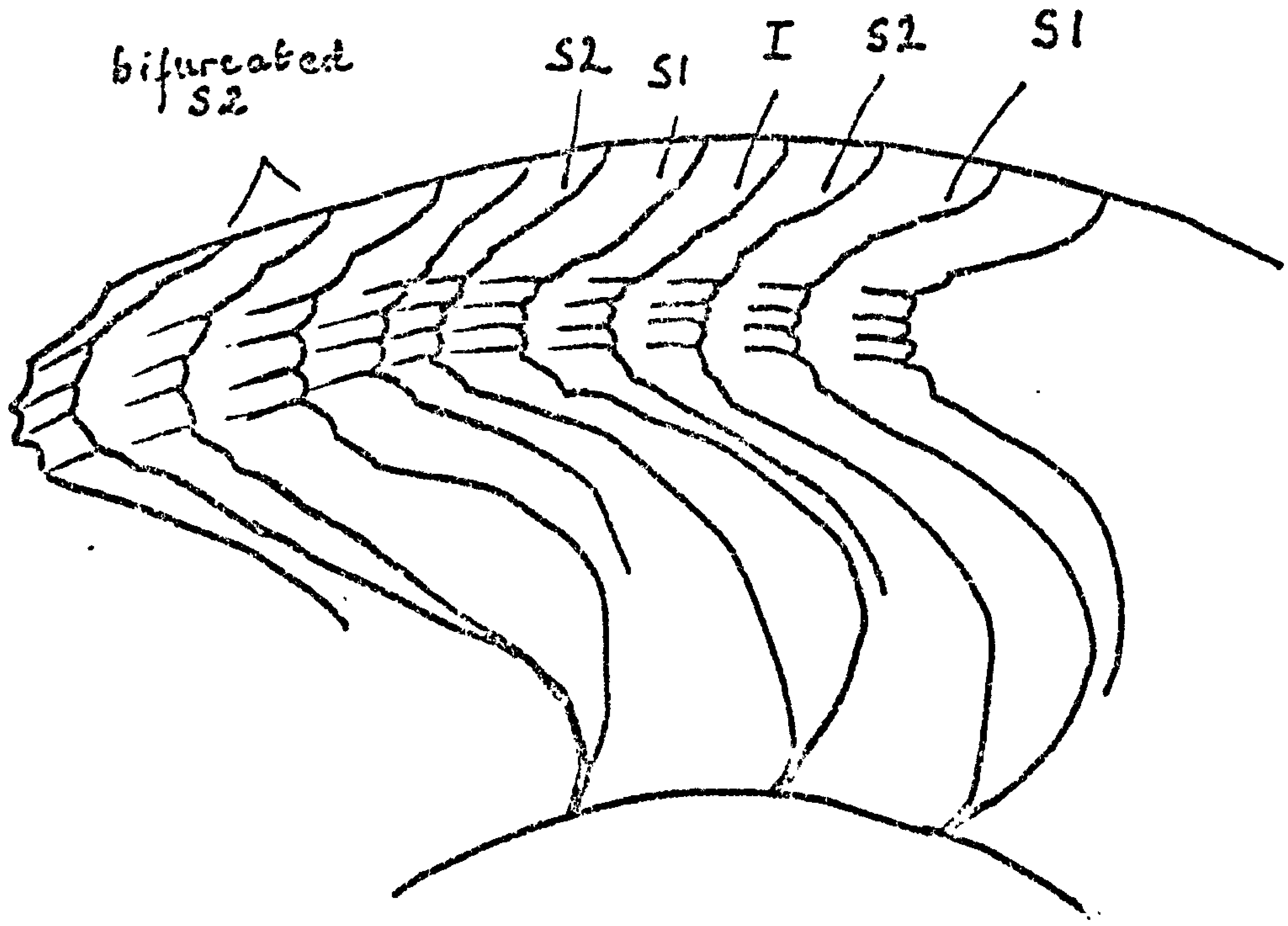


Plate 1.20

1.20a _R. latelirifer_ sp. nova

x6.5

Locality: Upper Churnet, specimen (102_6)

Impression of shell ornament in shale.

1.20b _R. latelirifer_

x10

Locality: Thorncliff stream (117_1). Loose block of shale in stream.

Impression of adult external ornament in shale.

Plate 1.21

1.21a _R. latelirifer_ holotype

x5.2

Locality: Upper Churnet, specimen (102_5)

Impression of external ornament in shale.

1.21b _R. latelirifer_

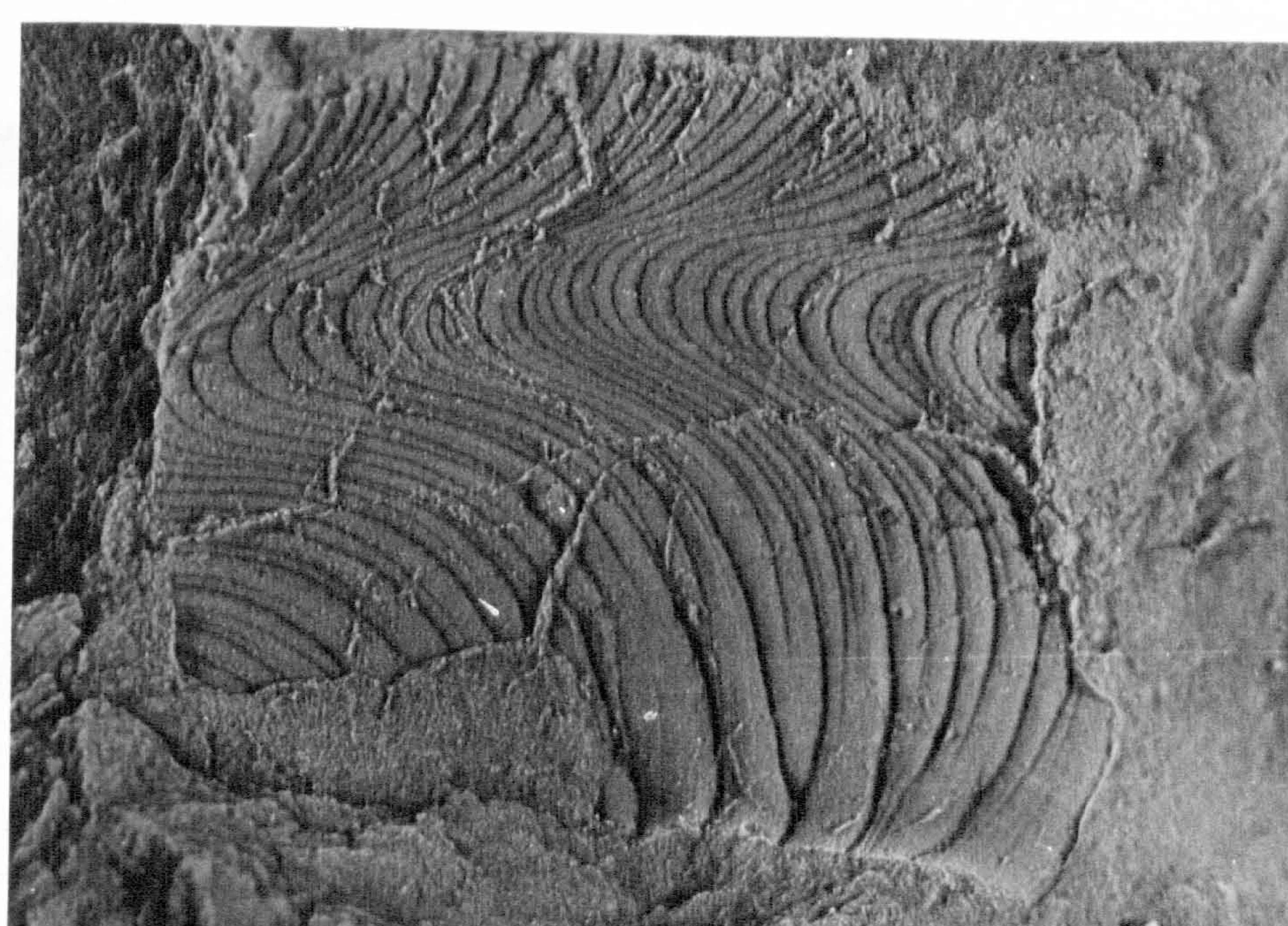
x8.5

Locality: Upper Churnet, (102_4)

Internal mould showing strong bifurcating ribs.

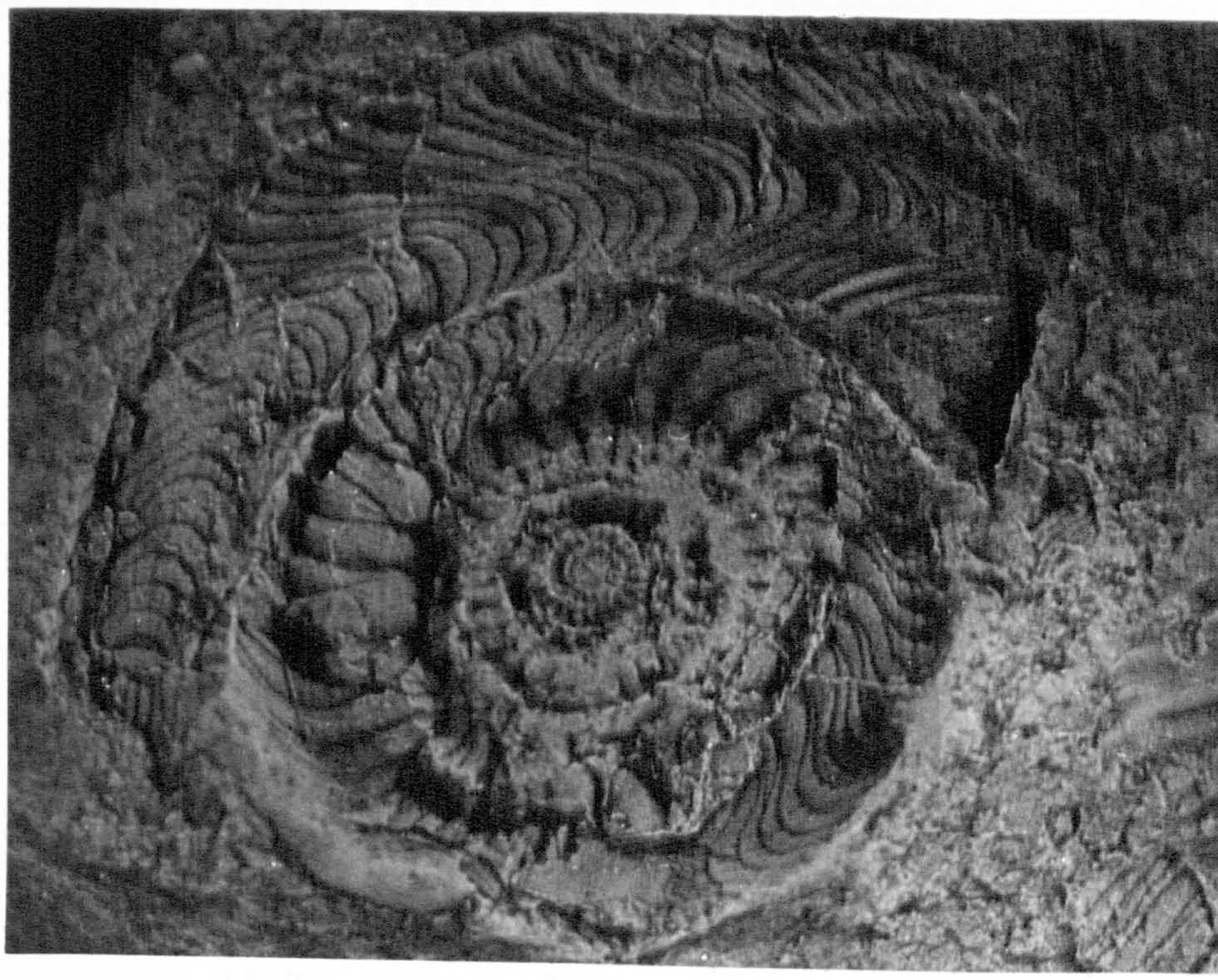
Pl. 1.20

a



b

Pl. 1.21



a

b

similarly controlled by the degree of involution of the shell. The two forms are also similar in their general lack of crenulation of the radial ornament, and strong development of the lingua. *R. latelirifer*, however, lacks *R. paucicrenulatum's* discontinuous concentric ornament at the umbilical edge. The concentric ornament on the lingua is discontinuous in *R. latelirifer*, unlike *R. gracilingue* and *R. paucicrenulatum*. The concentric ornament is itself strong, but is subsidiary to the even stronger radial ornament, resulting in discontinuity of the concentric striae (Plate 1.21a).

Spec. no.	Lingual Diam.	Projn. L.	Striae/mm L.	Umbilical D.
102_6	13.0 mm	1.5 mm	2	7.5 mm
102_1	15.0	-	3	9.5
102_5	17.0	3.1	3	-
102_4	18.0	3.0	-	8.0

R. latelirifer appears to be undescribed elsewhere. This may be attributed to its occurrence in only a small part of the total *gracile* fossiliferous sequence. Stephens *et al.* (1942, p.359) mentioned a possible fourth variant of "*alpha*", a strongly evolute form, which occurred with "late mut. *alpha*" (*R. graciloides*), in the Rombalds Moor district of Yorkshire. This may be the variant described above since it is distinguished from all other forms in R2a by its extremely evolute conch and simple ornament. *R. latelirifer* also occurs in the same marine leaf as *R. graciloides* in Staffordshire.

Reticuloceras graciloides Ramsbottom MS., species nova

Reticuloceras gracile Bisat, late mutation (Reticuloceras reticulatum late mut. alpha). Bisat 1924, p.116-117, Pl. II, fig.5.

Reticuloceras gracile Bisat, late form. Price et al. 1963, p.63, Pl. III, fig.3.

Reticuloceras graciloides Ramsbottom. Ramsbottom, in manuscript.

Specimens intermediate between R. gracile and R. bilingue early form were originally described by Bisat (1924) as "late mut. alpha". Collection from the Pule Hill locality (ibid. p.116) has yielded specimens similar to that figured in Price et al. as "the late form", but only a few specimens in Staffordshire have been doubtfully referred to R. graciloides. The shales in the position where R. graciloides might be expected to occur are frequently sparsely fossiliferous and the apparent paucity of the fauna might be attributed to this factor. Core recovered from Brund Borehole no.5 yielded only a few poor specimens in the upper main leaf immediately above R. latelirifer. Although no typical forms of R. graciloides have been found in North Staffordshire, it is evident from the succession at Pule Hill that this form occurs in the upper part of the main leaf, as it occurs immediately beneath R. retiforme (upper occurrence). It is suggested that the name "late mutation" or "late form" should be discarded and the name R. graciloides, as proposed by W.H.C. Ramsbottom, substituted in its place.

R. graciloides in North Staffordshire

Specimens doubtfully referred to R. graciloides have been collected from locality 106 (Upper Churnet) and 119 (near Thorncliff). At the latter locality, R. graciloides occurs in the highest of the three R. gracile marine band leaves present, the upper R. retiforme fauna having been incorporated, it is believed, into the upper main leaf, as a few extremely delicately ornamented specimens immediately succeed *R. graciloides*. A few specimens from the condensed red limestone bed at Oakamoor have also been identified as *R. graciloides* (Plates 1.22a,b and 1.23). This is the locality from which Bisat (1924) obtained his figured specimen of the "late mutation".

R. graciloides can be distinguished from *R. gracilingue* by its slightly more involute form, stronger bifurcated ribs and less pronounced concentric ornament on the lingua. Spirals tend to be more marked on the flank at all stages of growth in *R. graciloides*.

R. graciloides can also be accompanied near the top of the upper main leaf by a form extremely similar to *R. bilingue* early form. This goniatite is distinguished from *R. graciloides* by the reduction of the concentric ornament on the flank, and the development of a less complex rib interpolation pattern. The figured specimen from 119 (Plate 1.24a) shows a more pronounced lingua than *R. graciloides*. Some of the specimens obtained from near the top of the fossiliferous shales at Pule Hill (beneath *R. retiforme*) also show a reduction in the spiral ornament and simplification of the interpolation pattern (Plate 1.24b). Without accompanying forms such as *R. graciloides* and *R. retiforme*, these specimens similar to *R. bilingue* early form would not normally be considered indicative of R2a.

Parametacoceras pulcher (Crick)

ORDER *Nautilida* Agassiz, 1847

SUPERFAMILY *Tainocerataceae* Hyatt, 1883

FAMILY *Tainoceratidae* Hyatt, 1883

GENUS *Parametacoceras* Miller and Owen, 1934

Pleurometacoceras pulcher Crick, 1904, p.15-20, pl. II, figs.1-5

Plate 1.22

1.22a *R.* aff *graciloides* Ramsbottom MS., sp. nova

x6

Locality: Star Wood, Oakamoor $(115)_3$

"Solid" specimen showing interpolated striations and concentric ornament. The umbilical plications are less strong than in *R.* aff *graciloides* (Pl. 1.22b). 1.22a may be intermediate between *R.* *gracile* and *R.* *graciloides*.

1.22b *R.* aff. *graciloides*

x5½

Locality: as above, 115_4

"Solid" more evolute form showing strong umbilical plications and interpolated striations.

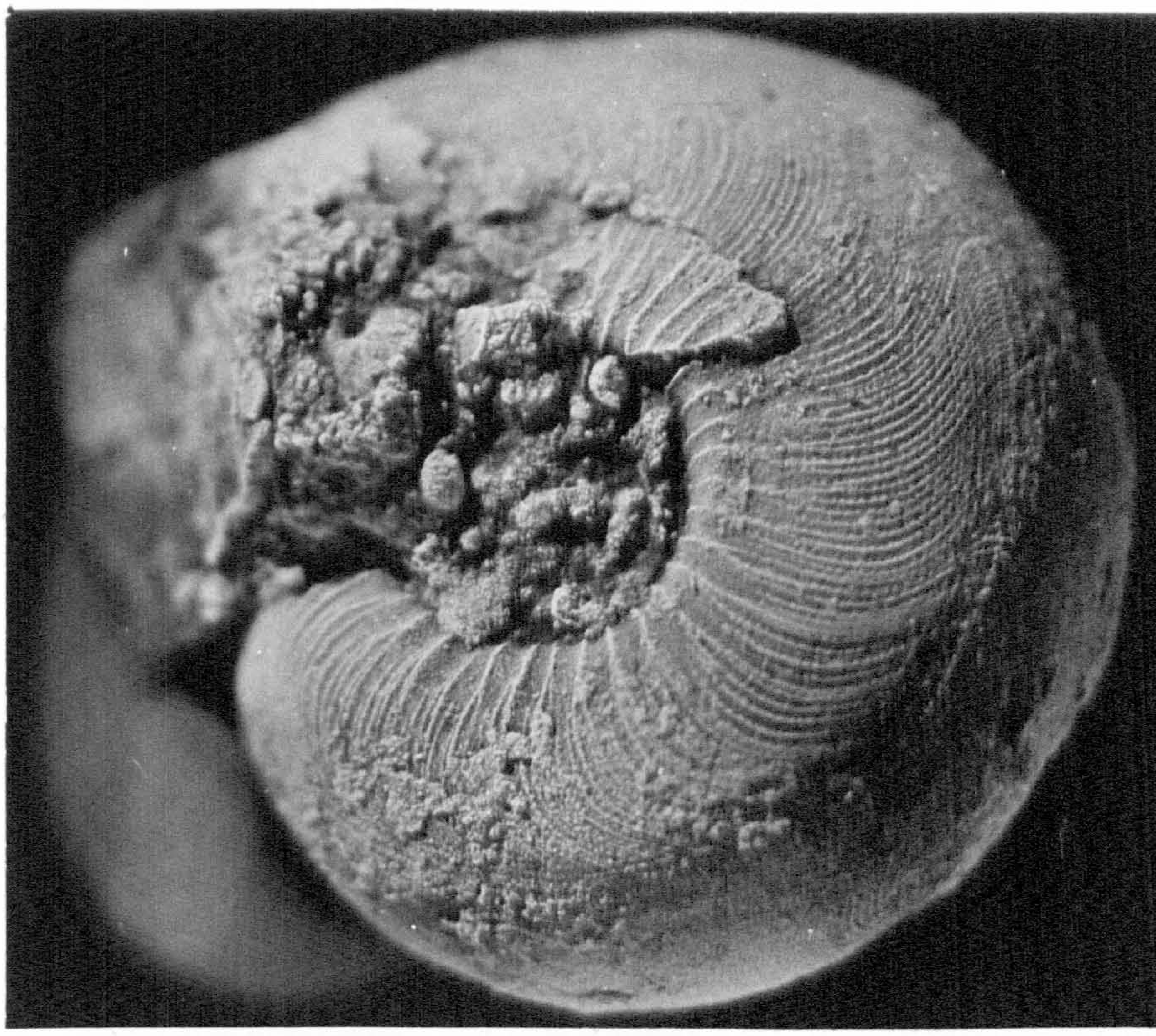
Plate 1.23 *R.* *graciloides*

x11

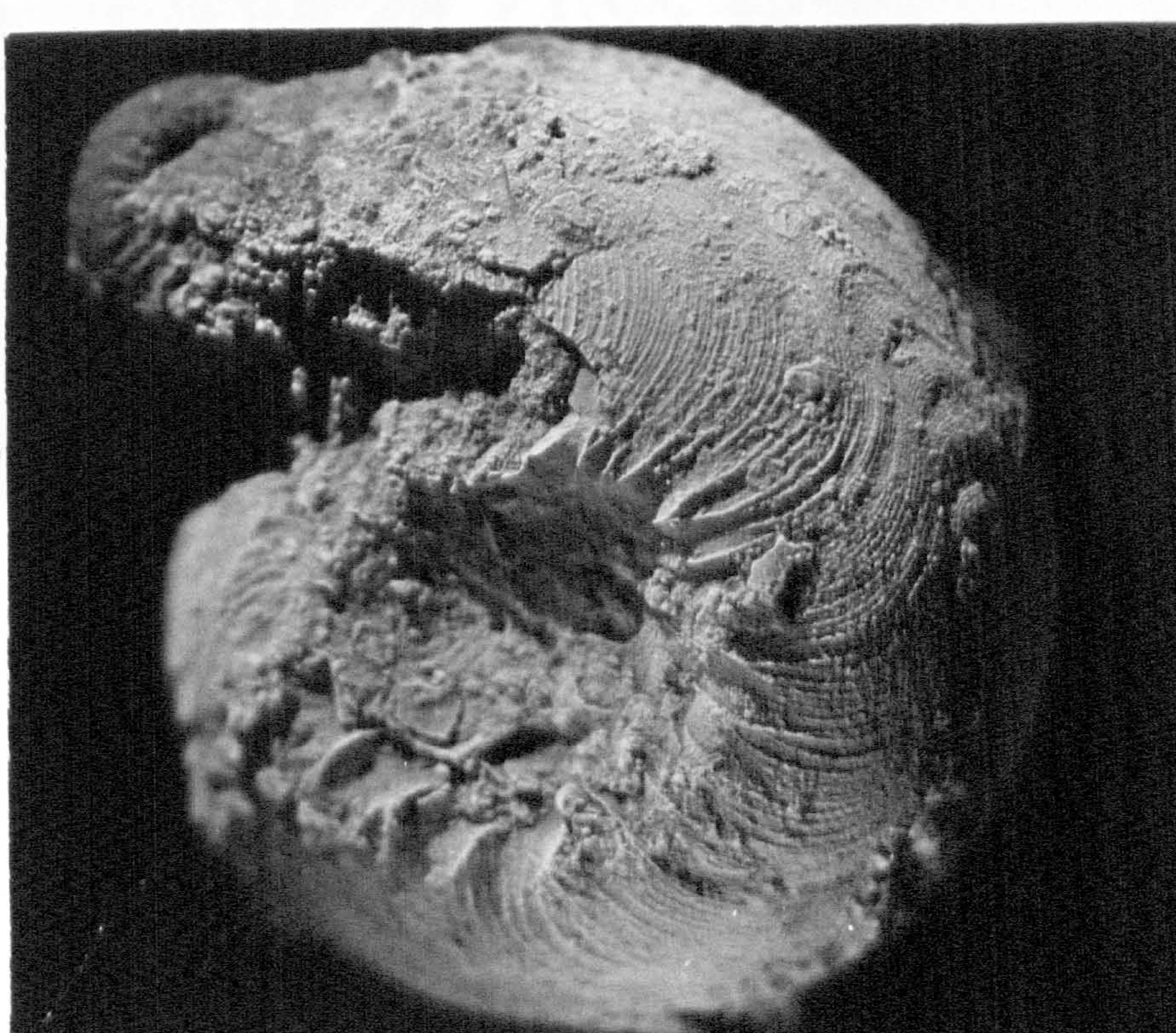
Locality: as above, 115_5

The "solid" specimen has a more involute conch than *R.* *gracilingue*. The ribs at the ventral diameter of the figured specimen (11 mm) are stronger than in *R.* *gracilingue*, and arise from umbilical plications. The primaries can bi- or trifurcate. The delicate interpolated striations occur as yet only on the lingua, the inner part of the conch being more coarsely ornamented than the outer. A concentric ornament occurs on the lingua and venter at this diameter.

Pl. 1.22



a



b

Pl. 1. 23

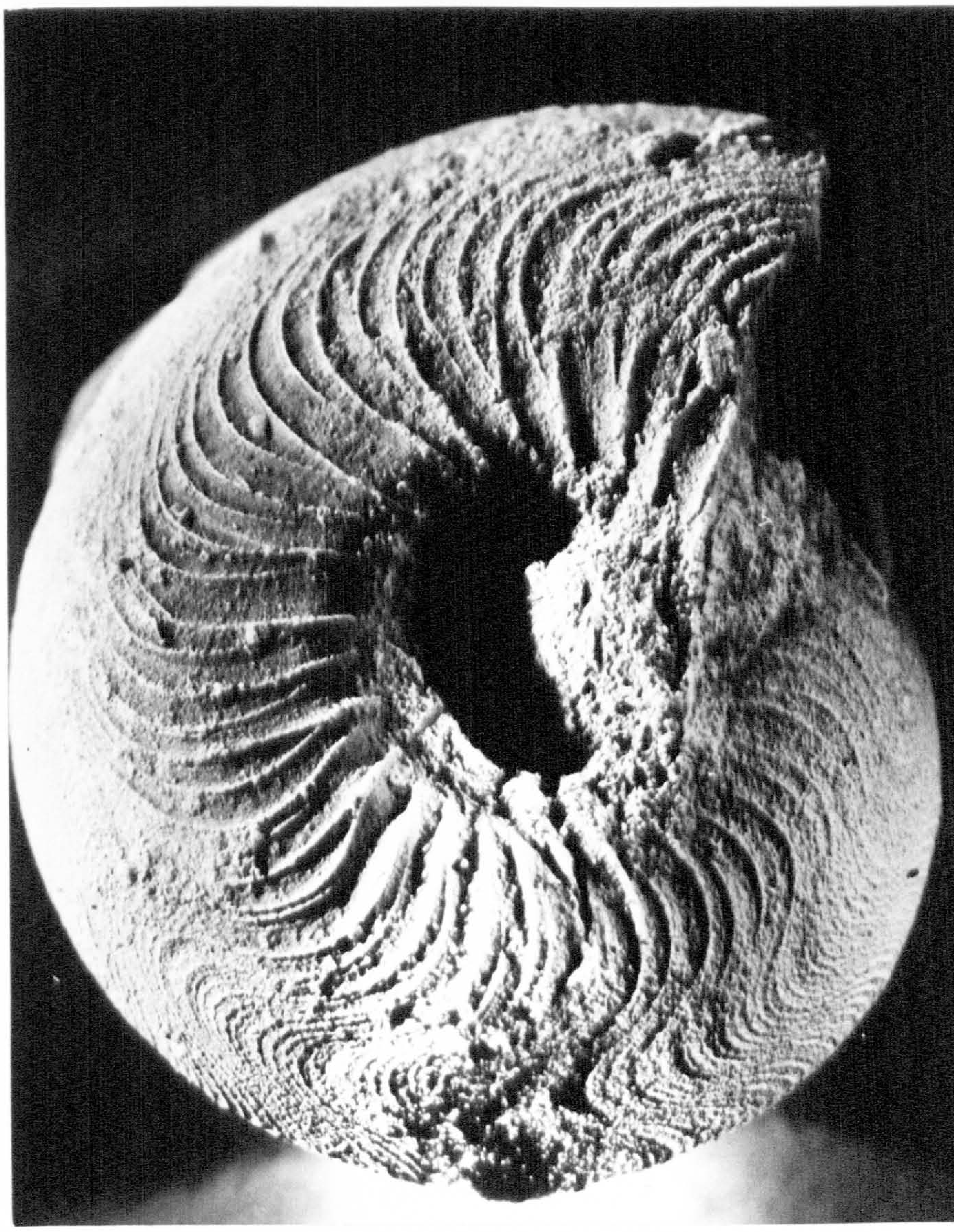


Plate 1.24

1.24a *R. gracile* Bisat s.l.

x6

Locality: Near Thorncliff, (119)

Impression of external ornament in shale.

Specimen obtained from upper main *gracile* leaf.

Similar in some respects to *R. graciloides*, but more similar to forms in the *R. bilingue* early form marine band.

1.24b *R. gracile* s.l.

x6

Locality: Upper part of *R. gracile* band, Pule Hill, Marsden.

Impression of external ornament in shale. Less pronounced concentric ornament on flank than in *R. graciloides*.

Plate 1.25

1.25a *Parametacoceras pulcher* (Crick)

x4

Locality: Star Wood, Oakamoor, (115)

"Solid" specimen from *R. gracile* shell bed.

1.25b *Parametacoceras pulcher* (Crick)

x9

Locality: R. Dove, loose bullion containing *Ht. prereticulatus* (Holdsworth, 1963a)

"Solid" specimen showing fragment of outer whorl.

Pl. 1.24

a

b

Pl. 1.25

a

b

The genus Parametacoceras is found in the Upper Carboniferous of Europe and N. America. In the Namurian of Britain, it may be possible to trace a series of slight changes in Parametacoceras pulcher (Crick) which might be used for correlation purposes (W.H.C. Ramsbottom, personal communication).

Material

1. "Solid" specimen, inner whorls not seen. Preserved in red limestone, Oakamoor.
2. "Solid" specimen, ornament preserved on a quarter whorl. In bullion limestone containing Homoceratoides sp. (probably Ht. prereticulatus, Holdsworth 1963a).

Description

At young stages of growth on the single outer whorl preserved (sp. 1, Plate 1.25a), four pronounced concentric ridges are present, plus a sharp umbilical rim. The outermost, or ventral, concentric ridge forms a rim to the shell and is continuous. But the three concentric ridges on the flank are interrupted by transverse folds, so that nodes are formed at the intersection of the two dominant ornaments. A slight swelling of the umbilical rim is also present. The nodes increase in magnitude from the umbilicus towards the venter.

Spec. no.	Ventral Diam.	Umbilical Diam.	Width	Whorl height
1	33.0 mm	9.0 mm	13.0 mm	10.0 mm approx. at 22.0 mm D.
2	20.0	-	14.0	7.0

At a larger diameter (22.0 mm), the nodes decrease in prominence as the concentric ornament becomes less pronounced and the folds develop into costae. The nodes at the umbilical rim become obsolete, but slight swellings formed by the lateral concentric ornament may be detected on the costae even at 33 mm diameter. This is in contrast to specimen 2 (Plate 1.25b), probably from H2, where the concentric ornament is obsolete at 22 mm diameter, so that the radial costae lack periodic thickenings.

With increase in size, the umbilical wall becomes more openly sloping. The umbilicus is not seen, and it cannot be determined if the specimens are perforate or not.

The R2a specimen is less inflated than that from H2. The maximum width of the conch occurs slightly lower on the flank in specimen 2 than in specimen 1 (Figure 1.I). The flank in specimen 2 is more rounded and the whorl height less than in 1.

The radial ornament, apart from the costae, consists of wavy striations which pass radially over the umbilical edge and flank. After crossing over the uninterrupted ventral concentric ridge, the striations bend abruptly into a deep hyponomic sinus on the broad and slightly convex venter.

Identification and conclusions

Specimen 1 (R2a) was identified as Parametacoceras pulcher (Crick) by W.H.C. Ramsbottom. The position of the siphuncle is unknown in these specimens. The ornament of the conch is similar to that of the specimens illustrated by Crick (1904). The delicate radial ornament is present in all specimens, as well as the folds or costae on the flank, and a strong concentric ornament and hyponomic sinus. The concentric ornament in specimens from the Pendleside series (Viséan)* is reduced, however, to only two instead of four lateral and latero-ventral concentric ridges. The reduction of this ornament in earlier forms suggests that there may be an evolutionary trend

* see errata

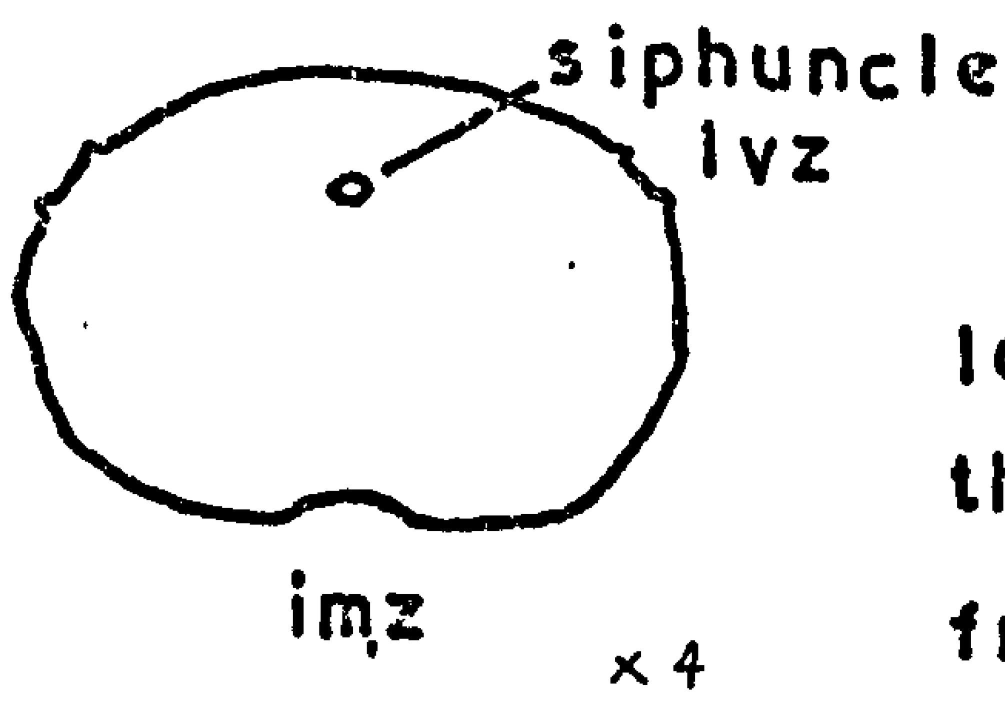
Figure 1.I

Parametacoceras pulcher

cross section of the final whorl

x 1 R2 specimen

x 1·5 H2 specimen



x 4

Anterior aspect of the last septal surface of the same [type specimen from the Pendleside Series] showing the position of the siphuncle, the lateral ventral zone [lvz], and the impressed zone [imz].

Crick, 1904.

towards a more pronounced ornament of this type in later forms. Change in the shape of the conch is also indicated by the shape of a whorl's cross-section which is more rounded in the Visean specimens, intermediate in the specimen from H2 and flat-sided in the R2a specimen (Figure 1.I).

Late "mutations" of "?Metacoceras pulchrum (Crick)" have also been recorded in the R. gracile marine band at Park Wood Brick Pit, Keighley, and Sun Hill Clough, Oxenhope (Stephens et al. 1953, p.102). This nautiloid and other non-goniatite elements in the fauna (sponges, gastropods, orthocone nautiloids and lamellibranchs) ". . . suggest vestiges of the rich assemblage found in the Otley Shell bed". ?Parametacoceras pulcher has also subsequently been noted in material from the R. bilingue marine band in a borehole at New Mill, Stainland and at Colne Mill in the higher of two R. bilingue marine leaves (I.G.S. specimens).

The fauna of the R. gracile zone in North Staffordshire and adjacent areas: Conclusions

R. gracilingue is the most common goniatite of the R. gracile fauna in the area. R. graciloides is comparatively rare, and less common than in Yorkshire, probably due to less than optimum conditions for population of the North Staffordshire area during its range. Its occurrence in the upper part of the R. gracile zone, as suspected by Bisat, has been verified. R. gracile appears to be rare in comparison with R. gracilingue, which occurs in the lower part of the same marine leaf.

"Solid" specimens of the gracile group obtained from the condensed succession of the red limestone bed at Star Wood, Oakamoor, range from R. gracilingue to the upper occurrence of R. retiforme. The ornament in these specimens is particularly well preserved, as well as the shape of the conch, and many of these show slightly different characteristics to the specific forms described. Some variation was also noted in the description of specimens crushed in shale of R. gracilingue. These observations indicate that gradations in features may take place across the marine band, as might be expected in a continuously evolving sequence.

The R. gracile variants appear in the same order at all localities. The absence in the area of deposition of the Longnor Sandstone of the lower R. retiforme leaf is explained by the local conditions of sedimentation (p.123). Thus the R. gracile fauna is not characterised by lateral local variation in the fauna, but shows a consistent change in the types present across the marine sequence, as might be expected from investigations on the fauna of other marine bands with varied faunas.

From the collection of variants of the R. gracile group at various localities in the Rombalds Moor district, Stephens et al. (1942) deduced that, "All these localities are concerned with one and the same horizon and it seems probable that any of the three forms of mut. alpha, early, typical and late, and possibly a fourth, the widely umbilicate form from the Keighley Nurses' Home (86), may exist together in this band. Their individual distribution, however, may be local.".

There is no indication in the paper by Stephens et al. that any systematic collection of the fauna across the width of the marine band was undertaken, nor is it mentioned that the R. gracile marine sequence is split into two marine leaves by ostracod-bearing shales, approximately 1 m (3') thick (Deans, 1934). It appears that goniatites from both the lower and upper marine leaves have been compared as they were thought to have come from the same horizon. This might result in an apparent local variation of the fauna, which in reality is unlikely as Deans states that, "Detailed collecting from these two bands {the two marine leaves} revealed distinct faunal variation as the beds are traced upwards. Mr Bisat can recognise changes in the form of R. reticulatum mut. alpha from the different levels." Sections across the R. gracile marine sequence in North Staffordshire support Deans' conclusions, and it seems likely that a reappraisal of the R. gracile fauna in the Rombald's Moor area in the light of subsequent information would lead to results consistent with those of Deans and the findings in North Staffordshire.

THE RETICULOCERAS BILINGUE ZONE, R2b

THE RETICULOCERAS BILINGUE BISAT EARLY FORM MARINE BAND, $R2b_i$

Previous records of the marine band in North Staffordshire

Morris (1966a) recorded R. bilingue Bisat early form from Star Wood, Oakamoor (loc. 137 of this account). His locality for an R1b fauna with Hd. ornatum in the Thorncliff stream section has been reidentified as $R2b_i$ (p. 61), and the locality for R. bilingue early form of Holdsworth (1963a) has been reidentified as R. gracile (p.215).

Evans et al. (1968) identified the R. bilingue early form marine band at several localities including the Heath Hay Ravines section (ibid. loca. 194, loc. 134 of this account), the River Dane section (ibid. loc. 176 = loc. 131) and at exposures in the Dingle Brook section. E.A. Francis (1967) also identified this marine band in the Upper Churnet in Stake Gutter (loc. 122 of this account). The author considers this latter locality could be $R2b_i$ or $R2b_{ii}$.

Value in correlation

This marine band is known over a large area, having been recorded at Bisat's original locality at Pule Hill Marsden, and in north and south Wales. *R. bilingue* early form also occurs in abundance in the Ashover Boreholes. As far north as the area around Colne, however, the goniatite fauna is depleted, and the only representatives of the *R. bilingue* early form marine band in the Colne Mill and the New Mill, Stainland boreholes, are possibly the *Planolites* horizons in each of the boreholes beneath the Readycon Dean beds and the Scotland flags (which are equivalent). The overlying *R. bilingue* marine band persists further north than that of the early form, but contains a more varied fauna of Nautiloids and lamellibranchs (*Palaeoneilo*, *Euchondria* sp. and *Sanguinolites* aff. *ovalis*) and *Lingula*.

Thickness variations of the marine band

Only a single complete section across the *R. bilingue* early form marine band is known in the area covered. At loc. 137 where 1.84 m of marine shales are uninterrupted, the preservation in the calcareous shales is so poor that it is not possible to deduce any change in the *R. bilingue* early form fauna across the marine band.

At most exposures, the total thickness of the marine band cannot be determined as the total number of marine leaves is unknown. The base of the marine band, in a fossiliferous section 2.13 m thick, is judged to be exposed in Upper Shell Brook (loc. 130), as the fauna at the base of the marine sequence exposed is the same as that of the base of $R2b_i$ at Pule Hill. The section across the *R. bilingue* early form marine band at Meerbrook (loc. 121) is 2.24 m thick, and exposes three fossiliferous leaves of shale separated by unfossiliferous or sparsely fossiliferous lighter grey shales. The upper and lower leaves (10 and 20 cm thick) each contain Hudsonoceras ornatum. The 2.24 m section is unlikely to represent the whole of the marine sequence, as the composite marine band shows a pronounced northerly thickening from the Oakamoor area to the Churnet, and the lower fauna exposed at Meerbrook does not correspond with the fauna obtained from the base of the band elsewhere (see above). One exposure in the Upper Churnet (loc. 126) shows two marine leaves, the lower one containing Hd. ornatum. This leaf probably correlates with the lowest marine leaf seen at Meerbrook as Hd. ornatum occurs at both exposures and the R. bilingue early form variants are similar.

Lithology and preservation of the fauna

Two limestone beds occur in the R. bilingue early form marine band at Oakamoor (137) and contain "solid" goniatites, abundant gastropod and goniatite spat and some broken shell debris. Laterally, one of the limestone beds becomes impersistent, developing into a line of bullions. Preservation in the shales is poor. Calcite bullions are well developed in the River Dane section (loc. 131), but they are sparsely fossiliferous. The overlying shales have yielded an indeterminate fauna, and the band has been identified only by its position in the section relative to the R. bilingue s.s. marine band.

The most abundant fauna has been obtained from the shales at loc. 130 and loc. 121. Siderite concretions are less common in the marine portion of the composite band than in the R. bilingue marine band, but occur locally, eg. at Meerbrook (loc. 121) where an abundant fauna with some goniatite spat is present on certain bedding planes. The goniatites are preserved only half crushed, the imprint of the external ornament of the shell being well preserved in the concretions. Calcite bullions occur at loc. 126 but have failed to yield any good "solid" goniatites. As at loc. 131, a poorly preserved sponge fauna is present.

Description of the fauna

More than one variant occurs in this marine band. Goniatites at the base are thought to be closest to *R. bilingue* early form described by Bisat. *Hudsonoceras ornatum* occurs higher in the band in association with more delicately ornamented variants of *R. bilingue* early form.

Reticuloceras bilingue Bisat early form

Reticuloceras bilingue early form (*Reticuloceras reticulatum* early mut. *beta*) Bisat, 1924, p.117.

The basal part of the *R. bilingue* early form marine band at Pule Hill yields specimens which are markedly evolute and strongly ornamented. Comparable specimens have been found only at the base of the marine band in Upper Shell Brook (loc. 130).

Specimens from Pule Hill

Spec. no.	Lingual Diam.	Projn. L.	Striae/mm L.
a	18.0 mm	4.0 mm	5
b	16.0	4.0	4
c	13.0	3.5	4
e	11.0	2.4+	4
d	7.0	2.0	4

Specimens from loc. 130, base of marine band

d	17.0	4.3	5
e	13.0	3.5	4
c	12.5	3.5	4
a	12.0	3.2	4-5
b	11.0	2.9	4

The ribs in this form are slightly crenulate (Plate 1.26a) but a concentric ornament occurs only on the lingua, which begins to form a slight groove in the impression of the external ornament. The ornament consists of bifurcating primary ribs, with a striation interpolated between sets of bifurcating primaries. An interpolated striation in the angle between the primaries does not appear to be present.

Because this form has a relatively coarse ornament and is strongly evolute, it is thought to be R. bilingue early form of Bisat, although the ornament never appears to be as widely spaced as 2/mm at 18 mm (ventral) diameter (Bisat, 1924, p.117).

Variants in the R. bilingue early form marine band

These variants have not been named, as the R. bilingue early form marine band is not particularly well exposed and no ordered or systematic faunal change could be found, such as that in the R. gracile marine band. At loc. 121 and 126, however, more delicately ornamented forms occur in the marine leaf containing Hd. ornatum. The base of the marine band is believed to be unexposed at both of these localities, as the coarsely ornamented form described above is absent, and Hd. ornatum does not occur at the base of the marine band at Pule Hill.

Delicately ornamented specimens, Meerbrook, loc. 121

Spec. no.	Lingual Diam.	Projection of the Lingua	Striae/mm L.
1	12.0 mm	-	5-6
2	12.0	1.8	8
3	9.0	1.8	6

The forward projection of the lingua in these forms is significantly less than in R. bilingue Bisat, and also less than R.

Plate 1.26

1.26a <u>R. bilingue</u> Bisat early form

x5$\frac{1}{4}$

Locality: Upper Shell Brook (130),

base of marine band.

1.26b <u>R.</u> aff. <u>wrighti</u> Hudson

x9

Locality: Meerbrook (12$\frac{1}{4}$).

Impression of external shell ornament from

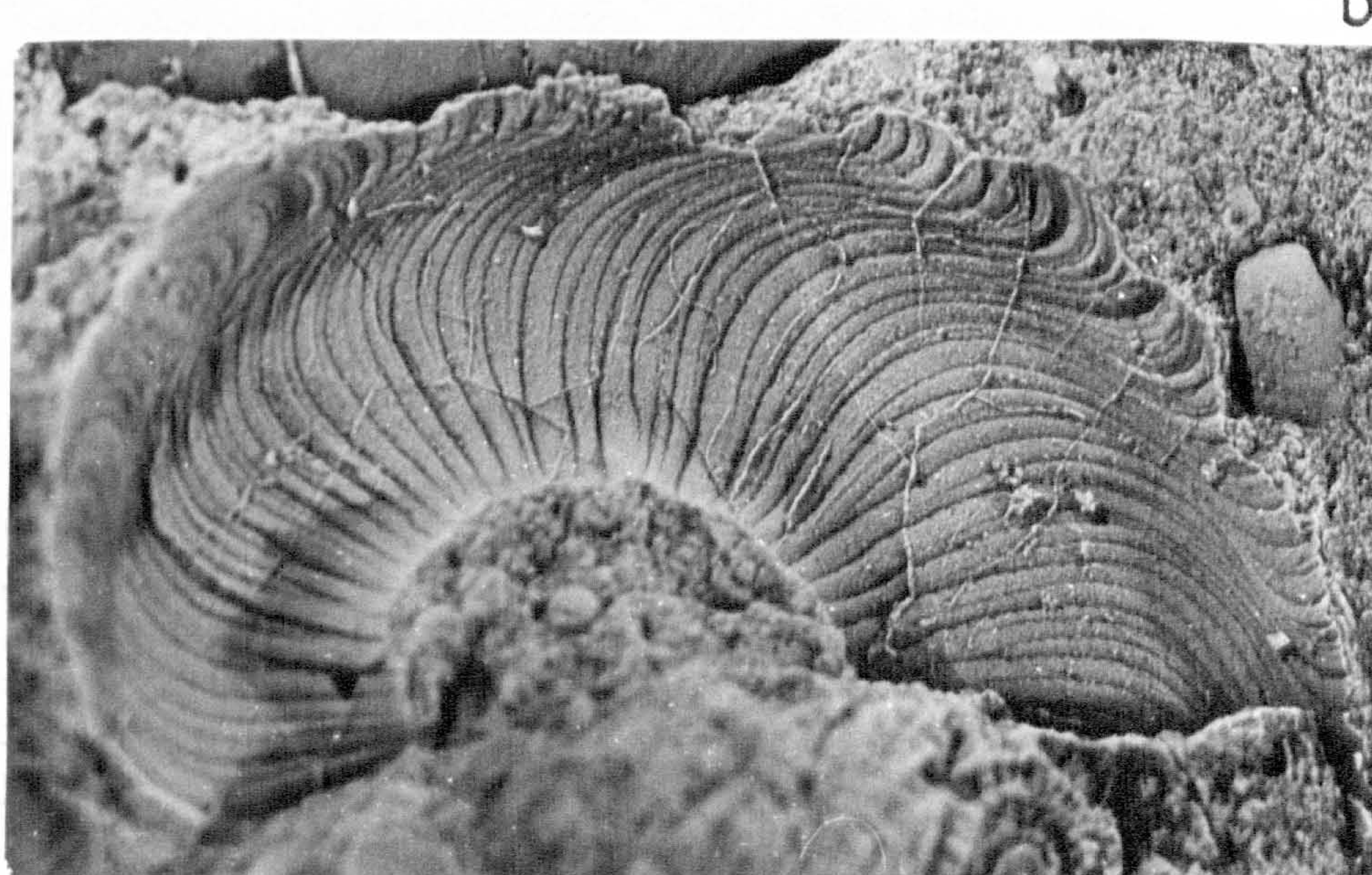
siderite concretion, middle marine leaf

exposed.

Pl. 1.26

a

b



bilingue early form from the base of the marine band. The strength of the ornament in different specimens is variable, but more closely spaced than in *R. bilingue* early form. Near to the top of the exposure (second and third marine leaves) more coarsely ornamented forms reappear, and specimens tending towards *R. wrighti* (Plate 1.26b) have been obtained. These show a pronounced raising of the lingua and strong forward flexure of the ribs.

Conclusions

The variation in specimens from this marine band is considerable when measurements of the rib strength and forward projection of the lingua are compared. However, there is no doubt that the specimens chosen for description all come from the *R. bilingue* early form marine band, identification of the band being made not merely by the presence of *R. bilingue* early form, but also by lithology and position in the succession. This emphasises, as in the case of the *R. bilingue* marine band, that collection across the width of the band is necessary for its identification, rather than collection from a single horizon. Although several variants occur, no order in the variation of the fauna could be established due to lack of continuous sections.

MARINE LEAF BETWEEN R. BILINGUE EARLY FORM AND THE R. BILINGUE BISAT MARINE BAND

Position of the leaf

At loc. 139 in the Upper Churnet, a thin marine leaf occurs at approximately 10.5-12.0 m above what are thought to be the higher beds of the *R. bilingue* early form marine band shales (preservation of these is poor). This interpretation of the succession is supported by the occurrence in Brund Borehole no.10 of a thin marine leaf at

10.8 m (36') above R. bilingue early form.

Fauna of the leaf

Because R.wrighti occurs in the "nodular beta band", above the R. bilingue early beds in Yorkshire (p.105), it might have been expected to occur in this marine leaf in the Churnet. The goniatites in this $R2b_i$ leaf, however, are confined to R. bilingue s.l., and a rarer more delicately ornamented form thought to be previously undescribed. The fauna in the Brund Borehole is restricted to lamellibranchs.

Reticuloceras species nova (no.9)

The radial ornament in this form is delicately crenulate, and extremely similar to the ornament of R. retiforme. In larger specimens (lingual diameter greater than 20 mm), all striae emerge radially from the umbilicus, and the mode of rib interpolation and bifurcation cannot be seen. A concentric ornament is developed on the flank but is subordinate to the radial. This concentric ornament is most prominent on the lingua where up to seven well defined spirals may be seen, causing distinct crenulation of the radial ornament (Plate 1.27).

Fragments of specimens at smaller diameters show the ornament during the adolescent stages. At 13 mm diameter, primary ribs emerging from the umbilicus are slightly stronger than the interpolated striations, in contrast to the mature specimens where the radial ornament is of equal strength. The typical R. bilingue ornament is not developed, the organisation of the radial ornament having greater affinity with that of R. retiforme and R. gracile. Primaries emerge straight from the umbilicus at 10 mm diameter, but do not bifurcate. Up to 3-4 striae are interpolated between the

Pl. 1.27

Reticuloceras sp. nova (no.9)

x5½

Locality: Upper Churnet (139_3)

Impression of external shell ornament in shale.

simple primaries at varying distances from the umbilical edge. One of these striations may approach a primary to give the appearance of bifurcation at 0.75 mm from the umbilical edge. At smaller diameters, umbilical plications are present and striations interpolated to within 1.0 mm of the umbilical edge. The concentric ornament is weakly and irregularly developed on the flank.

This goniatite is extremely similar to R. retiforme and could be derived from the earlier species. It can be distinguished from the R2a species by the lack of development of folds on the flank, parallel to the radial ornament, slightly coarser ornament and greater projection of the lingua than in R. retiforme.

Spec. no.	Lingual D.	Projn. L.	Striae/ mm L.	Striae/ mm flank	Umbilicus
139_1	21.0 mm	3.0 mm	6-7	8-10	7 mm (33% of diam)
139_2	13.0	2.5	10-11	10-11	-

THE RETICULOCERAS BILINGUE BISAT MARINE BAND, $R2b_{ii}$

Previous records of R. bilingue Bisat in North Staffordshire

The R. bilingue marine band was originally recorded in the Upper Churnet Valley by Challinor (1929, loc. S 16) as the mut. beta marine band, and also recorded by Cope (1946) at one of the contorted band localities. Morris (1966a) mentioned Challinor's locality, and also recorded the R. bilingue marine band in Star Wood, Oakamoor. Localities north of the Churnet were also recorded by Cope.

Evans et al. (1968, p.70-71, locs. 174a-b and 173a-b) recorded two exposures of the $R2b_{ii}$ marine band in the River Dane section, confirmed in this account (locs. 149, 150). The locality in

Fairboroughs Wood (ibid., p.71, loc. 185) was not found but another at 152 yielded R. bilingue Bisat.

Value in correlation

In districts to the east of the Pennines around Ollerton (Edwards, 1967), the R2b marine bands fail, and to the north around Kirkby Malzeard and the River Ure, Wilson and Thompson (1965) record only Lingula bands as the representatives of the R2 fauna. The Ashover Boreholes record an R. bilingue fauna in a band 1.25 m (49") thick (Ramsbottom et al. 1962, p.120), so that a change must take place in an easterly direction towards the Ollerton and Mansfield areas, where goniatites are absent. The marine band has also been recorded in north Wales (Wood, 1936).

R. bilingue (Salter) has been recorded in Belgium by Demanet (1941). The figured specimens of R. bilingue (Salter) (ibid. pl. XVIII, figs. 1-5) are not, however, R. bilingue Bisat (see p.148), as the lingua is too broad and projects insufficiently far forwards. Patteisky (1959, Plate 6, figs.1-20) figured R. bilingue (Salter), and included Bisat, 1924 (Pl. III, fig. 9) in his synonomy (Patteisky 1959, p.24). Patteisky's specimens are certainly not the same as R. bilingue Bisat, and some may even be R. gracile (s.l.). Similar forms to those described as R. bilingue (Salter) by Demanet are known to occur in $R2b_{i}$ and $R2b_{ii}$. These goniatites could well be from either marine band as Demanet probably followed Bisat (1924) who said that either his "mutation beta" or the "early mutation" could be "goniatites bilingue" of Salter. R. bilingue has also been recorded from the region of Colomb-Bechar, Algeria by Deleau (1960).

Thickness variations

As in the R. bilingue early form and R. gracile marine bands, the R. bilingue marine band shows considerable variation in thickness and in the number of fossiliferous leaves developed in the North Staffordshire area. The marine band is often composite, showing the development of three marine leaves.

In the Upper Churnet Valley, where thin sandstones are present between R. bilingue and R. bilingue early form, the band is split into three marine leaves. The composite marine band, including the intervening leaves of unfossiliferous shales, totals 3.87 m at loc. 140. Where a thick sequence of $R2b_i$ turbidites is locally developed in the River Dane section, the $R2b_{ii}$ marine band is also split into at least two marine leaves (the exposure is limited), and to the south of the Churnet in the Thorncliff stream section, the band is also split despite the absence of the K-feldspathic lithofacies.

On the southern margins of the North Staffordshire basin, however, the R. bilingue marine band is represented by a single marine unit 2.8 m thick. The total interval between $R2b_i$ and $R2b_{ii}$ marine bands is approximately 7.5 m in this area, compared with 21 m (70') in the Brund Boreholes, 29 m (99') in the River Dane section, and 15 m (50') approximately in the Upper Churnet.

Lithology and preservation of the fauna

Specimens from the lowest marine leaf in the Upper Churnet (loc. 140) are poorly preserved at the base of the band, as the shales adhere to the shell and no impression of the external ornament is obtained. The shales are black and fissile, and contain abundant Dunbarella and Posidoniella, often pyritised. Orthocone nautiloids occur. Preservation is better in the upper part of the lowest marine leaf where R. bilingue s.l. occurs, beneath R. bilingue Bisat.

The second marine leaf contains siderite nodules which have yielded abundant, well preserved goniatites (only half crushed) which show the impression of the external ornament. The third leaf has the most abundant fauna, goniatite impressions often overlapping and covering the whole of shale slabs.

An abundant fauna has also been recovered from siderite nodules in the Thorncliff stream section (loc. 158), and the River Dane (loc. 150). Calcite bullions occur in the first leaf of the marine band at loc. 149, and contain a well preserved fauna, often with mineral oil in the cavities of the shell. Aragonite has been found in these bullions also. All specimens from Oakamoor are crushed in shale, as occasional ankerite bullions are barren.

List of fauna

Reticuloceras species nova	Third marine leaf (top)
Reticuloceras species nova	Second marine leaf
R. bilingue Bisat	First marine leaf
Reticuloceras species nova of *R. bilingue* group	First marine leaf
R. bilingue s.l.	First marine leaf

Material

Because measurement of the position of the specimens within the marine band is facilitated by the development of three marine leaves in the Upper Churnet (loc. 140), and preservation of the fauna is relatively good, most specimens used in the description of the fauna have been chosen from this locality. Specimens are described from each of the three marine leaves.

Description of the fauna of the R. bilingue marine band

A. Description of the fauna of the first (lowest) marine leaf

Reticuloceras bilingue Bisat s.l.

Description

Material obtained from the base of the first marine leaf is all preserved as shale impressions. The lingual groove of the impression is not well defined in this form, the striae, radial at first, bending gently forwards into a rather blunt lingua. The ornament is finer than in R. bilingue s.s. and the accompanying specimens of R. bilingue group. The ornament is also delicately crenulate, unlike R. bilingue Bisat s.s., and a concentric ornament, marked on the lingua, persists in a modified form on the upper part of the flank.

Specimen no.	Lingual diam.	Projn. L.	Striae/mm L.
140_{3i}	8.0 mm	2.0 mm	4-5
140_{3k}	12.0	2.5	5
140_{3j}	14.0	2.8	5
140_{3l}	17.0	3.0	5

This is the dominant form in the lower part of the marine band, and is indistinguishable from some goniatites in the R. bilingue early form group. Similar forms were found to accompany R. bilingue s.s. and R. bilingue group in the Colne Mills borehole (I.G.S. specimens).

Reticuloceras sp. nova of R. bilingue group

A single example (Plate 1.28a) was found in the lowest marine leaf and it was suspected that it might be a distinct type. Material from the Colne Mills Borehole (I.G.S. specimen GN 379) confirmed that this was the case. In the borehole material, R. sp. of R. bilingue group was accompanied by both R. bilingue s.s. and R. bilingue s.l. R. sp. of R. bilingue group is characterised by its evolute form with a strong, barely crenulate ornament. The radial ornament is slightly more widely spaced than in R. bilingue s.s., but the projection of the lingua less. The lingua in this form is broader than in R. bilingue s.s., and less clearly defined because of the gentle inflexion of the striae across the whole of the flank instead of the sharp inflexion of the radial ornament into the lingual groove (raised in the "solid" specimens).

Reticuloceras bilingue Bisat

Reticuloceras reticulatum mutation beta (Reticuloceras bilingue)
Bisat, 1924, pl.III, fig. 9 only, p.117.

Spirals on the lingual groove are virtually lacking, and less well developed than in R. bilingue s.l. The lingual groove, in impressions of the external ornament, is formed by the raising of the lingua into a distinct ridge. A concentric ornament is absent from the flank at all diameters, and the ornament virtually non-crenulate. The ornament is coarser than in R. bilingue s.l. (compare striations per mm on the lingua) and the striations of the radial ornament itself consistently stronger. The striations are at first radial but

Spec. no.	Lingual D.	Projn. L.	Ribs/mm L.
140_{3h}	13.0 mm	4.5 mm	3
140_{3e}	14.0	4.0	4
140_{3c}	12.0	4.2	3
140_{3d}	9.0	3.0	4
140_{3g}	7.5	1.8	4
140_{3f}	4.5	0.8	3-4

bend rapidly forwards midway up the flank into a pronounced lingua. This is more sharply defined than in *R. bilingue* s.l., as the striae bend further and more sharply forwards, and a lingual groove is formed. The lingua in the specimen at 9 mm diameter (Plate 1.28b) projects 3 mm forwards, compared with just over 3 mm for Bisat's figured specimen at 9 mm diameter (ventral).

Discussion

This species was described by Bisat and named "mutation *beta*" -- this name now having been discarded in preference to "*R. bilingue*". "*R. bilingue*" was figured by Bisat in Pl. III, figs. 7-9 and Pl. VII, figs. 1-4. In the latter plate, the specimens are not of a suitable size for specific identification, except for the specimen in fig. 2, now known as *R. wrighti*. In Pl. III, specimens in figs. 7 and 8 are also unsuitable for specific identification, but fig. 9 is taken to represent *R. bilingue* Bisat.

This species is in fact relatively rare in the *R. bilingue* marine band. A few specimens were noted in the Colne Mills Borehole, but the form appeared to be absent in the borehole at New Mills, Stainland. *R. bilingue* Bisat in Staffordshire is limited to the upper part of the lowest of the three leaves developed at loc. 140. Consequently, although the form is distinctive, it is often not particularly useful in the identification of the marine band where the whole of the marine sequence is not exposed. *R.* sp. nov. of *R. bilingue* group is even rarer, and *R. bilingue* s.l. occurs in both $R2b_i$ and $R2b_{ii}$. Thus the forms described from the two uppermost leaves have often been used to identify this marine band. *R. bilingue* Bisat is extremely similar to *R. eometabilingue* of the overlying marine band, but can be distinguished from it by the slightly lesser projection of the lingua. The width of the raised

Plate 1.28

1.28a *Reticuloceras* species nova of *R. bilingue* group

x11

Locality: Upper Churnet, $(140)_{3m}$, from lowest of three marine leaves

Impression of external shell ornament in shale.

1.28b *R. bilingue* Bisat

x5

Locality: Upper Churnet, $(140)_{3c}$, from upper part of lowest marine leaf.

Impression of external ornament in shale.

Plate 1.29

1.29a *Reticuloceras* species nova (no.11)

x8½

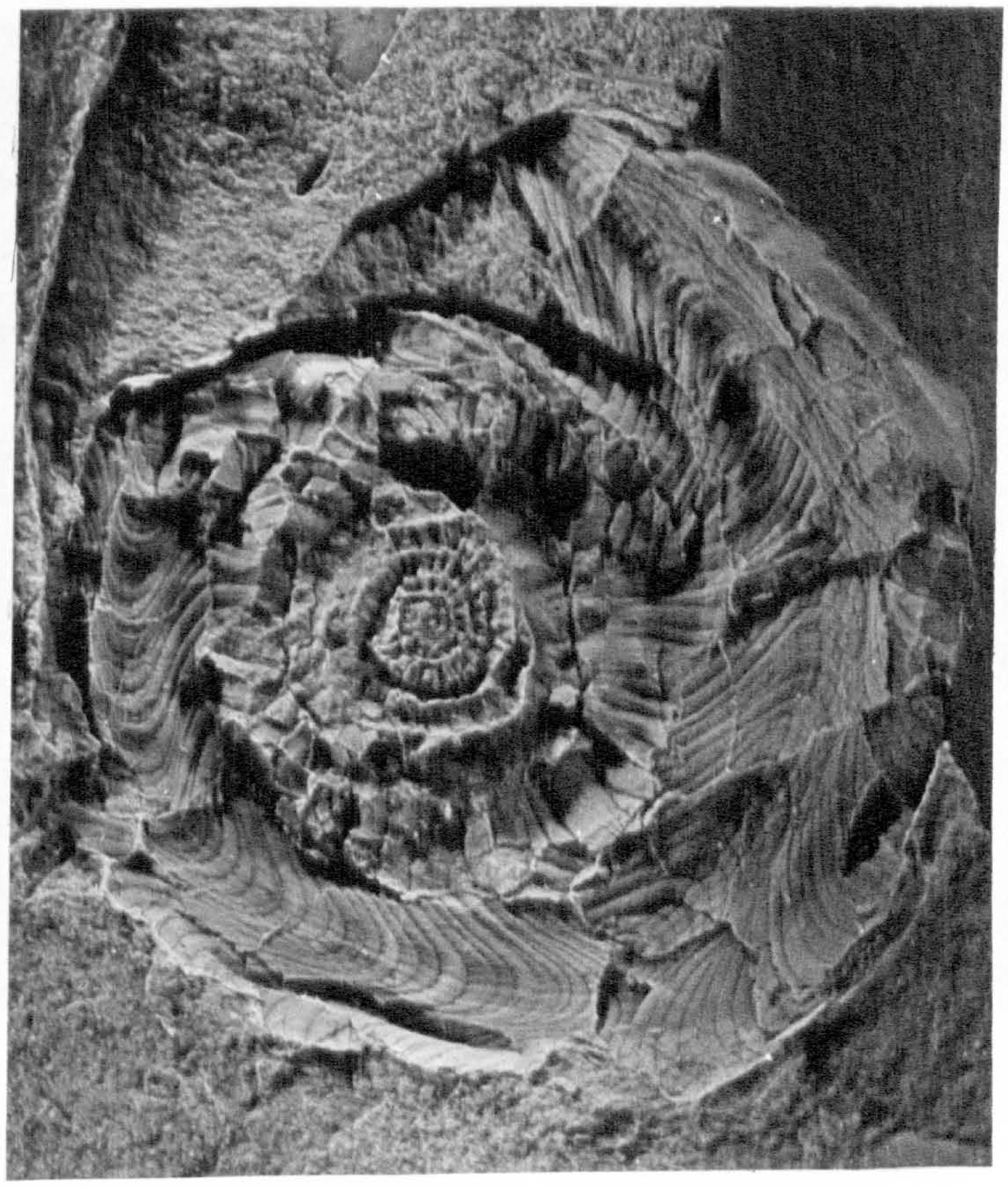
Locality: Upper Churnet, $(140)_{4f}$. Second marine leaf

1.29b *Reticuloceras* species nova

x5½

Locality: as above, third marine leaf, 140_{5d}

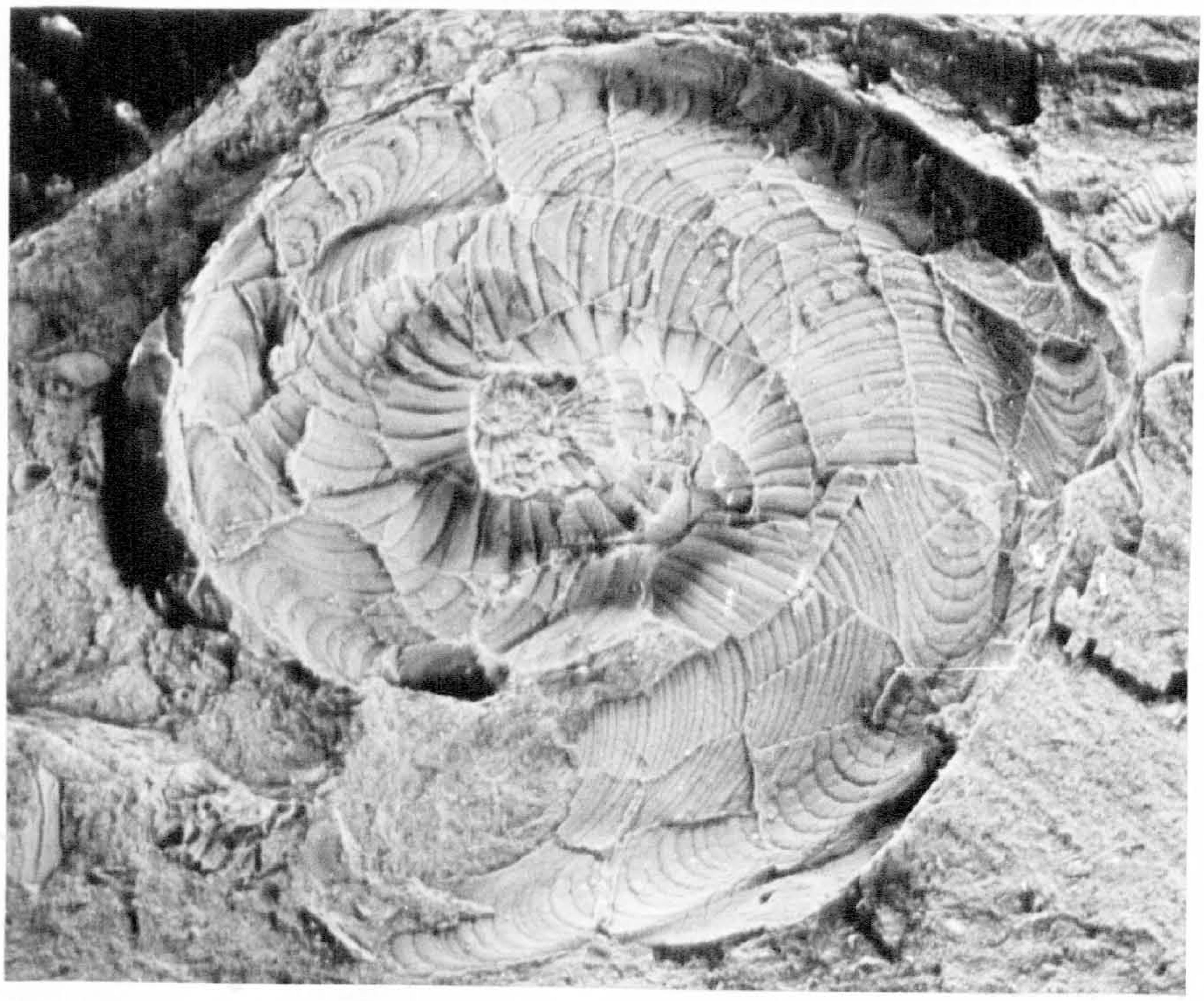
Pl. 1.28



a

b

Pl. 1.29



a

b

area of the lingua is similar, but the grooves at the margin of the raised lingua are less well developed.

B. Description of the fauna of the second and third marine leaves

Reticuloceras species nova of R. bilingue group

The goniatites of the second and third marine leaves, although exhibiting slight differences, are clearly related to each other. Although two forms can be distinguished where the marine band is split into marine leaves, it is doubtful if the distinction could easily be recognised in a thinner succession. The goniatites of the second and third leaves have, therefore, been described together.

Specimens from the second marine leaf

Specimen no.	Lingual D.	Projn. L.	Striae/mm L.
140_{4d}	6.0 mm	1.5 mm	4
140_{4a}	8.0	1.8	6
140_{4f}	9.0	2.0	5
140_{4c}	11.0	2.8	6
140_{4b}	14.0	2.5	8-9
140_{4e}	25.0	4.0	8-9

Specimens from the third marine leaf

140_{5c}	8.0	2.2	4
140_{5a}	11.0	2.8	7
140_{5b}	13.0	3.4	4-5
140_{5d}	15.0	3.5	5

Spirals are virtually absent on the lingua, only two faint ones occurring in some specimens from the second leaf. Juvenile specimens have almost straight ribs and interpolated striations (Plate 1.29a and b) but wavy striations occur at larger diameters and are accompanied by faint concentric striations on the flank in specimens from leaf three. The spacing of the radial ornament is similar in specimens from the two leaves, but the forward projection of the lingua in the higher form is slightly greater. The projection of the lingua in no case exceeds that of R. bilingue Bisat. The raised lingua is well developed in specimens from both leaves, but becomes more clearly defined in the higher form where adjacent slight lingual grooves are present (compare Plate 1.29a and b).

The delicate ornament and raised lingua, which projects less far forwards than in R. bilingue Bisat, suggest that this species is more closely related to R. wrighti than R. bilingue, which has more affinity with R. eometabilingue.

R. sp. nova may have been the goniatite noted as R. bilingue late form in the R. bilingue marine band by Hudson (1945b). The species has been recognised by Ramsbottom (in Evans et al. 1968, p.82), who found that at loc. 150 in the River Dane section, in the upper part of the R. bilingue band, ". . . there is another Reticuloceras which appears to be undescribed and is involute with fine subcrenulate transverse striae".

APPENDIX TO PALAEONTOLOGY

THE BRUND BOREHOLES

A series of boreholes, known as the Brund Boreholes, were drilled across the Manifold Valley, south of Longnor (just north of Wiggenstall) in 1969. The material was collected and catalogued by The Institute of Geological Sciences, and the material deposited at Leeds. Dr Ramsbottom has kindly given permission to reproduce the author's results of the examination of the material and correlation of the boreholes in this account. All records were in feet and inches, and have not been converted to metric equivalents.

The boreholes chosen for detailed examination record the R1 succession {see Appendix Figure II} from the R. paucicrenulatum marine band (in Brund 1), up to $R2b_{ii}$ in Brund 10. No borehole proved the full thickness of the Longnor sandstone. Potentially, the boreholes were of great interest palaeontologically, because they were expected to provide useful information on the R1b succession (imperfectly known), and also to indicate how many R1c faunal bands are present. The boreholes have also provided some useful and otherwise unobtainable information on the complex distribution of the protoquartzite sandstones in the area (Chapter 3).

THE KINDERSCOUTIAN

THE R. TODMORDENENSE SUBZONE, $R1a_2$

This was penetrated in Brund 1 only. A "bentonite" horizon (kaolinised ash band) consistently occurs near the base of the R. paucicrenulatum marine band in North Staffordshire and was penetrated in this borehole, where it was recorded as a "pale grey pyritous band".

Most abundant at this horizon is R. pulchellum. It occurs with R. paucicrenulatum/circumplicatile group (evolute forms with more than one interpolated striation between the bifurcating primaries, probably of late R. circumplicatile stock). Accompanying them is the distinctive, delicately ornamented form, described in this account as R. sp. nova of R. pulchellum group. Doubtful specimens of R. adpressum-dubium group were recorded at 104' 8".

The $R1a_2$ marine band is apparently thicker than expected from measured field sections, and it is thought that the borehole succession may be repeated due to faulting. Vertical beds were recorded at 98' 3", and above this a fauna of _R_. cf. _dubium_ recorded at 95' 6", _R_. cf. _pulchellum_ (94'), _R_. cf. _paucicrenulatum_ (92' 7" and 90') -- these evolute forms were mistakenly identified as _R_. _nodosum_ group at first -- and _R_. cf. _dubium_ and other specimens of barely crenulate goniatites at 87' 8" and 87' 10". Apart from the record of _R_. cf. _dubium_ at 95' 6", the fauna of _R_. cf. _paucicrenulatum_ passing upwards again into _R_. cf. _dubium_ also suggests a repetition of the succession. Goniatites are rare from 87' 2" to 78' 1". These strata are characterised by a fauna of _Dunbarella_, _Caneyella_, rare _Reticuloceras_ sp. and a specimen doubtfully identified as _H_. _spiraloides_ (82' 6"). Matted _Dunbarella_ horizons occur at 77' 9" and 84' 9", at the base and top of the sparsely fossiliferous shales which occur between recognisable R1a and R1b faunas. The lower of the _Dunbarella_ horizons has been correlated with that which occurs at the top of the $R1a_2$ fauna in the Blake Brook section. Apart from one goniatite, spat phases and a barren sample were recorded between 79' 6" and 81' 6" suggesting a slight break between R1a and R1b. This is less than the non-marine break recorded in the field between the two marine bands. _R_. _dubium_ in Staffordshire occurs only in $R1a_2$, however, the occurrence of this form at 87' 8" suggesting that this position is virtually the top of the $R1a_2$ sequence. This conclusion is supported by the fauna which occurs between 78' 1" and 72' 6" which consists predominantly of _R_. _moorei/eoreticulatum_ group with (?)_H_. _spiraloides_, and is similar to the fauna of $R1b_i$ recorded from the Blake Brook.

THE R. NODOSUM ZONE, R1b

The R1b fauna of _R_. _moorei/eoreticulatum_ group, with (?)_H_. _spiraloides_ and _R_. cf. _nodosum_ is followed by a barren interval from

72' 1" to 67' 6", where Dunbarella and thinner-shelled goniatites reappear. The fauna between 67' 6" in the borehole and 60' is characterised by an abundance of Homoceras, also noted in $R1b_{ii}$ in the Thorncliff section. Reticuloceras specimens are rare and poorly preserved, and could only be referred to R. cf. moorei. The position of this fauna with respect to $R1b_{i}$ and the abundance of a Homoceras (probably H. henkei) fauna indicate that the band is in fact $R1b_{ii}$.

The succeeding marine band in the borehole (53' 5" to 47' 2", with a sparse fauna between 47' 2" and 45' 3") is followed by a matted Dunbarella band between 45' 2" and 44' 10". This band corresponds to $R1b_{iii}$, the matted Dunbarella horizon correlating with that recorded in the Thorncliff section, the Ashover Boreholes, and in Swint Clough. The fauna is characterised by a preponderance of R. nodosum group (R. aff. nodosum and R. cf. nodosum were recorded), accompanied by more delicately ornamented forms of R. moorei/eoreticulatum group. Orthocone nautiloids occur. This marine band was also penetrated in Brund 2, where the bullion recovered at 102' may correspond to the level of the impure limestone in Brund 1 (48' 6"), and the matted Dunbarella horizon at 98' 1" to that at the top of the marine band in Brund 1.

No specimens were collected in Brund 2 from 97' 10"–90' 3", possibly indicating a sparse fauna. This postulated break is thought to correlate with a less fossiliferous section between 43' 4" — 40' 11" in Brund 1 where the shales do not contain goniatites. There is no development of barren shales between the fauna of $R1b_{iii}$ (poorly preserved in Brund 2, and only identified by extrapolation downwards from the fauna of $R1b_{v}$) and $R1b_{iv}$ in either of the two boreholes, both of them recording a fauna of spat and bivalves (occasional Dunbarella and Caneyella) in the interval between the $R1b_{iii}$ and $R1b_{iv}$ thicker-shelled goniatites.

$R1b_{iv}$ in the boreholes was of interest because a distinctive thicker-shelled goniatite fauna had not so far been found at this level in the field exposure. The band in the boreholes, as in the field exposures, has been identified by its position adjacent to $R1b_v$. The band was penetrated in Brund 1, 2 and 3. In Brund 3, R. moorei/stubblefieldi group was recorded at 140'. The absence of records of a fauna between 139' 6" and 132' 4" probably indicates a less fossiliferous break between this fauna and that identified as $R1b_v$ above 132' 4". The $R1b_{iv}$ goniatite fauna between 40' 10"--37' 9" in Brund 1 is not well preserved, only a few fragments of coarsely ornamented forms occurring. These have, however, been correlated with the fauna of Brund 2 between 90' 3"--78' 6", where coarsely ornamented forms also occur. The best specimens are found at 88' 11"--89' 1" and are characterised by a widely spaced radial ornament which lacks the development of nodes characteristic of R. nodosum. These specimens have been noted as R. stubblefieldi group, and do suggest that the horizon of the holotype could be as low as $R1b_{iv}$, rather than $R1b_v$.

$R1b_{iv}$ is closely followed by $R1b_v$. Correlation of the boreholes was facilitated by the presence of this band and that of $R1a_2$, both of which contain faunas more distinctive and better preserved than all the other R1 marine bands. Core recovery was unfortunately poor in Brund 1 at this level, but the typical fauna was recovered at 29--30'. The best specimens, however, have been obtained from Brund 2, 3 and Brund 11, which also penetrated as low as $R1b_v$. The band was recorded between 73' 2"--59' 2" in Brund 2, from 132' 4"--116' 6" in Brund 3 and 153' 10"--141' 11" in Brund 11. The goniatite-bearing parts of the bands in Brund 11 and 3 are also overlain by quasi-marine shales with a few lamellibranchs.

The fauna of $R1b_v$ in the boreholes is relatively well preserved, and goniatites of the R. moorei and stubblefieldi groups are common. At the base of the marine band, more delicately ornamented forms (referred to in this account as R. prereticulatum species nova) predominate, but higher in the marine band coarsely ornamented forms appear. A single specimen thought to be R. moorei occurs in Brund 3, 7" from the base of the marine band.

R. prereticulatum species nova

Spec. no.	Lingual D.	Projn. L.	Striae/mm Lingua
CGB 4759	16.0 mm	2.0 mm	5
CGB 4760	13.0	2.0	4

This is an involute form with faint spirals on the flank which become more pronounced on the lingua. It is similar to R. reticulatum s.s.

R. moorei/stubblefieldi group

A goniatite referable to this group occurs commonly only in boreholes 2, 3 and 11.

Brund 2	CGB 4721	at	62' 9"
	4756	at	70'
Brund 11	CGB 4302	at	153' 3"
	4305	at	153' 8"
Brund 3	CGB 4954	at	130' 1"
	4978	at	140'

These specimens are too evolute for R. moorei, but the ornament is less widely spaced than in R. stubblefieldi, the rib spacing on the lingua being intermediate between the two.

R. aff. stubblefieldi

	Lingual D.	Striae/mm L.	Projn. L.
Brund 2 CGB 4719 at 62' 7"	15.0 mm	2	2.0 mm approx.

This specimen and also CGB 4720 have been recorded as R. aff. stubblefieldi. They are similar to the specimens described from $R1b_v$ of this account as R. stubblefieldi. R. cf. stubblefieldi has also been recorded lower in Brund 2 from 69' 10" to 70' 1" (specimens 4754-7).

Reticuloceras species nova (number 3)

Apart from the specimen from Brund 3, all of these goniatites are fairly delicately ornamented, the striae occurring at about 5/mm on the lingua at 15 mm lingual diameter. All the specimens are involute with ribs radial from the umbilicus. These flex forward into an extremely shallow lingua. The delicate ribs are non-crenulate on the flank, but slight roughening of the radial ornament is just perceptible on the lingua. This and the absence of a concentric umbilical ornament suggest that the form is Reticuloceras rather than Homoceras. The form is probably previously undescribed. Chalard (1960), however, refers to an R. moorei/stubblefieldi fauna from the north of France, the fauna including a form called "R. adpressum". This may be the same form as that described above from the boreholes.

In the boreholes, this non-reticulate goniatite is confined to the upper part of the $R1b_v$ marine band, and is extremely useful in correlation. In the field, this part of the marine band is often poorly exposed, and collection of the fauna has largely been made from the lower part of the band only. At loc. 066, however, this non-reticulate form is present, indicating (with the R. moorei and stubblefieldi specimens) an $R1b_v$ fauna.

Dimensions of *Reticuloceras* sp. nova

		Lingual D.	Striae/ mm L.	Projn. L.
Brund 2.	CGB 4694	15-20 mm	4	- (internal mould)
	4695	8	3-4	small
	4697	13 approx.	5	0.5 max. (good specimen)
	4698	20 approx.	7	0.75 (fragment)
Brund 11.	CGB 4232	14	5	small (small umbilicus, 3 mm)
	4233	fragments only		
	4234	fragments only		
	4236	15 approx.	6	0.5
Brund 3.	CGB 4929	20 approx.	2-3	1.2 (small umbilicus, 4mm)

Homoceratoides aff. *divaricatus*

This form has been recorded at several exposures in $R1b_v$ as well as in the Ashover Boreholes. In the field, it is most common near the base of the marine band where it accompanies *R. prereticulatum*. Fragments of a *Homoceratoides* specimen have also been found in the basal part of the marine band in Brund 2.

"Bentonites"

Two "bentonite" horizons, referred to in this account as kaolinised ash bands (Chapter 2), have been found near the base of the $R1b_v$ marine band at several localities in the North Staffordshire area. Around Longnor, the ash bands fail, probably because of the greater rate of sedimentation associated with the local development of the protoquartzites. The ash bands may have been seen in Brund 11, however, as the borehole log records a "pale grey very silty lamina (?K bentonite)" at 148' 5", and a "thin paler silty lamina" at 151' 11".

THE R. RETICULATUM ZONE, R1c

The R1c succession is seen in boreholes 3 and 11. No faunal bands above $R1b_v$ were penetrated in Brund 2 which proved only thin beds of quartzites and ironstones from 9' to 56', still in R1b. Traces of a marine fauna were encountered, however, in Brund 3 at 55' 4"--56' 8", where pale brown markings and spat were noted, and pyrite traces below 58' 5". The same quasi-marine conditions were recorded in Brund 11 above the protoquartzite/ironstone succession. Brown patches and a few spat were recorded at 95' 0"--97' 0", and pyritic burrows at 98' 8"--99' 0". This marine band is thought to correlate with a low R1c marine band of the Blake Brook succession, where a few lamellibranchs occur and similar brown patches on the shales and in bullion material. It is suggested that this R1c marine band of the Blake succession and of the boreholes is equivalent to one of the middle R1c marine bands rather than the lowest R. reticulatum band. The fish and spat phase at 137'--138' (above $R1b_v$) in Brund 11 could represent the lowest R1c marine band. Traces of marine conditions were suggested in Brund 3 at 44' (?spat with pale brown markings), at 50' 1" (fish debris), and below 48' (pyritous markings). These traces were correlated with quasi-marine conditions in Brund 11 between 74' 3" and 86' 7" (74' 3"--74' 9", brown patches abundant and a few spat, 78'--pyritous burrows, 82' 6"--83' 0" and 86' 6"--86' 7", pyritous burrows). These indications of quasi-marine conditions have not been noted in the field, and could be the equivalent of a middle R1c marine band. The succession in Brund 11 is slightly thicker than in Brund 3, and the traces of a fauna are separated from the R. sp. nova (no.4) marine band by thin K-feldspathic sandstones. The latter are absent in Brund 3, and quasi-marine conditions appear, in fact, to persist between the level of the marine band mentioned above and occurrences of R. sp. nova.

This illustrates how rapidly conditions can change laterally. The boreholes were situated only approximately 425' apart, yet the sandstone development of Brund 11 appears to have replaced the quasi-marine indications of Brund 3.

The highest R1c fauna recorded in Brund 3 and 11 is that of R. sp. nova (no.4). This form was recorded at 51' and 49' 3" in Brund 11, and a fragment of a non-crenulate (small) goniatite at 37' in Brund 3. Traces of marine conditions occur up to 7' 6"--8' 6" below the base of the Longnor sandstone.

THE MARSDENIAN

THE R. GRACILE MARINE BAND, BRUND 5

As expected from field exposures, the marine band is split into an upper and lower main leaf, separated in the borehole by virtually barren beds between 128' 2" and 112' 2" (16'). Bioturbated laminae occur at 123'--123' 6", and "fucoids" below 121' (?pyritous trace fossils). There is no development of the lower R. *retiforme* leaf, as the base of the lower main leaf occurs at only 3' 1" above the Longnor sandstone. The upper R. *retiforme* leaf occurs at 88'--90'. Sporadic goniatites and spat occur between R. *retiforme* and the fauna of the upper main leaf at 100' 3".

The sequence of the R. *gracile* fauna in the split main leaf is the same as deduced from field exposures. Evolute forms of the R. *gracile* group (R. *gracilingue*) occur at the base of the marine band from 141' 8"--139' 3". Above this, more delicately ornamented goniatites occur, thought to be close to R. *gracile* Bisat. At the base of the upper main leaf (111' 11"--106' 4"), there are strongly evolute forms with a simple ornament, (R. latelirifer sp. nova), succeeded by more involute forms with a more delicate ornament (R. cf. graciloides), at 100'. The R. graciloides fauna is poorly developed in the boreholes, as in field sections.

THE R. BILINGUE EARLY FORM MARINE BAND $R2b_i$, BRUND 5 AND 10

78' of shales, and thin sandstones immediately beneath $R2b_i$, separate the R. gracile and R. bilingue early form faunas in Brund 5. No distinctive Reticuloceras specimens were obtained from the $R2b_i$ marine band in Brund 5, but just over 19' of $R2b_i$ fossiliferous shales were penetrated in Brund 10. The base of the marine band is not seen, but the occurrence of strongly evolute forms at the bottom of the borehole suggest that it penetrated almost to the marine band base. Hd. ornatum occurs at 106' 5" (7' 7" from the base of the borehole), accompanied by more delicately ornamented forms of the R. bilingue group, as in field exposures.

No specimens of R. wrighti were found in the $R2b_i$ marine band. A thin marine leaf was recorded at 58' 9"--58' 3", containing Posidoniella, spat and thinner-shelled goniatites. This could be the equivalent of the "nodular beta band" in Yorkshire, but it is thought to correlate with a thin marine leaf containing Reticuloceras sp. nov. (no.9). The marine leaf is followed by sandstones and ironstones from 58' to 35' 8", the siltstones and mudstones above the sandstone succession passing upwards into the R. bilingue marine band at 25' 9".

THE R. BILINGUE MARINE BAND, $R2b_{ii}$, BRUND 10

Only two lower leaves of the R. bilingue marine band are seen in the borehole, the first occurring at 25' 9"--16', and the second from 13'--12', above which no core was recovered. The intervening rocks are described as dark grey mudstones. The fauna from the upper of the two leaves is poorly preserved, and has been referred only to the *R. bilingue* group. *R. bilingue*, near typical, was recorded at 19' 6" in the lower leaf.

Comments on the succession

The Marsdenian succession was much as expected, both in the sequence of the fauna and development of marine bands. The lower *R. retiforme* leaf was not developed in this northern part of the field area, as expected from evidence from the Upper Churnet Valley.

In contrast to the Blake Brook section in R1b, however, the fossiliferous sequence of the boreholes extends uninterrupted from R1a to $R1b_v$ with no development of protoquartzites until after the $R1b_v$ marine band. In the Blake Brook, protoquartzites are developed post $R1b_{iii}$ (possibly $R1b_{iv}$) as well as between $R1b_v$ and lower R1c. As pointed out for the R1c succession, local arenaceous sedimentation appears to have taken place with very little effect on the adjacent rate of sedimentation and development of fossiliferous shales. Very little of the R1b sequence of the boreholes is in fact unfossiliferous (as was found in the Ashover succession) and the impression gained of discrete "marine bands", as seen in field exposures, may often be erroneous.

GLOSSARY OF TERMS USED IN DESCRIPTION OF THE GONIATITE FAUNA

lingua --- tongue-like, lateral or ventro-lateral forward inflexion of the radial ornament.

node --- rounded protuberance of the shell ornament also seen in relief on the internal mould.

plication --- elongated radial fold at the umbilical edge which degenerates into ribs or finer striations.

primary rib --- arises at the umbilicus or from the umbilical ornament of nodes or plications. The primary generally bifurcates to form two secondary ribs.

striation --- weaker radial ornament interpolated between primary ribs, or in the angle between secondary bifurcating ribs.

spirals --- concentric ornament usually weaker than the radial; often more pronounced on the lingua.

CHAPTER II

CORRELATION AND ORIGIN OF KINDERSCOUTIAN KAOLINISED ASH BANDS

CORRELATION AND ORIGIN OF KINDERSCOUTIAN KAOLINISED ASH BANDS

INTRODUCTION

In the course of collection of fossil material from goniatite-bearing shales, several light coloured bands, often with abundant iron pyrites, were recognised to occur consistently at particular stratigraphic horizons in the faunal succession. In view of the records of Trewin (1968, 1969) of lower Namurian K-bentonite horizons, these light coloured bands were examined to determine whether or not their mineralogy and genesis were similar to the bentonites.

Trewin (1969, p.97) recorded the bentonite clay bands as being less than 5 cm thick and variable in colour from white to yellow and orange, or green and blue. Secondary calcification was rare in his examples, and is also uncommon in the bands of the Kinderscoutian, although they often appear to have a carbonate cement in hand specimen. The colour of these specimens also varies from orange to yellow to white. A few pyrite-rich examples are greenish.

The Kinderscoutian bands are not prominent in the field in water-logged conditions where they are darker in colour. They are sometimes reduced in thickness to a mere parting which can only be recognised in dry conditions. The bands do not exceed 1.3 cm in thickness, and are generally between 0.5 and 1.0 cm thick.

STRATIGRAPHIC OCCURRENCE

The light coloured bands have only been found in the black fossiliferous shales. Despite careful examination of the unfossiliferous shales, similar bands do not appear to occur in this part of the succession, although Trewin (1969) recorded bentonite bed B3 within shale-mudstone between protoquartzites and siderites. The best developed bands occur in Rla_1 at the horizon of R. circumplicatile. A single band occurs in Rla_2 at the R. pulchellum horizon, and two bands also occur in Rlb_v (Appendix Figure I).

FIELD OCCURRENCE OF THE BANDS

The R. circumplicatile horizon

Table 2.1

The R. circumplicatile subzone bands

Locality	Distance between bands 3 and 4 in cm	Distance between bands 4 and 5 in cm	Width of bands 3	4	5	Distance of 5 below the Rla_2 band
007	31	27.5	4mm	10mm	5mm	-
008	-	33	-	4	5	4.0 m
009	-	7	-	2	4	4.0
010	28	27	3	6	5	4.1
012	-	27	-	6	10	4.2
014	35	25	4	8	8	4.5
017	-	61	-	8	5	7.0
020	-	27.5	-	5	10	4.5
Storris House, Otley, 93 km from Leek	-	32	-	8	8	-
Uppertown Borehole } 35 km	¼" band or pyrite only					3.0
Highoredish Borehole } from Leek	greenish-brown parting only					2.5

A well exposed section in the Upper Churnet (loc. 007) shows five clay bands, all continuous across the width of the exposure. The lower two bands (1 and 2) are the thinnest, each only three millimetres thick. They are separated from each other by 5 cm of black shale. Elsewhere, they are unrecorded. 10.5 cm above bed 2 are three more persistent bands, numbered 3, 4 and 5 in ascending order. These are 0.4, 1.0 and 0.5 cm thick respectively, compared with 0.3, 0.6 and 0.5 cm for three bands in Rla_1 in the Upper Manifold. These are thought to be the same three bands at the *R. circumplicatile* horizon because 1 and 2 are thin, and *R. circumplicatile* has been found at the level of bands 3-5 and above, but not as low as 1 and 2.

At other exposures where only two of the *R. circumplicatile* horizon bands are present, they are identified as 4 and 5 as band 3 is consistently thinner where it is seen to occur. Thicknesses and localities are given in Table 2.1.

The R. pulchellum horizon

The light coloured band which occurs at this horizon is as persistent as bands 4 and 5 of Rla_1. A list of localities where the band occurs is given below.

loc. 021 Churnet Valley
023 Oakenclough Brook
024 Upper Manifold Valley
027 Blake Brook
loc. 028 near Thirkelow Farm
031 Bearda
033 Shell Brook

In the field the band commonly occurs as a single orange-weathering streak. Fresh surfaces are a pale buff colour or greenish. The band often contains abundant pyrite, and in such cases is often irregular in thickness across the width of an exposure. At two localities, the band is light grey or white in colour and pyrite appears to be completely absent. The band does not occur in the south of the area in the Heath Hay Ravines section.

The R. moorei/stubblefieldi marine band, $R1b_v$

Two bands occur near the base of this marine band. The bands recorded in North Staffordshire are friable and lack a carbonate cement. They consist largely of clay minerals and pyrite. In the field they weather to a pale buff colour but when less leached, as in the exposure at Swint Clough, they are stained orange from the oxidation of the pyrite.

These two bands are less persistent than those in R1a. Thickness varies from 0.6-0.4 cm in these two bands at loc. 072 to 0.5 cm for a single band of pyrite and clay minerals at loc. 062. The goniatites and crinoid stems establish that at these two localities the same marine band is exposed and that it is one of the clay bands which fails. In the River Dane area, these two bands are sporadic in their development. At loc. 067 the typical $R1b_v$ fauna is present, but there is no trace of either of the clay bands. Within the same area, a thin, pyrite-rich band at loc. 071 may also be one of these bands. Other variations are given in the table below.

Localities	Thickness of upper band in cm	Thickness of lower band in cm	Distance between bands in cm
062	one band, 0.5 cm		-
068	0.5	0.8	5
069	0.5	0.8	8
072	0.4	0.6	7
073	1.0 (approx.)	1.0	45

EXTENT OF THE LIGHT COLOURED CLAY BANDS

The bands are often rich in pyrite and probably correlate with similar "greenish" and "pyritous" bands and streaks recorded in the Ashover Boreholes, judging by their positions relative to the faunal succession (Appendix Figure I). The light coloured bands tend to be impersistent at the *R. circumplicatile* horizon in the boreholes, only one having been recorded as a ¼" band of pyrite in the Highoredish Borehole, and one as a "greenish-brown parting" in the Uppertown Borehole. There is no record of their presence in the Tansley Borehole (Ramsbottom *et al.* 1962). The three main $R1a_1$ bands (numbers 3-5) are persistent in the North Staffordshire Basin except in sections marginal to deltaic areas.

Two light coloured bands have also been recognised at the *R. circumplicatile* horizon in the section at Storris House, Otley in Yorkshire. These bands persist at a greater distance from Staffordshire than any other light coloured bands or bentonites known so far.

The $R1a_2$ clay band is present in Edale, and has been recorded from two of the Ashover Boreholes. A 4" band of "cank" with a ½" band of pyrite occurs beneath *R. pulchellum* and *R. paucicrenulatum* in the Tansley Borehole, and 3" of "pyritous cank" in the Uppertown Borehole at the same horizon. The $R1b_v$ bands are absent in the boreholes, but have been found in the same marine band in Swint Clough in Derbyshire.

INVESTIGATION OF THE MINERALOGY BY X-RAY DIFFRACTION

Preparation of the slides for x-ray diffraction

Only a limited amount of information could be obtained from thin sections of the specimens, and it was necessary to determine the clay mineralogy by x-ray diffraction. Dry specimens were ground with a pestle and mortar and the powder passed through a 240 mesh sieve. Approximately one gram of material was mixed with 10-15 c.c. of distilled water and a drop of 1% Calgon solution to prevent flocculation of the clay. The beaker containing the mixture was held in an ultra-sonic vibrator for a minute to aid in dispersion of the particles. Specimens rich in pyrite contained too much of the mineral to produce satisfactory results using Copper K-alpha radiation, as fluorescence of the iron-rich material produced high background radiation. The copper tube was used in preference to the iron tube for convenience, and for comparison of different diffractometer charts with shales previously x-rayed, using copper radiation. Excess pyrite was removed by agitation of the mixture in the beaker, allowing it to stand for twenty seconds, and then decanting the suspension. The majority of the pyrite was left behind and the suspension used for the slides.

Three slides were made for each sample and allowed to dry at room temperature. This method resulted in an even surface for the specimen and better basal orientation of the clay minerals than any other method. Estimations of the relative proportions of clay minerals present in charts obtained from slides made in this way can only give an approximate quantitative value. Gibbs (1965) showed that techniques using aqueous solutions, such as his pipette-on-glass slide method (similar to the method used here) produced results with higher amounts of montmorillonite relative to the 10 and 7 Å minerals. This was thought to result from the surface segregation of the smallest clay particles (montmorillonite in this case) due to the different settling velocities of the minerals in suspension. Estimates of clay mineral quantities in slides prepared from these Namurian samples must therefore be treated only as a rough guide.

Basal orientation of clay minerals is preferable to random orientation for easy identification as the sensitivity for detection of the various clay minerals is increased and the diffraction pattern simplified. A powder-press method (McCreery's method, in Klug and Alexander, p.300-301) was tried as this method gives quantatively more accurate results. Diffractometer charts were so poor, however, that this method was discarded. Gibbs (1965) used a smear-on-glass technique which has the advantages of orientating the clay minerals in a sample and also producing results which can be treated quantitatively as no segregation of the minerals takes place. This technique was also tried, but diffractometer charts were less distinct than those obtained using a drop-on-glass method, so that the latter, despite its quantative disadvantages, was retained.

Of the three slides prepared for each sample, one was used dried and untreated. A second was examined after glycolation for one hour at 60°C, and a third after heating for two hours at 550°C.

Diffractometer control settings

Cu K-alpha radiation, nickel filter

Generator 35 Kv 20 mA

Slits : fixed aperture diaphragm 0.3 mm

receiver diaphragm 0.1 mm

Baseline 12.0

Channel width 9

Detector voltage 1947.5

Statistical error 4 or 5%

Impulses per minute 1×10^4 or 4×10^3

Scanning speed 1° 2θ per minute

Charts speed 1 cm per minute

X-ray diffraction results

The light coloured bands consist largely of iron pyrites and clay minerals, with small amounts of quartz. No carbonates were recorded in any of the specimens x-rayed. Kaolinite is the predominant clay mineral in all but one of the samples. Some show strong peaks from 11 to 13 Å. The peak positions of the clay minerals are recorded in Table 2.2, and the results from adjacent samples of fossiliferous black shales for comparison in Table 2.3.

The Rla_1 clay band

The bands sampled at the R. circumplicatile horizon (Sample 014, band 4; sample 020, band 5) contain small amounts of quartz. 014_4 contains a larger amount of 12 Å clay minerals than kaolinite, in the ratio 3.2:1, calculated from peak areas. Kaolinite predominates in sample 020_5 in the ratio 6.4:1. Muscovite and illite peaks in the 10.1 - 9.99 Å range (Grim 1968) are absent. On glycolation, the 12 Å clay mineral peak disappeared in both samples but on heating to 550°C, the clay mineral peaks shifted to the 10 Å position, becoming sharper. Kaolinite peaks disappeared.

The Rla_2 clay band

The Rla_2 clay band (specimens 028, 021 and the sample from Edale*) showed more variable diffraction results. Specimen 028, white in hand specimen, showed no trace of 12 Å clays, illite or muscovite in the untreated sample. Heating to 550°C did not produce a 10 Å peak, but a 4.7 Å peak stayed indicating that some mixed layer clays could be present. All peaks recorded as kaolinite disappeared on heating and it was concluded that the white band consisted largely of kaolinite, subsidiary quartz and gypsum.

* upstream from loc. 14 in Hudson and Cotton, 1945.

021 and the specimen from Edale (E) produced different diffractometer traces. 021 produced a high background on the diffractometer chart, probably from the retention of pyrite not wholly separated by the decanting method. A poorly defined raised area from 12 - 10 Å disappeared on glycolation, and shifted to 9 - 10 Å on heating to 550°C. Kaolinite is more abundant than the 10 - 12 Å clay minerals.

Specimen E showed a marked reduction in the kaolinite peak heights (001 and 002), 12 Å clay minerals predominating over kaolinite in the ratio 7.1:1 (using peak areas). Glycolation resulted in a partial collapse of the 12 Å peak and also resulted in a shift of the average peak position to 12.82 Å from 12.13 (untreated sample). Kaolinite remained unaffected. Heating (550°C) resulted in the disappearance of kaolinite peaks, and the sharpening of the 12 Å peak at 10 Å.

$\underline{R1b}_v$

The lower of the two light coloured clay bands in Swint Clough (073_1) contains a significant proportion of 11.4 Å clay minerals. Peak areas of the kaolinite and 11 Å clay minerals indicate a 1.3:1 ratio of the clays. Glycolation produced a partial collapse of the 11 Å peak and a spreading of the peak in the range 11.52 to 11.04 Å. Only a weak shift in the average peak position was observed. Heating at 550°C destroyed the kaolinite peaks and resulted in the sharpening of the 11 Å peak at 10 Å.

The $R1b_v$ clay bed at loc. 062 showed negligible proportions of 11 - 12 Å clay minerals in untreated and glycolated specimens, but a diffuse 10 Å peak was produced on heating at 550°C.

Table 2.2

Diffraction results in Å from the light coloured clay bands

Specimen number		MM 001	K 001	MM	MM	K 002
014_4	O	13.07-11.40 (ave. 11.93)	7.16	5.091	4.449	3.574
	H	9.87	-	-	4.480	-
020_5	O	12.19	7.29	5.097	4.436	3.567
	H	10.33-9.5	-	-	4.426	-
021	O	(12.53-10.97)	7.19	-	4.475	3.574
	H	(10.33-9.87)	-	-	4.458	-
028	O	-	7.21	5.099	4.469	3.581
	H	-	-	-	4.469	-
062	O	-	7.22	-	4.465	3.581
	H	(10.71-9.93)	-	-	4.480	-
072	O	(12.8-10.36)	7.15	-	4.470	3.595
	H	(10.39-9.7)	-	-	4.469	-
073_1	O	11.04	7.16	(5.035)	4.480	3.588
	G	(11.52-11.04)	7.16	-	4.470	3.588
	H	9.87	-	-	4.750	-
E	O	12.98-11.18 (ave. 12.13)	7.17	-	4.465	3.581
	G	12.82	7.17	-	4.430	3.581
	H	10.04	-	-	4.502	-

O = untreated slides K = Kaolinite ( ) = weak reflections

G = measurable results of glycolation at 60°C for one hour

H = heated at 550°C for 2 hours MM = mixed layer mica-montmorillonite

Table 2.3

Diffraction results in Å from the black marine shales

Specimen number		ML	K	ML	ML	K
014	O	10.6-9.82	7.13	5.02	4.49	3.58
	H	10.04 ave.	-	5.01	4.49	-
020	O	12.34-9.99	7.19	4.99	4.50	3.588
	G	10.77				
	H	10.39-9.87	-	5.02	4.47	-
021	O	(11.14-10.01)	7.17	4.97	4.45	3.576
	H	-	-	4.97	4.49	-
028	O	poor	7.17	4.99	4.45	3.580
	H	10.7-9.76	-	4.77	4.49	-
072	O	12.27-10.01	7.19	5.007	4.46	3.574
	H	10.10	-	5.035	4.49	-

O = untreated slides

G = measurable results of glycolation at 60°C for one hour

H = heated at 550°C for 2 hours

( ) = weak reflections

ML = mixed layer clays

K = kaolinite

Specimen 072 behaved in a similar manner to the Rla_2 specimen, 028. Few clays at 11-12 Å, illite or muscovite peaks were shown on the diffractometer charts except on heating when a 10 Å peak appeared. Kaolinite is the predominant clay mineral. As in specimen 028, a sharp peak for gypsum at 7.6 Å occurred and was destroyed on heating at 550°C.

Interpretation of the mineralogy

Mixed layer expandable clay minerals -- 11-12 Å clays

11-12 Å clays occur in significant quantities in beds 073, 014_4, 020_5 and E. Minor amounts can occur in kaolinite-rich beds. Peak positions vary between 11.4 and 12.19 Å. Unlike those of kaolinite, peaks for these minerals are broad. 001 peaks in the 9.99 - 10.1 Å range for muscovite and illite (Grim 1968, p.142) are consistently absent.

Slides containing 12 Å clay minerals were heated at 60°C for one hour in ethylene glycol vapour, following the method outlined by Brindley (1966, p.238) to determine if any expandable layers were present within the clay mineral structure. A Silurian bentonite specimen (Trewin 1969, p.121-122) was also glycolated to determine if the method was satisfactory. Glycolation resulted in a peak shift and slight lowering of the peak height in the bentonite, but the Namurian clay band minerals behaved erratically. 12 Å peaks, marked in untreated specimens, disappeared completely on glycolation in 020_4 and 014_3. No peak was observed when specimens were x-rayed after standing overnight over a dish of ethylene glycol. Specimens E and 073 showed a decrease in peak height, but a distinct peak shift on glycolation for one hour and cooling in the presence of glycol.

Glycolation was also attempted by placing drops of ethylene glycol on the edge of the slide, and allowing the liquid to diffuse into the clay (Brindley 1966). No results were obtained by this method, 12 Å clay mineral peaks disappearing in all cases.

Montmorillonites commonly show 001 peaks between 12.4 and 15.4 Å (position dependent upon hydration) and at 17 Å after glycolation. The small degree of expansion observed in these Namurian specimens (see Fig. 2.A) and the main peak at only 12 Å suggests that the clays are only partially expandable and are not pure montmorillonite. As suggested by Trewin (1968) the 12 Å clays probably consist of interlayered montmorillonite and 10 Å micas, the structure resulting in an intermediate peak in the untreated specimens. The tendency for the collapse of the peaks after glycolation may indicate irregular expansion of the clay minerals, interrupting the structure and affecting diffraction results.

Clay mineral peaks in the 12.3-9.8 Å range are present in most of the black shale samples (Fig. 2.A). Reflections were weak in samples 028, 021 and E black shales and the dominant mineral was disordered kaolinite. A small amount of chlorite may occur in some specimens.

Glycolated slides of the black shales were also poor because the clay minerals even in untreated specimens were often indistinct. Heating at 550°C, however, produced a peak at 9.9-10.1 Å (Table 2.3). In the untreated samples, the 12.3-9.8 Å peaks are asymmetrical, the highest part of the peak at 9.9-10.1 Å probably indicating muscovite or illite, and the rest of the peak (10.2-12.3 Å) mixed layer clays which contract on heating. Trewin (1969) found that glycolation produced reduction of the mixed layer clay mineral peak, possibly

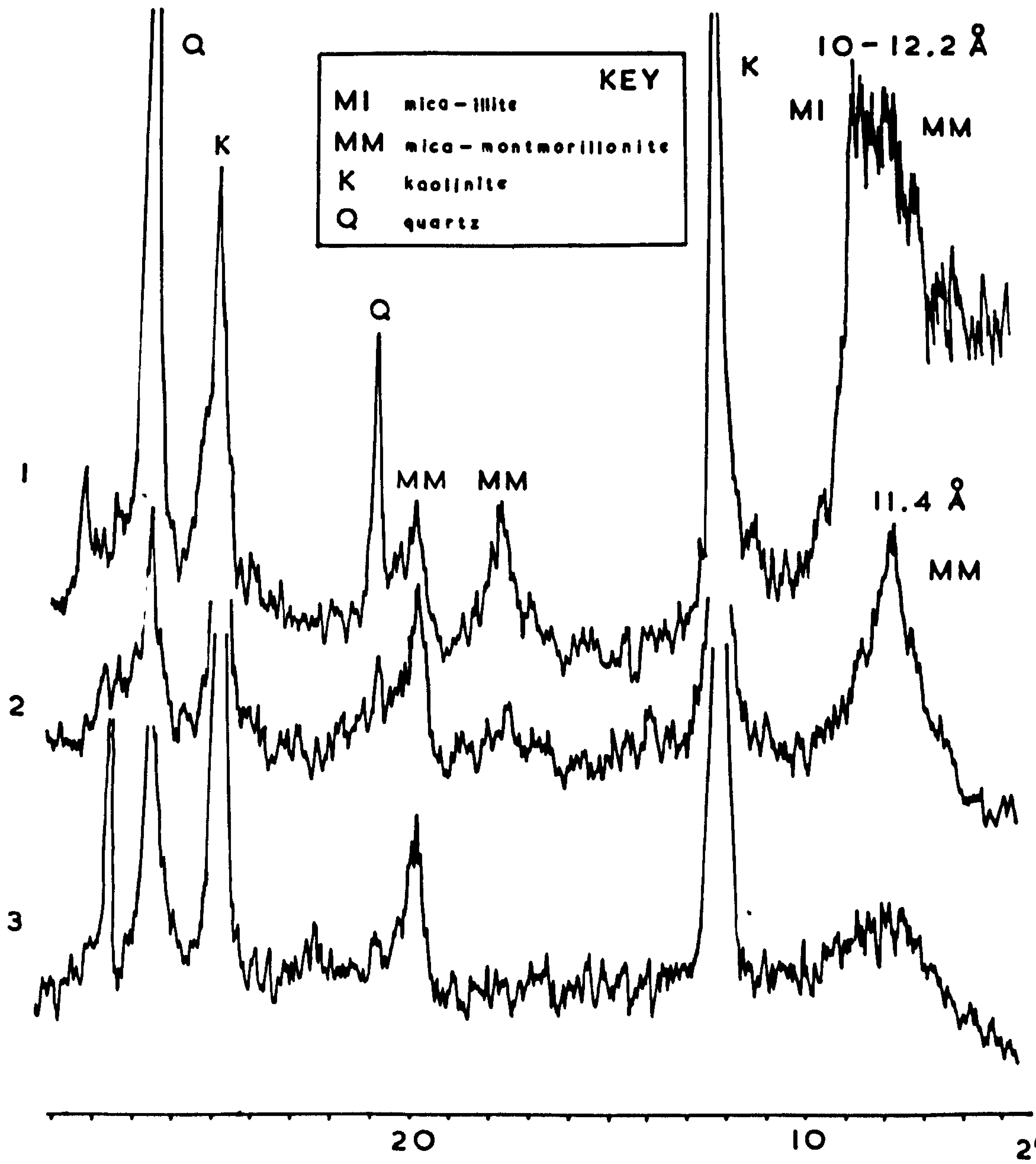


Figure 2.A

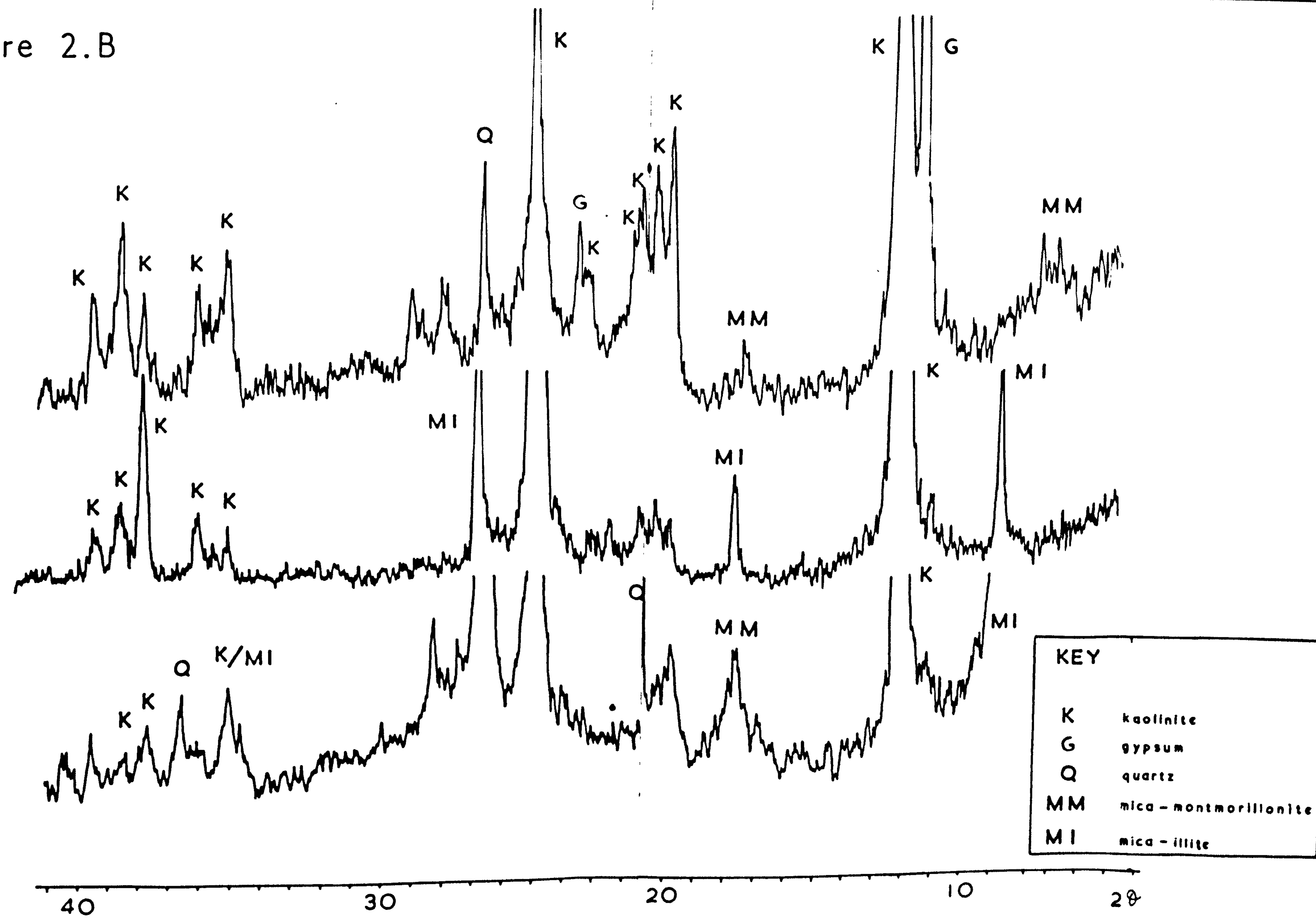
Diffractometer charts - mixed layer [MM] clays

1 marine band black shale

2 kaolinised ash band O73

3 as 2, glycolated

Figure 2.B



Diffractometer charts - kaolinite

1 kaolinised ash band loc.028 – well crystallised kaolinite
2 china clay – well crystallised kaolinite
3 marine band black shale loc.072 – poorly crystallised kaolinite

Table 2.4

X-ray data for kaolinite

Well crystallised (Grim 1968, p.131) I	Å	hkl	Well crystallised English clays, Lovering, Pochin and Co. RLO/419	loc. 072 light coloured clay band	loc. 028 light coloured clay band
10+	7.16	001	7.16	7.22	7.22
4	4.46	020	4.46	4.47	4.45
5	4.36	$1\bar{1}0$ 110	4.32	4.36	4.36
5	4.18	$1\bar{1}1$	-	-	4.17
3	4.13	$1\bar{1}\bar{1}$	4.13	4.13	4.12
4	3.845	$02\bar{1}$	-	-	3.831
2	3.741	021	-	-	-
10+	3.573	002	3.573	3.581	3.574
4	3.372	111	obscured by illite/muscovite peak		
3	3.144	$11\bar{2}$	-	-	-
3	3.097	$1\bar{1}\bar{2}$ $0\bar{2}2$	-	-	-
3	2.753	022	-	-	-
6	2.558	$1\bar{3}0$ $20\bar{1}$ 130	2.557	2.561	2.557
4	2.526	$13\bar{1}$	2.526	2.523	2.517 approx.
8	2.491	$1\bar{1}2$ $1\bar{3}\bar{1}$ 200 112	2.492	2.490	2.489
6	2.379	003	2.377	2.382	2.378
9	2.338	$20\bar{2}$ $1\bar{3}1$ $11\bar{3}$	2.336	2.336	2.336
8	2.288	131 $1\bar{3}\bar{1}$	2.290	2.280	2.282
2	2.247	132 040	-	-	-

because of irregular expansion of the interlayered clay minerals, probably consisting of montmorillonite and a 10 Å mica.

<u>Kaolinite</u>

All peaks of diffractometer charts thought to be characteristic of kaolinite were checked by heating the powder on the slides at 550°C and x-raying again. After removal of absorbed water at 105°C, kaolinite decomposes above 450°C through loss of OH groups as water. The residue was thought to consist of amorphous alumina and silica, but is now known to retain something of the original kaolinite structure if the temperature is not too high (Worral, 1968). Heating at 550°C, however, destroys kaolinite reflections and supplies useful confirmation of the clay mineral's identity.

Kaolinite peaks, in contrast to those of illite and mixed layer clays, are always sharp in black marine shales and in light clay band specimens. A comparison of the 001 and 002 peak shapes and positions indicates no difference between kaolinites from the two different lithologies, although first order spacings are generally higher (7.15-7.20 Å) for poorly crystalline kaolinite than for well crystallised material (Grim 1968, p.130).

A sample of kaolin (china clay) and some black shale and light clay band samples were scanned from 5° to 40° 2 θ. The china clay failed to show the weakest peaks of well crystallised kaolinite (Table 2.4) possibly because of the orientated nature of the specimen. However, the pattern of intermediate peaks in the range 2.5-2.2 Å (compare Tables 2.4 and 2.5 and see Figure 2.B) was indicative of relatively well crystallised kaolinite compared with b-axis disordered kaolinite. Kaolinite-rich samples 028 and 072 from the light bands produced diffractometer charts comparable with that of the china clay, and 028 also showed the weaker $1\bar{1}1$ peak and the $02\bar{1}$ peak, neither of which are apparent in the china clay sample. Brown (1961, p.62) regards the resolution of the $1\bar{1}1$ and $1\bar{1}\bar{1}$ doublet (4.18 and 4.13 Å, Table 2.4 and Figure 2.B) as an indication of a well crystallised kaolinite.

Diffractometer charts of the black shales (locs. 062 and 071) produced a distinctly different pattern of kaolinite peaks between 34° and 39° 2 θ. The results (Table 2.5) are comparable with those of Grim (1968) for b-axis disordered kaolinite. Brindley, and Robinson

Table 2.5

X-ray data for disordered kaolinite

b-axis disordered kaolinite (Grim 1968, p.133)				loc. 072, black fossiliferous shale	loc. 021, black fossiliferous shale	Bentonite Swint Clough loc. 073
I	Å			Å	Å	Å
10	7.18	001	sharp	7.19	7.15	7.16
8	4.48	021	band	obscured by illite and mica peaks		
10+	3.584	002	sharp	3.574	3.588	3.588
8	2.565	$20\bar{1}$ 130	sharp	2.562	2.562	2.561
8	2.502	$13\bar{1}$ 200	sharp	-	-	-
8	2.386	003	sharp	2.387	2.385	sharp 2.383
9	2.341	$20\bar{2}$ 131	broad	2.341	-	broad 2.336
1	2.206	$13\bar{2}$ 201	broad	-	-	-

and Brindley (1946 and 1951) showed that some kaolinites (such as those of the English fire clays) may be of lower crystallinity and show fewer reflections than normal kaolinite. Grim (1968, p.65) observed that displacements probably take place parallel to the b-axis, cutting out some reflections.

Not all the clay bands show well crystallised kaolinite diffraction patterns. A large proportion of kaolinite must be present for the weaker reflections to show above the background level, and satisfactory results were obtained from only one other specimen from Swint Clough (073). Despite the appearance in thin section of tabular crystals thought to be kaolinite, a pattern of disordered kaolinite was obtained, probably from microcrystalline kaolinite in the matrix. The degree of crystallinity of the kaolinite in the clay bands is likely to vary, as in tonsteins, and it is probable that well crystallised kaolinite occurs abundantly only in bands consisting largely of this mineral, where conditions for kaolinisation were at an optimum.

X-rayed samples of the Erda tonstein revealed only b-axis disordered kaolinite, the state of the disorder possibly being associated with the small crystalline size of the clay (Moore 1964a, p.262). Eden _et al_. (1963) found that the kaolinite of the tonsteins from the East Midlands possessed a fairly highly ordered lattice. Both of the above examples contained rouleaux of kaolinite, as well as tabular kaolinite in the Erda tonstein. Disordered kaolinite was identified in clay band 073 which showed well developed tabular kaolinite, but ordered kaolinite was found to be present in 072 which showed little tabular kaolinite. It is likely that the x-ray diffraction pattern in both cases refers to the greater amount of kaolinite in the matrix. The well crystallised tabular kaolinite in the Erda and Swint Clough specimens probably occurs in insufficient quantities to show on the diffraction pattern.

A sharp peak from the two well ordered kaolinite specimens (028 and 072) at 7.6 Å has been identified as gypsum. This peak and a lower intensity peak for gypsum at 4.36 Å disappear with loss of water of crystallisation on heating to 550°C.

FOSSILIFEROUS BLACK SHALES

Slides were prepared by impregnation in bakelite and cut perpendicular to the bedding.

Fossil content

No fossil debris has been recognised in any of the kaolinised bands, although they rest upon crushed goniatites, crinoid stems, etc. This suggests that their accumulation was more rapid than that of the black shales. Fossil material is preserved in the shales in the form of large calcite plates, or prisms which are arranged radially to give spherulitic extinction in the case of small rounded bodies such as goniatite spat. The fossil material is generally aligned parallel to the bedding, but can be inclined at an angle to the laminae, causing a sharp bend in the laminae as a result of compaction (Plate 2.1).

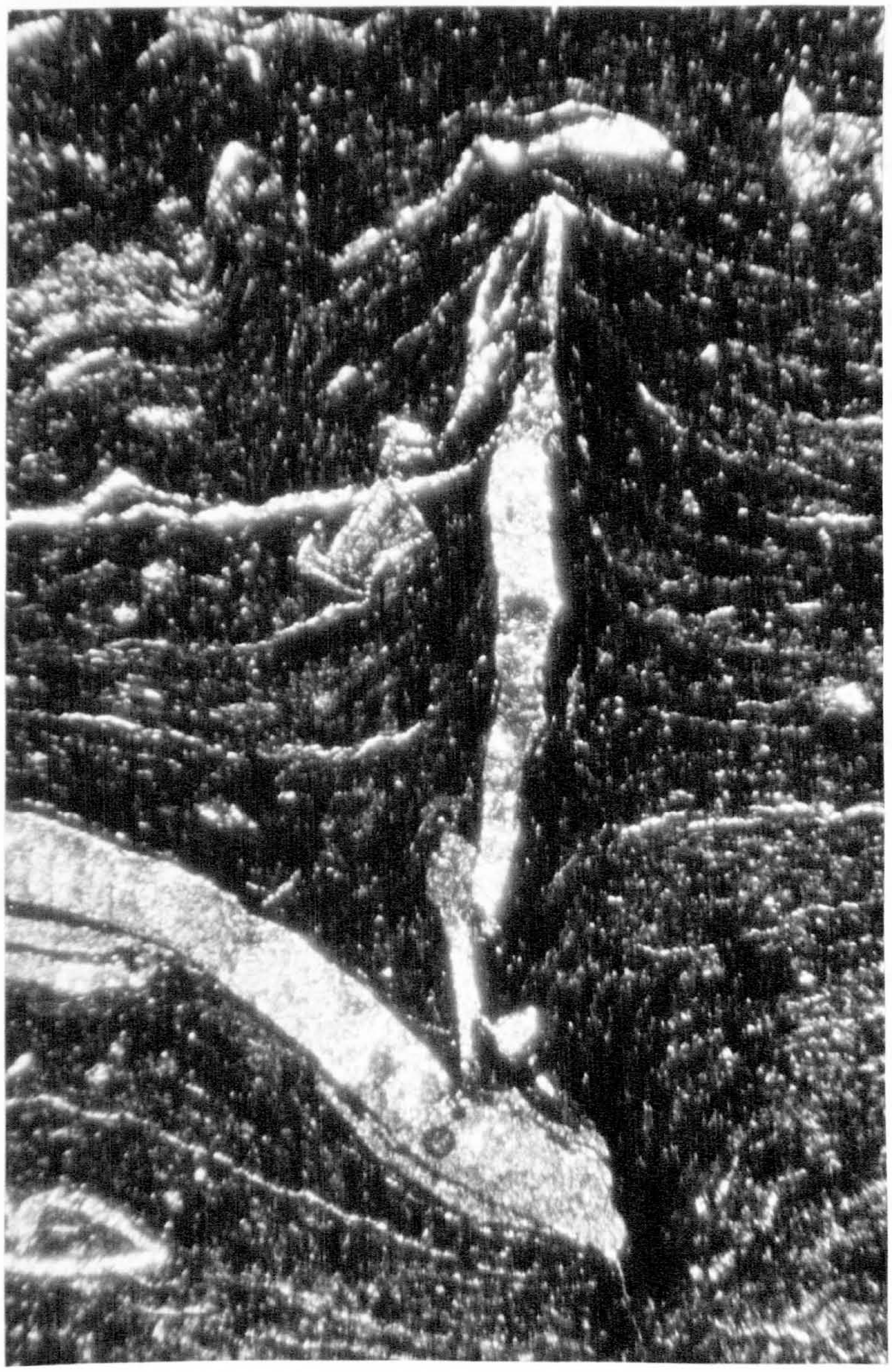
Lamination

This is invariably present in black shale specimens but has rarely been noted in light clay bands. Wisps of black shale have been incorporated into the light material in two known examples, indicating some bottom current activity.

Quartz

This is more abundant than in the kaolinised bands but of smaller grain size.

Pl. 2.1



Thin section of typical black marine shales, showing fossil debris, and lamination, which is deformed on compaction by the compression against fossil material.

x55, crossed polars.

Locality: 071, $R1b_v$.

Micas and clay minerals

Micas and clay minerals are weakly birefringent and by x-ray diffraction have been shown to consist of illite, muscovite, (possibly degraded), and mixed layer clays. In coarser grained, unfossiliferous sediments, flakes of layered minerals can reach 0.2 mm in length and show interference colours suggesting muscovite. Tabular kaolinite, 0.2 mm in length, has been noted in black shales only in a position adjacent to a thin, pyrite- and kaolinite-rich band. The kaolinite may have come from the thin band, which is only 2 mm thick (Plate 2.2a).

PETROGRAPHY OF THE LIGHT COLOURED BANDS

All specimens from these bands were impregnated in bakelite before slide preparation, and sections made perpendicular to the bedding where possible. A part of each slide was stained in methylene blue solution to indicate the areas of kaolinite. The absorption of methylene blue by montmorillonite and kaolinite was tested by staining slides of kaolinite and montmorillonite (Wyoming bentonite) powders. Montmorillonite appears to absorb the blue colour, but only absorption by kaolinite results in enhanced polarisation colours -- a property noted by Hambleton and Dodd (1953, p.145) on staining kaolinite in p-amino phenol. Holdsworth (1963a) has also recorded this property of kaolinite on staining Namurian subarkoses in methylene blue.

$R1b_v$ clay bands

Slides prepared from the two clay bands in Swint Clough ($R1b_v$) are similar in texture and mineralogy and are described together. Textural evidence and their mineralogy points to a volcanic origin.

Quartz

Quartz grains are abundant in both slides, varying in grain size from 0.1 mm to 0.001 mm. The shape of the grains varies from spherical to elongated and the grains are invariably angular. In weathered specimens of the band the grains are seen in various stages of replacement by goethite, resulting in an angular shape. In the less weathered examples, quartz can be enclosed by pyrite and is irregular in outline. Where it is surrounded by matrix clay minerals the margins are entire and show that the original shape of the grains was angular.

Plagioclase feldspar

Feldspar is more abundant in 073_2 (the upper band) than 073_1 (lower band), only one grain having been found in the latter. The grains are either triangular shaped fragments (Plate 2.2b) or lath-shaped in outline. All show twinning and give a maximum ?001 extinction angle of 16^o, indicating a composition of An_0 or An_{34}. Refractive index could not be determined. 2v was determined from two grains of feldspar in specimen 073_2. These grains gave figures of approximately 78^o and 82^o (+ve). As biaxial angles tend to be larger in low temperature feldspars, these suggest either low temperature albite or andesine. A more accurate determination on another grain was made by P.D. Ryan using Slemmon's method (1962). This indicated that 2v was 79^o (-ve). Such high biaxial angles are unlikely to be encountered in -ve albites (high temperature) and suggest that the feldspar is within the andesine range where high temperature feldspars can be -ve. Using Smith's determinations (1958, in Heinrich, p.358) this feldspar could be a high temperature andesine (An_{33} approximately). The other two specimens could be low temperature andesines. Thus the evidence for a low or high temperature origin for the feldspars is inconclusive.

Montmorillonite

Clay minerals with the property of expansion to a certain degree are known to exist in the rock from x-ray diffraction, and are thought to have been identified optically in the matrix, by a process of elimination of the easily recognisable minerals. Montmorillonite has also been separated from kaolinite by the staining technique. The matrix consists of fibrous minerals of first order grey, yellow and red, of slightly higher order than the tabular kaolinite. The birefringence is slightly lower than that of montmorillonite, but interference colours for this mineral in slides seldom go above second order as the crystals are thin. The probable mixed-layer nature of the mineral could also reduce the interference colours in this case. On staining the slide, parts of the matrix take a pale blue stain, but the magenta polarisation colours of stained well-crystallised kaolinite are rare indicating that the mineral is not abundant, although disordered kaolinite was identified by x-ray diffraction.

Iron pyrites

Pyrite occurs abundantly in both specimens as cubes, occasionally developing octahedral faces. The cubes can be isolated, or form more irregular aggregates (Plate 2.3). Quartz or clay minerals form irregular inclusions.

Goethite

When pyrite is fresh and opaque, the matrix montmorillonite is light yellow in colour. A few granules of a brown mineral (?goethite) occur in the matrix, but are never abundant. On weathering of the rock, and oxidation of the pyrite, a brown stain becomes pronounced, particularly in the matrix, and the pyrite is replaced by an oxide. Granules of the brown material replace quartz, the shape of the

Plate 2.2

a. Possible thin ash band. The band of opaque pyrite indicates the (?) ash band, only 2 mm thick. Adjacent to the pyrite layer are laminated marine shales.
x165, uncrossed polars. Loc. 071, $R1b_v$.

b. Fragment of plagioclase feldspar, badly corroded, in matrix of mixed layer clay and kaolinite. The opaque areas are iron pyrites.
x420, crossed polars. Loc. 073, Swint Clough, $R1b_v$.

Plate 2.3

a. Thin section of clay band showing tabular kaolinite macrocrystals and ovoid in matrix of mixed layer clays and kaolinite. The opaque areas are iron pyrites.
x165, uncrossed polars. Loc. 073, Swint Clough, $R1b_v$.

b. As above, crossed polars.

Plate 2.4

a. Tabular kaolinite, turbid due to replacement by goethite. Replacement has taken place selectively along the cleavage planes.
x420, crossed polars. Loc. 073, Swint Clough, $R1b_v$.

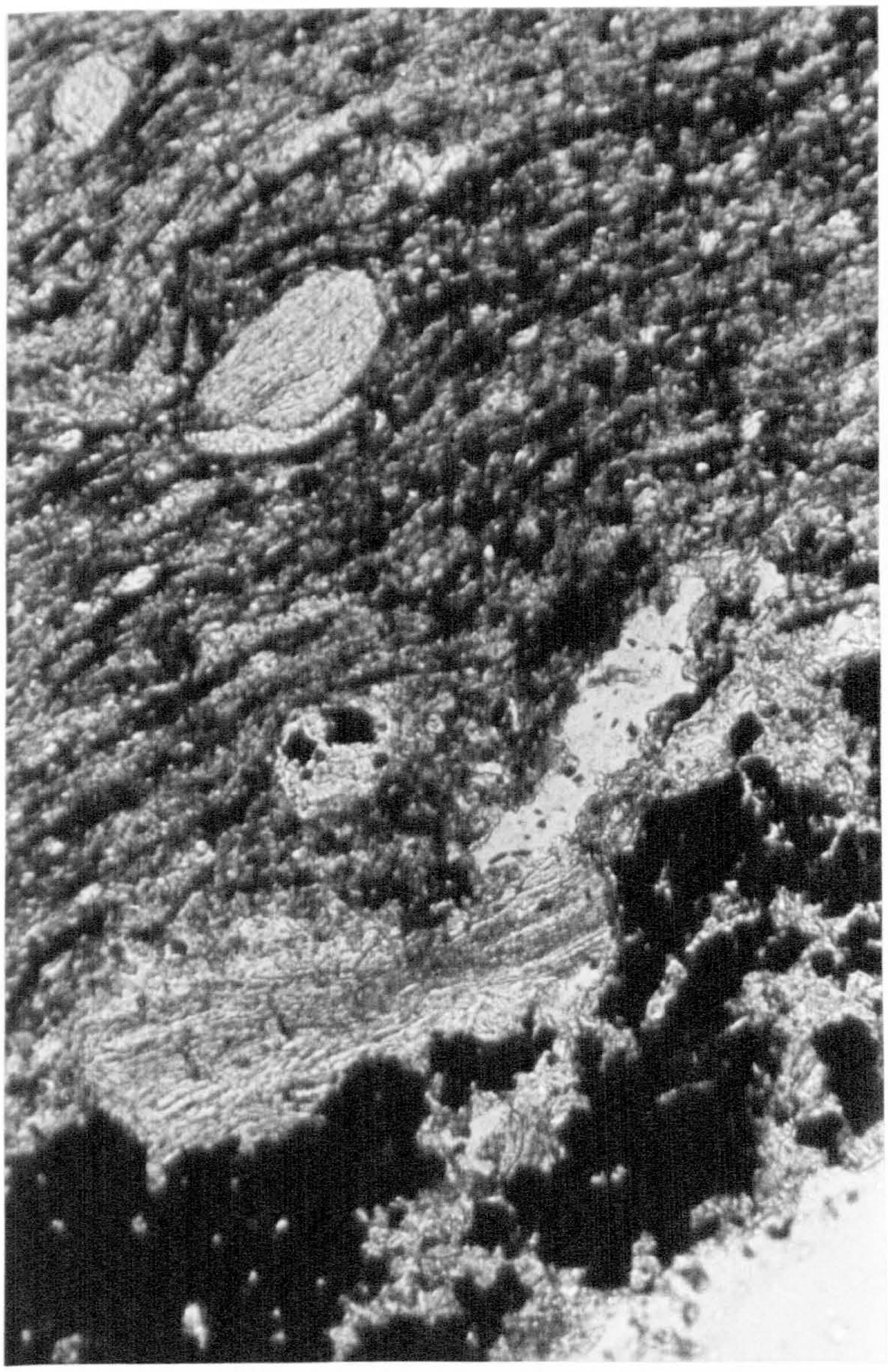
b. As above, uncrossed polars.

Plate 2.5

a. Kaolinite macrocrystal set in carbonate cement. The edges of the kaolinite are irregular, the crystal appearing to have formed before the carbonate which has partially replaced or grown into the kaolinite.
x420, crossed polars. Loc. 028, $R1a_1$.

b. Recently formed gypsum crystals in kaolinised band.
x18, crossed polars. Loc. 028, $R1a_2$.

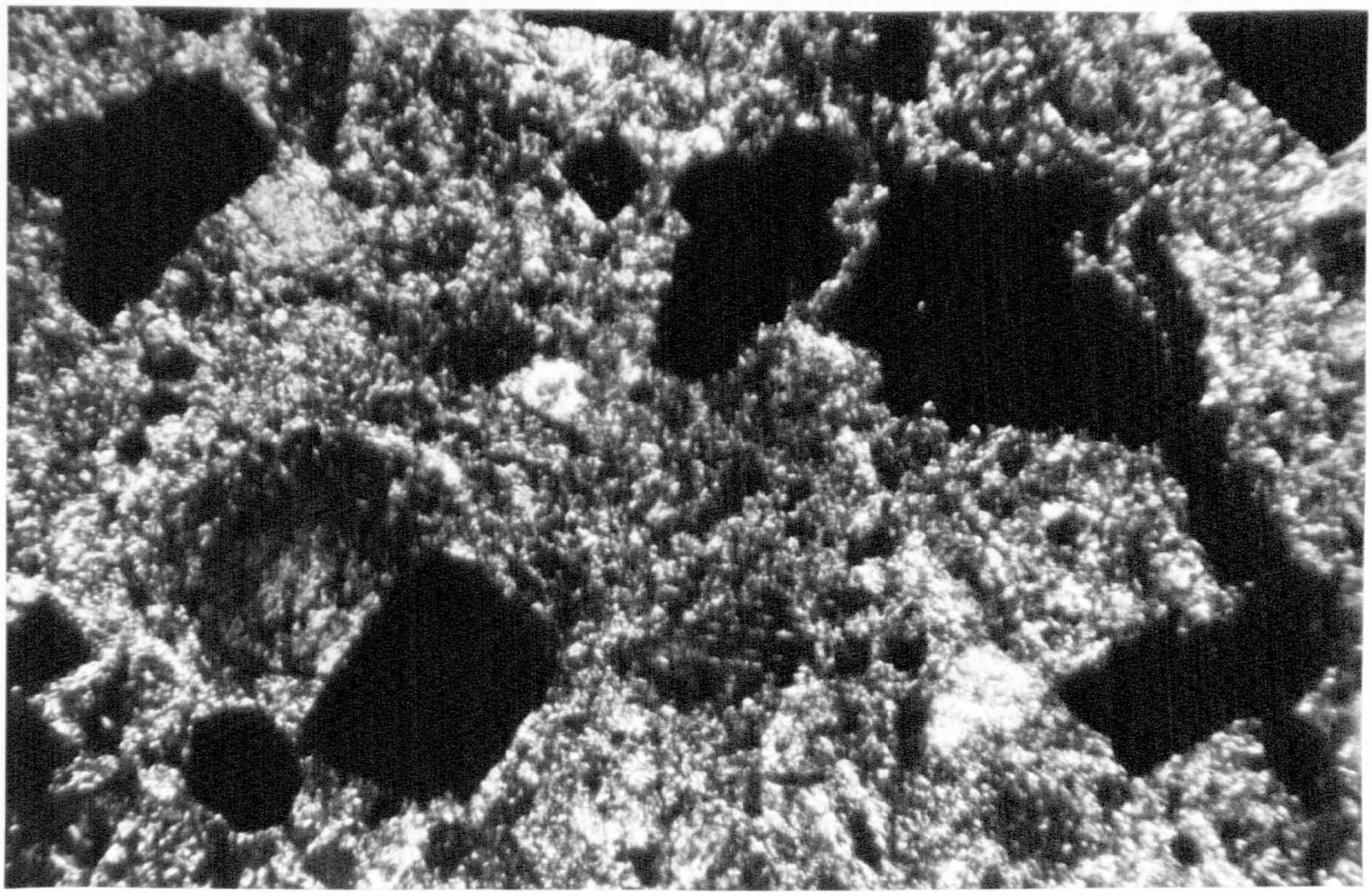
Pl. 2.2



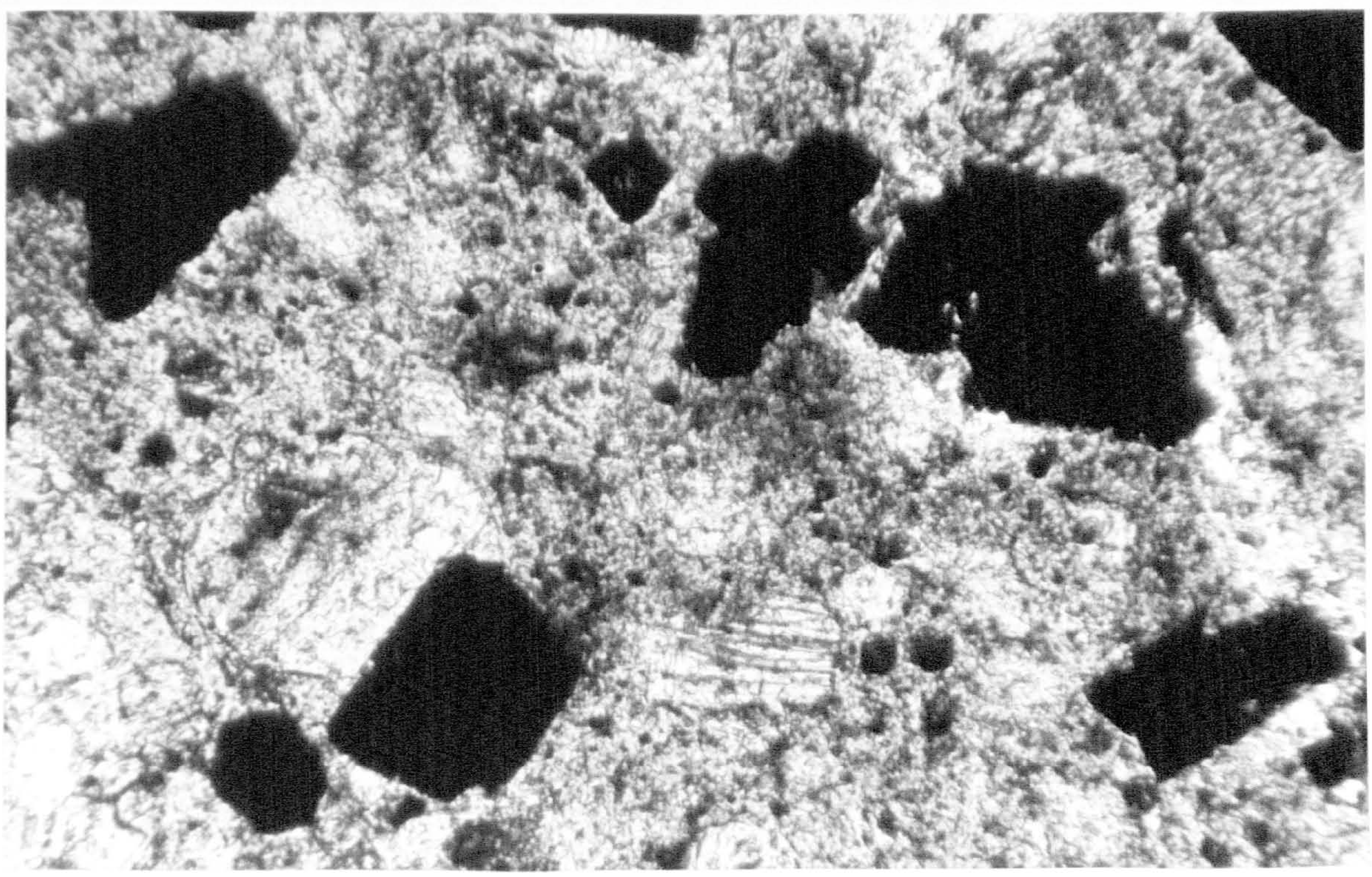
a

b

Pl. 2.3

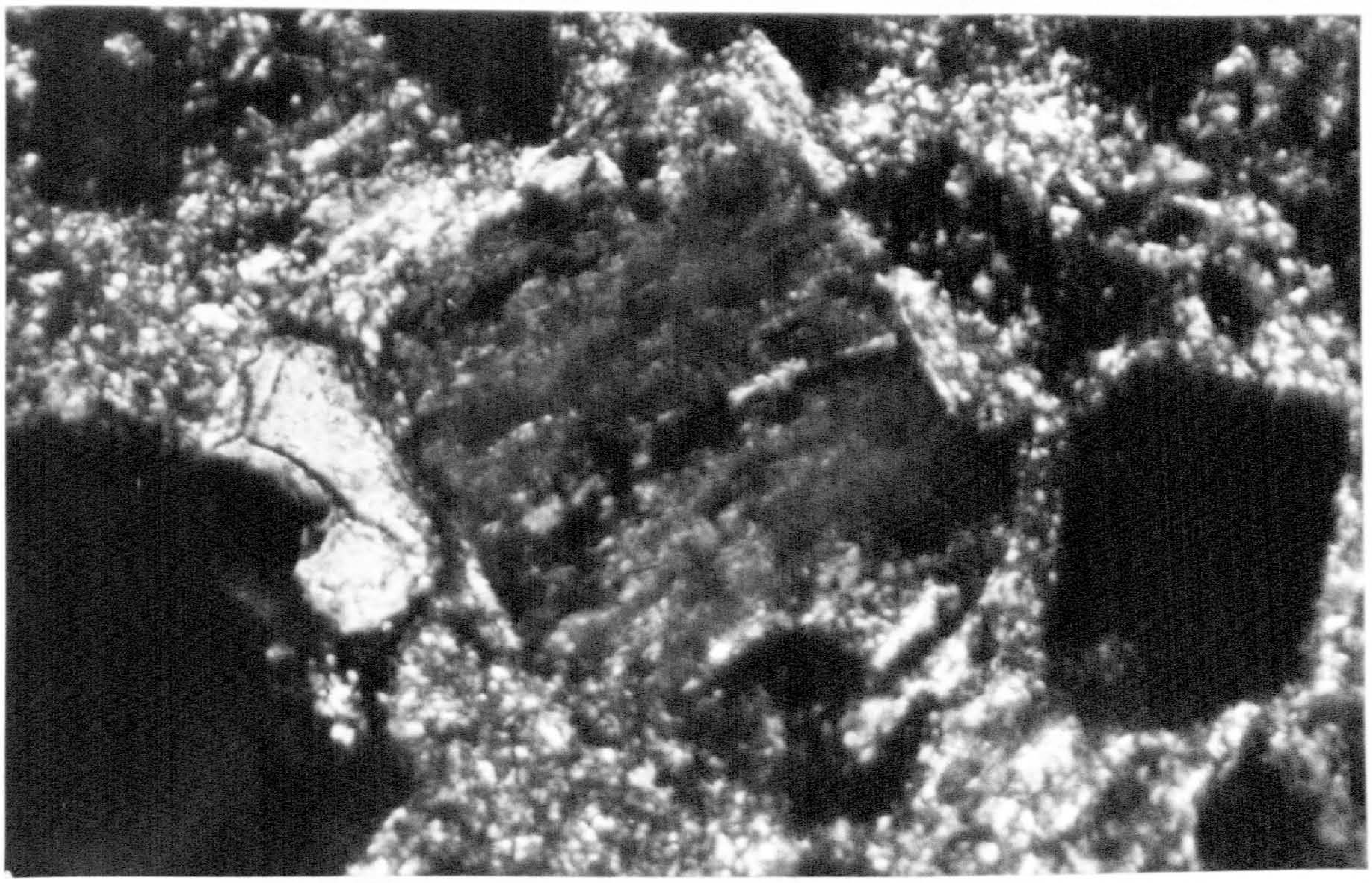


a

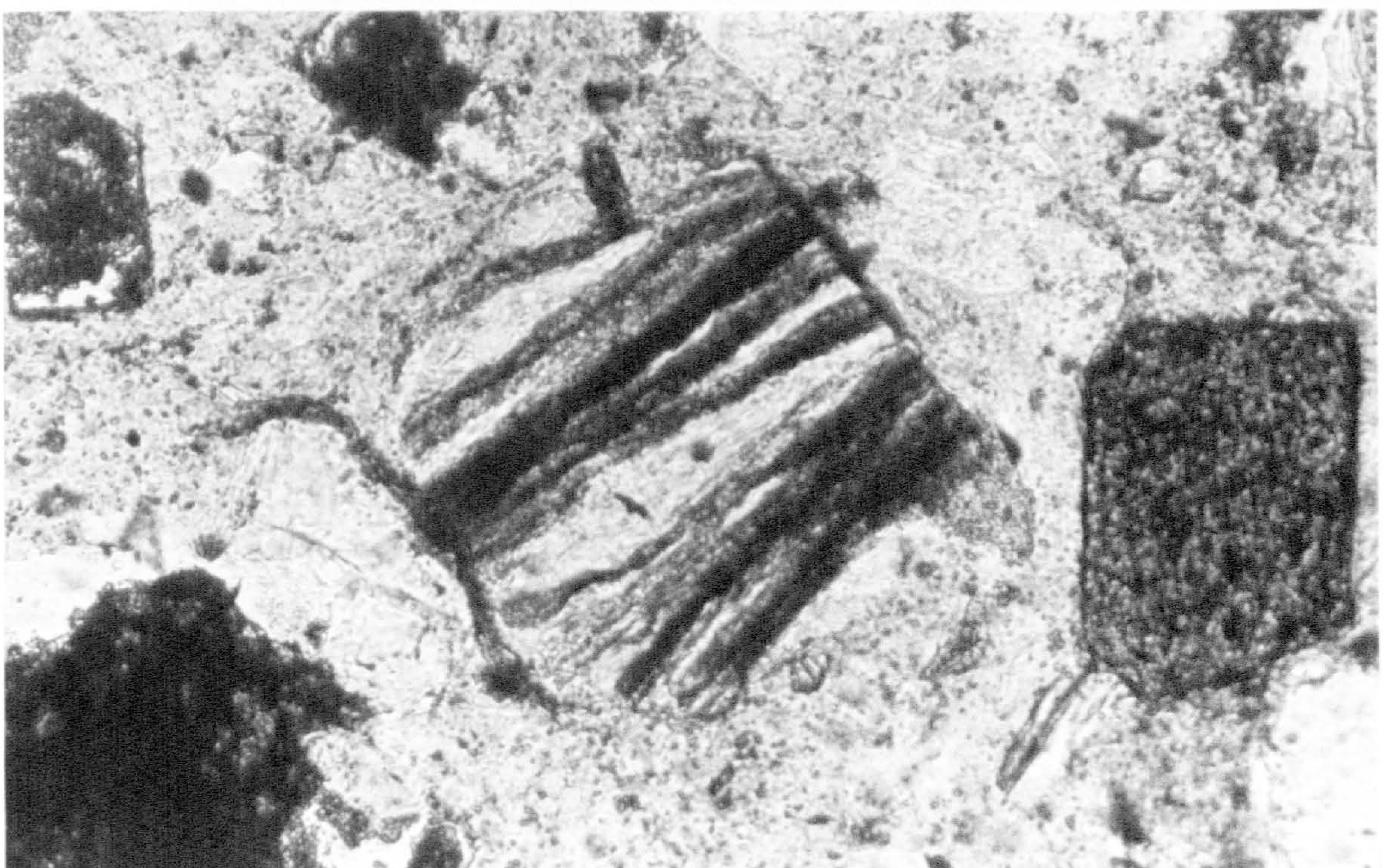


b

Pl. 24

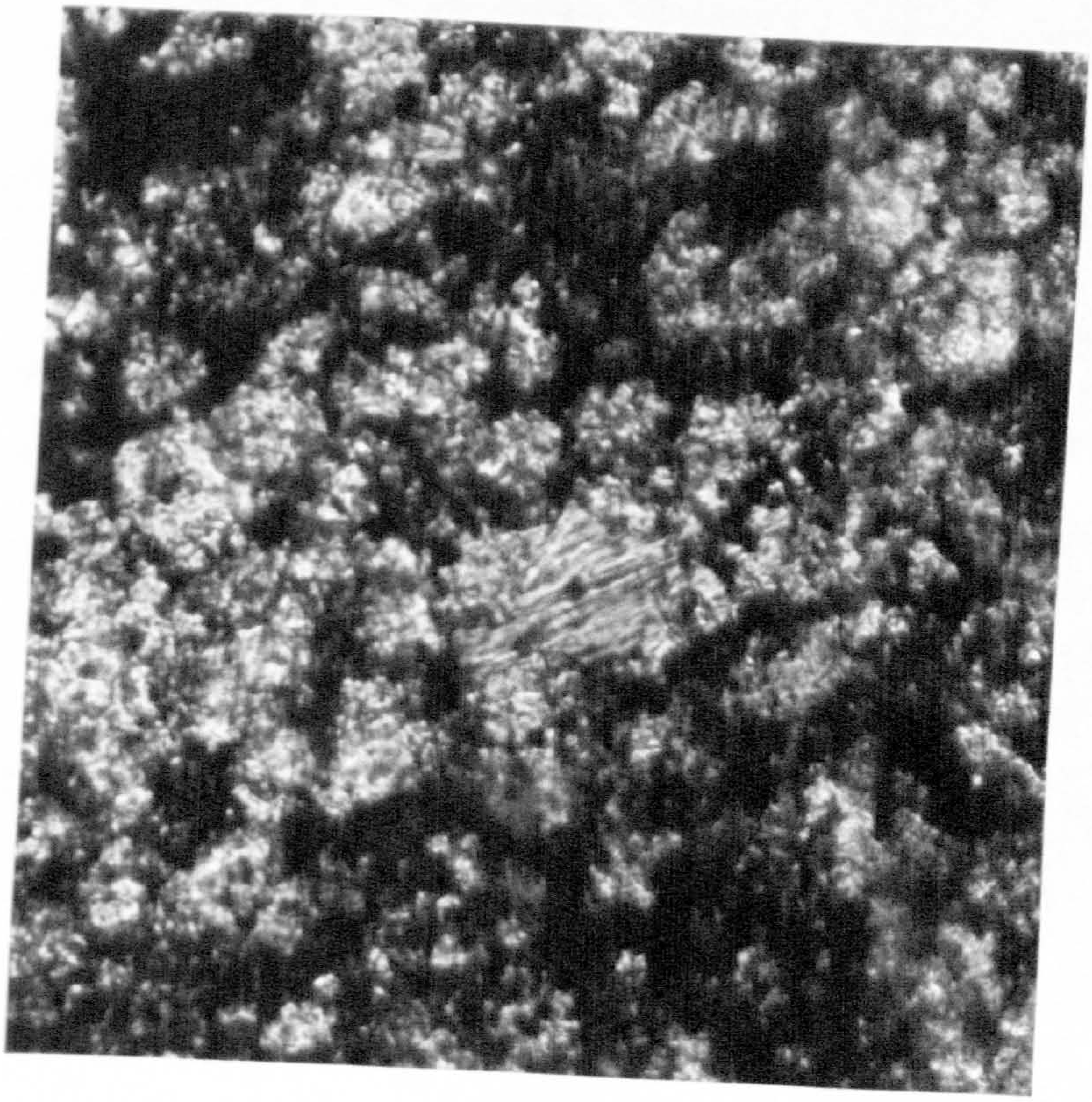


a



b

Pl. 2.5



a

b

granules suggesting that the oxide is in crystalline form such as goethite rather than limonite.

Altschuler and Dwornik (1963) found that the alteration of green montmorillonite-bearing clays to kaolinite was accompanied by the growth of goethite needles. The association of granular goethite with pseudomorphed cubes of pyrite, and paucity of goethite granules in less weathered specimens, indicates that its presence is a result of present-day weathering unassociated with the kaolinisation of the rock, which contains as much tabular kaolinite in stained as in unstained portions. Goethite also grows over tabular crystals of kaolinite (Plate 2.4) in more weathered portions of the rock.

Heavy minerals

Small granules (12μ) of a birefringent mineral (second order colours) of high relief occur in the matrix. These granules are probably zircon. They are sometimes surrounded by dark brown areas, but the sharp margins to the grains suggest that they are detrital rather than authigenic.

Kaolinite

Kaolinite, showing typical magenta polarisation colours on staining in methylene blue, occurs largely in two distinct forms. A small amount may also be present in the matrix.

a. Tabular kaolinite

This form has a pronounced 001 cleavage. The cleavage planes can be slightly curved resulting in wavy extinction. The tablets (or "books") of kaolinite rarely exceed 0.06 mm in height and 0.1 mm in width. Vermicular forms are uncommon. Interference colours are first order grey, but plates of slightly higher order colours occur interleaved with the grey areas, suggesting that there may be an intergrowth of two minerals as indicated by Kerr (p.413) in kaolinite prisms with hydromuscovite (illite) plates. Sand (1956, p.37) also found that feldspars weathered to form "books" of secondary mica and kaolinite, the mica showing lower birefringence than the primary micas. Books of clay minerals and micas derived from muscovite were also found to be composed of muscovite and kaolinite.

Tabular kaolinite appears to be randomly orientated within the specimens and does not appear to occur in association with organic material, unlike the examples described from the Erda tonstein by Moore (1964a).

b. Microcrystalline kaolinite

This form of kaolinite forms irregular but well defined patches which have wavy extinction. Grey polarisation colours in untreated slides are replaced by a patchy magenta colour in slides treated in methylene blue, indicating that the areas of wavy extinction may not consist wholly of kaolinite. However, as polarisation colours are restricted to first order grey, a different clay mineral is unlikely to be present. The stain and extinction may be affected by the grain size and orientation of the kaolinite.

The definite boundaries to the areas containing kaolinite indicate that the mineral aggregate is pseudomorphing original crystals or rock fragments. The shape of the areas can be angular, but many of them are round, becoming ovoid in outline. Francis (1961, p.198) notes that in the kaolinised tuffs of Fife, angular fragments of igneous rock (fine grained or glassy) are replaced by kaolinite but, at what appears to be a later stage of alteration, the fragments become less well defined and ovoid in shape. The darker more altered tuffs of Fife, which show few remnants of a volcanic texture, consist wholly of seed-like bodies similar to the ovoid shapes in the paler tuffs.

The rounded fragments in the Rlb_v specimens may also have been derived from originally angular pyroclastic rock fragments, of which little trace of the original composition remains. No unaltered fragments remain to determine the original composition of the rock, but some patches of kaolinite retain an angular shard-like shape. One fragment of microcrystalline kaolinite contains a polygonal area of a more highly birefringent micaceous aggregate (?montmorillonite) which may represent a pseudomorphed phenocryst.

<u>Rlb_v marine band, Thorncliff stream, loc. 072</u>

The two bands at this locality are equivalent to those described from Swint Clough. A slide of one of the bands indicates, however, that all traces of an original igneous texture have been lost, either by more advanced stages of kaolinite formation, or because the band was deposited further from source. Francis (1961, p.208) found that there is a suggestion that when ash bands are traced away from the source direction, the deposits show a decrease in the amount of recognisable igneous debris.

Montmorillonite cannot be recognised in thin section, although it was indicated in very small amounts by x-ray diffraction. Only one fragment of feldspar in the stage of alteration to kaolinite has been observed, and the angular and rounded patches of microcrystalline kaolinite are absent. Both tabular and rare vermicular kaolinite crystals up to 0.06 mm in length occur.

An opaque mineral is present only as scattered granules in the ground mass. Quartz is present as scattered ragged grains. Fresher material from the band contains abundant pyrite cubes, however, and it is thought that the absence of iron staining and the lack of goethite which forms from the oxidation of the pyrite in the examples from Swint Clough may be explained in this case by the leaching of the band, resulting in a white clay. The band is of significantly different clay mineral composition from its lateral equivalent in Swint Clough. This may be explained by differences in the chemical environments of the sediments during diagenesis, or present day weathering (p.194).

The Rla_1 clay bands

These kaolinised bands are variable in composition, the matrix varying from abundant montmorillonite to a carbonate cement seen in thin section.

Kaolinite occurs in tabular form as well as dispersed flakes in the groundmass in the sample from loc. 012. Montmorillonite cannot be distinguished in thin section because of the abundance of siderite rhombohedra, clearly of diagenetic origin. The rhombohedra are approximately 0.016 mm in width.

A few crystals of feldspar are present, all showing alteration to the carbonate of higher refractive index. The paucity of iron pyrites in the slide is explained by the incorporation of excess iron from the original sediment into the carbonate phase on diagenesis, rather than present day weathering of pyrite.

The tabular kaolinite, as in the kaolinite from Swint Clough, shows variable birefringence which suggests alternating layers of hydromica and kaolinite. Alteration of the kaolinite macrocrystals themselves is common, siderite rhombohedra growing into the clay along well developed cleavage planes (Plate 2.5a). The carbonate cement is certainly of early diagenetic origin and not a product of present day acid weathering conditions, in which it is impossible for the carbonate to precipitate. This relationship between the carbonate and kaolinite demonstrates that the macrocrystals are not of recent origin, confirming the conclusions drawn from textural evidence in the $R1b_v$ examples.

Sample 014_5 has a similar texture to 012, a siderite cement enclosing macrocrystals of tabular kaolinite, rare corroded quartz granules and kaolinite flakes in the groundmass. Samples 020_4 and 014_3 lack a carbonate cement and have abundant pyrite cubes, weathered in some cases to a brown mineral, probably limonite. Tabular kaolinite is present in both specimens and the groundmass is of weakly birefringent micas, identified as montmorillonite from a comparison with the x-ray diffraction results.

The $R1a_2$ clay band

No indications of an igneous texture have been found in specimens from this band. Feldspars appear to be absent and quartz sparse.

Tabular kaolinite occurs in the montmorillonite-rich specimen from Edale and in specimen 021. Pyrite cubes 0.075 mm^2 occur in the Edale sample and are extremely abundant in 021. The latter band is split by a thin streak of black shale containing abundant detrital quartz grains and carbonaceous material. Some tabular kaolinite derived from the clay-rich layers is also present.

Specimen 028 is unusual in hand specimen, as it occurs as a relatively hard white band, similar in this respect to the appearance of some tonsteins. As in specimen 071, pyrite is not common, only scattered grains of an opaque mineral appearing in the groundmass. It is possible that iron has been removed from the band by leaching after oxidation of the pyrite. No carbonate cement is present to account for the paucity of the iron sulphide. Tabular and rare vermicular kaolinite (0.05 mm in length) occur in a groundmass of microcrystalline kaolinite. X-ray diffraction results indicated the presence of gypsum in 072 and 028, and the mineral has been identified optically in the latter (Plate 2.5b). The sulphate occurs as stellate aggregates, or euhedral crystals twinned along the 010 cleavage direction (Plate 2.5b). The imperfect 100 cleavage is also well developed. The gypsum occurs in areas stained brown by iron oxide and is thought to have formed as a result of present day weathering of pyrite which produces the acid to form gypsum. The calcium is derived from the fossil content of the shales. Opaque material in the slide could be an iron mineral or carbonaceous material, although the latter seems unlikely.

COMPARISON OF THE SHALE AND PALE CLAY BANDS

Clay band contacts with the shales are always sharp, though slight gradation has been noted in thin section. The texture of the two lithologies is entirely different, black shales consisting of well defined laminations with fossil material, clay bands lacking laminae (except where they occasionally include wisps of dark shale). The mineralogy in thin section is clearly different; tabular kaolinite macrocrystals and feldspar are confined to the clay bands, as is pyrite. The clay bands and black shales were therefore derived from different sources. They were also deposited in a different manner. The similarity of two of the specimens to previously described kaolinised tuffs suggests a volcanic origin for the pale bands.

ORIGIN OF THE MONTMORILLONITE

Montmorillonite is known to form from volcanic ash deposits in an aqueous marine environment, soon after deposition of the ash (Grim 1968, p.569), and from hydrothermally altered plagioclases (Fournier 1965). The ash must have a certain content of MgO, as ashes lacking Mg do not appear to alter to montmorillonite. The formation of the clay minerals takes place by devitrification of the glass shards, excess silica and alkalis being carried away in solution.

A proportion of illite in the Namurian ash bands may be accounted for by diagenesis of the sediments after formation of montmorillonite. Burst (1959) observed that montmorillonite in the Wilcox formation of the Gulf coast became less common below 3000', and is not normally found in an unmixed state below 9 - 10,000' of overburden. Between 3 - 14,000', montmorillonite is usually interlayered with illite, and below 14,000', swelling characteristics of the clay mineral are absent. Depth of burial rather than geologic age seems to be the most important factor in the control of the swelling properties of the montmorillonites. This factor may have contributed to the reduction of the swelling capacity of the Namurian mixed layer clays.

ORIGIN OF THE KAOLINITE AND THE CLAY BANDS

In the field, these bands are identical to those described as bentonites by Trewin (1968, 1969). The clay mineral composition in some of the bands which consist of mixed layer clays and kaolinite is similar to that of the bentonites, but other examples are markedly different and consist largely of kaolinite. Because of this difference in the clay minerals, such bands cannot be called bentonites; in many ways they more closely resemble tonsteins typical of the coal measures.

Scheere (1955) indicated the name "tonstein" to have no genetic significance. A tonstein is essentially a clay deposit which consists almost exclusively of kaolinite. Most tonsteins are associated with coal-bearing rocks of Carboniferous, Permo-Carboniferous or Tertiary age (Moore, 1964b). As Francis (1961) points out, a greater degree of kaolinisation is observed in darker kaolinised tuffs forming coal partings than those in mudstones, indicating the association of kaolinite formation with carbonaceous deposits.

Volcanic ash has frequently been cited by other authors as the source of tonsteins (eg. Bouroz 1962, Spears 1970) but most theories of tonstein formation, especially in the case of the less widespread examples, favour non-volcanic origins. Williamson (1961), Scheere (1955) and Spears (1970) summarise theories on the formation of tonsteins. Kaolinite could have formed from kaolinised soils, which originated outside the area of deposition of the tonstein, and were transported by wind or water. Kaolinisation could have taken place in the formation of seat earths. Scheere suggests that the weathering of materials derived from granites could produce tonsteins. After deposition of such material, reorganisation of the clay in a suitable environment may have produced the commonly observed macro-crystals. Moore (1964a,b) suggests that in the Erda tonstein, which formed in close association with a coal, bacterial action played an important part in the *in situ* formation of the kaolinite crystals.

Kaolinisation of volcanic deposits can take place in a marine environment without any association with acid waters, such as were found in the coal swamps. Zen (1957, 1959) found that detrital grains of volcanic glass (largely basaltic) devitrified to form kaolinite, calcite, dolomite, mica ("illite"), quartz and iron oxide, all in mutual equilibrium, in sea bottom samples off the coast of Chile and Peru. Although Francis (1961) noted a greater degree of kaolinisation in tuffs associated with coals, kaolinisation had also occurred in the tuffs intercalated in marine sediments, nearly 100' (30 m) above the nearest coal horizon. This suggests also that kaolinisation may be purely a chemical reaction in material susceptible to alteration in a marine environment. Trewin (1969) also found that kaolinite was present in unweathered specimens of bentonites, obtained from the Ashover Boreholes. Kaolinite is also abundant in a Silurian bentonite specimen x-rayed by Trewin, and Grim (1968, p.567) notes that up to 50% of the total clay minerals of bentonites may consist of kaolinite and illite.

The kaolinised tuffs of Fife, containing appreciable amounts of mixed layer montmorillonite (Francis 1961), are similar in their clay mineralogy to the bentonites of Trewin and some of the clay bands described in this section (eg. 073_1 and 073_2). Fragments of crystalline basalt appear, in Francis' examples, to have been most susceptible to kaolinisation. In early stages of alteration, the kaolinite is finer grained and almost isotropic. At later stages, ovoid shapes develop and finally crystalline kaolinite as granular or vermicular shapes. Thus the kaolinite in these examples, as in the unweathered examples x-rayed by Trewin, must be produced at an early diagenetic stage and not under present-day weathering conditions.

It is well established that a certain amount of kaolinite can form from volcanic ash in a marine environment, but from known examples it seems unlikely that a kaolinite-rich rock with little or no mixed layer clay mineral content should form. Conditions for the formation of such a deposit would have to have been similar to those of the paralic environment where the initial ash deposit could have been modified by acid waters and leaching under oxidising conditions. There is no evidence to suppose that such conditions existed in the Namurian marine basin, and even had they done so, the variability of the ash bands' mineralogy across the basin would still have to be explained. Some variation is to be expected in the paralic environment, but conditions during marine band sedimentation must have been fairly uniform over large areas and unlikely to produce a "tonstein" in one area and a "bentonite" in another. The most likely cause for clay mineral variation in the bands would seem, unlike Francis' (1961) examples, to be from recent weathering, assuming the initial deposit to have been fairly uniform in composition.

Trewin (1969, p.116-7) suggested that the kaolinite of the bentonite bands could have formed from recent weathering of montmorillonite under acid conditions although some kaolinite was found in fresh borehole samples. Poncelet and Brindley (1967) found that some kaolinite forms from montmorillonite under experimental acid conditions thought to be comparable with natural conditions over a longer period. The greatest yield of kaolinite was produced from a synthetic Al--OH montmorillonite with gibbsite-like layers between montmorillonite layers. When gibbsitic layers are introduced into the montmorillonite, the resultant structure is a dioctahedral chlorite. Al-interlayered minerals occur commonly in soil fractions, and Poncelet and Brindley suggest that in an acid natural environment the initial montmorillonite is converted to an Al--OH type. Once this has formed the mineral need not be maintained in a strongly acid environment as "The Al is introduced throughout the interlayer region of the montmorillonite and thereby is brought into intimate contact with the silica layers, an arrangement which will facilitate kaolinite formation". This sequence is also suggested by field evidence. Altschuler et al. (1963) noted that a green clay soil of disorganised montmorillonite and poorly crystallised kaolinite passes laterally into better crystallised kaolinite with minor amounts of montmorillonite, the deposit having formed during low temperature weathering. Several authors have also reported a chlorite-like clay mineral in soil fractions, although none was found in the ash bands samples here. It is not unlikely, however, that the formation of some of the kaolinite took place under present-day weathering conditions, and petrographic and x-ray data indicate that two phases of kaolinisation have taken place.

Petrographic evidence

In the $R1b_v$ specimens from Swint Clough, some areas of kaolinite in thin section show enhanced birefringence and poorly defined cleavage traces (similar to the cleavage better developed in the tabular kaolinite) more clearly than others. This suggests that there might be a progression from microcrystalline kaolinite pseudomorphing fragments to macrocrystalline kaolinite. On the other hand, the presence in some tabular kaolinite of layers of more birefringent mica, and its apparent absence in the kaolinised fragments, suggests that the two forms of kaolinite have originated from two physically distinct sources, the ovoid patches from rock fragments and the vermicular kaolinite from feldspar (see below).

Moore (1964a) suggests that the tonstein kaolinite macrocrystals formed in situ from an aluminium silicate gel. Sand (1956) found, however, that in igneous material books of kaolinite and muscovite formed from the weathering of feldspars via an intermediate mica stage. Strong leaching of all the bases from the feldspars resulted in the total disruption of the mineral structure, and produced the formation of hydrated halloysite with no transition from kaolinite to halloysite. If the feldspars altered to secondary mica first, a compositional and structural control was superimposed. The secondary micas, and in all cases flakes of primary muscovite, caused vermicular kaolinite to be the final weathering product with no formation of a gel phase. The interleaved layers of more highly birefringent micas in the tabular kaolinite suggests that they too were formed in a sequence similar to that described by Sand rather than from an aluminium silicate gel. A gel stage would have resulted in more homogenous macrocrystalline structures, without the interleaving of more birefringent micas on a gross scale rather than a mixed layer structure. It is not impossible, however, that micas could form from kaolinite during diagenesis on burial in this case. The alteration of feldspar to kaolinite is suggested by an example of a feldspar showing alteration in patches to kaolinite and a micaceous mineral which does not stain in the dye.

The original composition of the ovoid patches is unknown, but sericitisation of volcanic glass and fine grained igneous fragments is common, and this phenomenon may have provided the intermediate stage for kaolinisation without the formation of a gel also.

Kulbicki (1954) found that in muds containing iron pyrites, oxidation of the mineral creates sulphuric acid which attacks the granular kaolinite and forms in its place vermicular kaolinite and halloysite, or dickite.

Textural evidence from the $R1b_V$ specimens indicates that formation of the kaolinite macrocrystals was an earlier process than the oxidation of the iron pyrites. Slides showing little alteration of the pyrite and only sparse goethite granules contain as much tabular kaolinite as those which are badly weathered, suggesting that the kaolinite formation and oxidation of the pyrite are unrelated processes. In weathered specimens, ovoid patches of microcrystalline kaolinite still occur, and it is doubtful if they would have remained in this state if the processes suggested by Kulbicki had been operative. Oxidation of pyrite results in the replacement of quartz by goethite, and staining of the groundmass, possibly by the growth of dispersed goethite or limonite. Goethite also takes over tabular kaolinite, progressing along cleavage planes, and stains microcrystalline kaolinite patches, suggesting that the oxidation of the pyrite post-dates the formation of the kaolinite.

Confirmation of the early diagenetic formation of the kaolinite macrocrystals has been obtained from slides containing abundant carbonate cement, where siderite crystals penetrate the kaolinite macrocrystals. The kaolinite has not grown over the carbonate cement as the margins of the kaolinite can show euhedral outlines, developed before carbonate crystallisation. The siderite rhombohedra are also uncorroded, which would have been unlikely had the kaolinite formed in present-day acid leaching conditions.

As suggested in the descriptions of the slides from $R1b_v$ (loc. 072), a difficulty arises in the interpretation of the variable amount of kaolinite within the same band at different localities. Although only two specimens consisting of virtually 100% kaolinite have been found, it may be significant that gypsum has been identified in both by x-ray diffraction, that pyrite was absent in the specimens examined and iron leached from the clay, and that these two specimens alone showed relatively well ordered kaolinite.

The formation of kaolinite in tonsteins is thought to result from the weathering of clay minerals. Kaolinite derived from montmorillonite is recorded by Altschuler et al. (1963), and Maurel and Brousse (1959) suggest that montmorillonite forms in rapid weathering of arkosic material but montmorillonite and kaolinite with prolonged weathering. Apart from the kaolinite macrocrystals and some matrix kaolinite which forms at an early stage in diagenesis, it is conceivable that kaolinisation in the almost 100% kaolinite bands is a result of present-day weathering of the montmorillonite by sulphuric, carbonic and humic acids. Sulphuric acid from the decomposition of the pyrite often forms gypsum from dispersed pyrite in black shales. The presence of authigenic gypsum in the kaolinite bands indicates that pyrite was originally abundant, as it still is in some of the less weathered parts of the bands at loc. 072. Variation in the original pyrite content of the clay bands and variations in the period of present-day weathering on exposed rocks at different localities could explain the local variation in the kaolinite and montmorillonite ratios. Leaching, necessary for the formation of the kaolinite, would explain the absence of iron staining after the decomposition of the pyrite. A similar reaction in the adjacent black shales would not take place, or at least not so rapidly, as pyrite is not as abundant as it is when it occurs in the clay bands, and 10 Å micas would not alter to kaolinite as readily as mixed layer montmorillonites.

An early diagenetic origin for the well ordered kaolinite, apart from the macrocrystals and some matrix kaolinite is thought unlikely. Even if acid conditions were developed on burial of the original deposit, the formation of wholly kaolinised rock is possible only with leaching conditions to carry away excess alkalis. The iron may be accounted for by its incorporation into the sulphide under reducing conditions within the muds but there is no evidence for the formation of other authigenic minerals. The few heavy minerals encountered in the bands (zircon and ?apatite) are probably detrital in origin as primary bentonites are characterised by a suite of minerals including apatite and zircon (Spears, 1970).

CONCLUSIONS

In the field, the clay bands are similar to those described as bentonites by Trewin (1969), suggesting that they also have a volcanic origin. The mineralogy and texture of the clay bands is distinctly different from the black fossiliferous shales, the clay bands frequently containing expandable mixed layer clay minerals but no 10 Å micas. Where the mixed layer clays are absent, the dominant mineral is a relatively well ordered kaolinite, in contrast to the disordered kaolinite of the bands with abundant mixed layer material and the black marine shales. The well ordered kaolinite is thought to have formed during recent weathering. In the less kaolinised fragments, petrographic evidence suggests that kaolinite aggregates pseudomorph volcanic fragments, resulting in a texture similar to the altered volcanic ash described by Francis (1961). Fragments of feldspar are present.

The wide extent of the clay bands is also convincing evidence of their volcanic origin (Whitcomb, 1932), since volcanic ash could have fallen over a large area. The clay bands are never associated with coals, and the material must have originated from air-borne material or bottom currents. The latter agent is unlikely to have deposited thin bands of clay at exactly the same horizon over positive areas (Ashover) and areas of thick accumulations of sediments alike; nor, in the case of the Rla_1 bands, in such widely separated parts of the basin as Staffordshire and Yorkshire. Clay bands in fact become more sporadic in their occurrence towards the areas of shallower water arenaceous sediments. They include within them wisps of black shales, or disappear completely, indicating that bottom currents removed the material. Air-borne material, volcanic in origin, remains the only plausible explanation for their persistence over large areas.

Altered tuffs and agglomerates have been described from the Ollerton area by Harrison (in Edwards et al., 1967) from a position above R. gracile. It is thought that where the succession is thickest, ". . . there is a likelihood that the Bothamsall No. 1 sequence represents an actual volcanic vent, and that the Bothamsall Nos. 3 and 5 cores contain a thin lava effusion from the same seat of highly localised vulcanicity" (op. cit. p.153). The lava of Bothamsall No. 3 well is recorded as an Andesite-Trachyandesite. A 10' "grey-green igneous" rock was also recorded at 155' beneath the Kinderscout Grit equivalent in Tuxford Well; this could represent one of the R1 pale clay horizons, although its exact stratigraphic position is unknown. However, because of the abundant evidence of thick volcanic deposits to the east of the North Staffordshire Basin, and evidence of a volcanic vent, it seems likely that the Staffordshire bands, the feldspars of which seem to be of intermediate composition, were derived from this area of vulcanicity.

Some clay bands at certain exposures are similar to the bentonites of Trewin. Such bands pass laterally into kaolinised deposits, the texture and mineralogy of which are more akin to the tonsteins of coal measures. As the mineralogy of the clay bands is variable but all contain kaolinite and appear to be volcanic in origin, they are best referred to as "kaolinised ash bands" to distinguish them from typical tonsteins and bentonites.

NOTE ON THE OCCURRENCE OF JAROSITE

Namurian marine shales frequently show yellow coatings of a powdery mineral, particularly in the Dunbarella-rich horizons. This mineral is generally referred to as jarosite, and is thought to be derived from iron pyrites (Cosgrove and Hodson, 1963).

Good samples of the mineral were obtained from veins, about 4-8 mm thick, in waterlogged shales immediately below an exposure of the position of the $R1b_v$ ash bands. The mineral had presumably formed from the decomposition of the abundant pyrite, seen in unweathered samples of the ash band.

Despite the microcrystalline nature of the mineral, which is generally less than one μ except where it is associated with mineralised veins with iron pyrites (Cosgrove and Hodson, 1963), the sample showed most of the peaks recorded by Brown (1961) on x-ray diffraction, and more than those recorded by van Tassel (1956) in specimens taken from black shales above Visean Limestones (see Table 2.6. Diffractometer results indicate that the mineral is jarosite rather than natro-jarosite.

Specimens of a pale pink variety of jarosite were also obtained from waterlogged material (possibly a decalcified band) near the base of the *R. superbilingue* marine band at Foxt (loc. 164). The x-ray results were comparable with those recorded from the $R1b_v$ example. The pink jarosite occurred in several thin bands parallel with the bedding. This suggests that the *R. superbilingue* pink bands were also derived from ash falls. It seems likely that, in wet conditions with little free drainage, ash bands with abundant pyrite alter to jarosite.

Table 2.6

Diffractometer results for jarosite measured in Å

I	Brown, 1961	loc. 073	van Tassel 1956	Cosgrove and Hodson, 1963	ASTM 10-443
8	2.283	2.29	2.292	2.28	2.29
3	2.370	2.477	-	-	-
7	2.541	2.543	2.547	2.54	2.55
7	2.853	2.859	2.870	2.85	2.87
5	2.966	2.97	2.97	2.96	2.97
2	3.010	-	-	-	-
10	3.073	3.076	3.08	3.08	3.08
8	3.108	3.108	3.11	3.11	3.11
4	3.52	3.50	-	-	-
7	3.65	3.646	3.65	3.66	3.65
8	5.09	5.080	5.09	5.09	5.09
5	5.70	5.713	5.74	5.71	5.74
7	5.93	5.930	5.97	5.94	5.94