PROBLEMATIC FABRICS IN THE CARBONIFEROUS REEF LIMESTONE OF DOVEDALE

by

Donald Parkinson

Summary

Fibrous and lamellar calcitic structures from the Lower Carboniferous reef limestone of Dovedale are described and it is concluded that they are indicative of reef-building organisms, including Collenia-like algal forms. These fabrics are discussed in relation to similar, though not identical, forms that have been described from the Clitheroe Limestone of the same age.

Introduction

In the so-called "knoll", "knoll reef" or "reef" limestone of Lower Carboniferous age in Lancashire, Yorkshire, Derbyshire and Staffordshire there are certain fibrous and lamellar constituents, which have attracted the attention of geologists since they were attributed by Tiddeman (1892) to tufaceous deposits in a growing reef. These structures are also found in the Lower Carboniferous of Ireland and Belgium and locally in Pembrokeshire.

The specimens of lamellar and fibrous calcite which are described in the present paper were all obtained from the Dovedale Limestone in the Upper Caninia Zone (C_2 or $C_2 S_1$) of the Lower Carboniferous, which forms the well-known crags and knolls extending alongside the River Dove on the Derbyshire-Staffordshire border from north of Lode Mill to Thorpe Cloud at the southern end of the dale.

The nature of these problematical structures is vital to an interpretation of the origin of the limestone knolls themselves. It has for long been my own view that the "tufa" bands and mosaics are a manifestation of reef-building activity, though I have not hitherto described any of them in detail either from Derbyshire or elsewhere.

However, this view is not generally held. In the re-survey of those parts of Lancashire and Yorkshire covered by the Clitheroe Sheet, it was concluded by the authors of the Clitheroe Memoir (Earp et al., 1961) that the limestone knolls of Clitheroe and Slaidburn, which had not yielded undoubted reef-builders, were not reefs, but lime-banks. My own view that these knolls are in fact reefs was based on other kinds of evidence, such as the possession of very high dips (first noted by Tiddeman) which diverge as much as 90% from the regional strike. The Survey officers confirm the high divergent dips, but attribute them largely to later compaction of the sediments. Now the Dovedale-Manifold Valley knolls resemble the Clitheroe knolls so closely that it would appear, if the Geological Survey is right, that they also are lime-banks rather than true reefs.

It is the purpose of this paper to try to show that some of the organisms in the Dovedale knolls were rock-formers of reef-building types, and it will be argued, as it was argued by Bathurst (1958, 1959) in the case of the Clitheroe knolls, that the original nature of the organisms, whether plant or animal, has been obliterated by diagenetic changes.

The term "diagenesis" has been recently excellently defined by Read and Watson (1962) as comprising "all those changes that take place in a sediment near the earth's surface at low temperature and pressure and without crustal movement being directly involved. It continues the history of the sediment immediately after its deposition and with increasing temperature and pressure it passes into metamorphism". (See also Taylor, 1964).

History of Research

R.H. Tiddeman (1892) after prolonged stratigraphical work on the Geological Survey in North-east Lancashire and the West Riding of Yorkshire suggested a tufaceous origin for certain laminar structures which are characteristic of the Clitheroe, Bowland and Craven knolls. He postulated (1892) that, where the reef was above water, sea spray or rain water dissolved carbonate from calcareous sand and redeposited it on drying. Similar structures in the Waulsortian (Lower Carboniferous) reefs of Belgium were ascribed by de Dorlodot (1911) to a growth of crystals on fenestellid flakes perpendicular to the surface of the flake. Dixon (1921) described structures in the Carboniferous Limestone of Pembrokeshire which he said could be matched with those of Clitheroe and Belgium; he noted that, where satisfactory examination had been possible, the thin laminae, consisting of calcite and dolomite crystals elongated normal to their length, bore the imprint of a fenestellid bryozoan on their sharp-cut under-surface. He pointed out that the upper surface shows the free faces of the crystals and suggested direct crystallisation from the waters of the Carboniferous sea as a likely explanation, a view substantially in accord with that of Tiddeman.

Between 1921 and 1951 different authors including Hudson, Parkinson and Bond made references to the "tufa" bands, without critically discussing their origin. W.W. Black (1952) in a detailed study of the "tufa" bands from knolls near Whitewell in Bowland adduced evidence against the view that they are primary structures and suggested that they are recrystallisations of the unbedded calcite mudstone which is a common constituent of the reef rock. Parkinson (1957) in a brief review of earlier work noted his own observations, which agreed with those of de Dorlodot and of Dixon to the extent that the fibrous bands are often associated with fenestellids. The researches of L.C. Pray (1958) stressed the importance of fenestrate bryozoans in the core facies of the Mississippian bioherms of the U.S.A.

The name Stromatactis was given by Dupont (1881, p. 268) to problematic structures in the Middle Devonian (Frasnian) reefs of Belgium which he suggested might be reef-building stromatoporoids. Lecompte (1937) described these structures in detail and (1938) noted their close similarity to the lacy networks of crystalline calcite in the Silurian (Niagaran) reefs of North America. He did not, however, believe them to be diagenetically altered stromatoporoids. Lowenstam (1950, 1957) considered the "Stromatactis-like forms" to play a part in the frame-building of the Niagaran reefs of the Great Lakes area. His view that

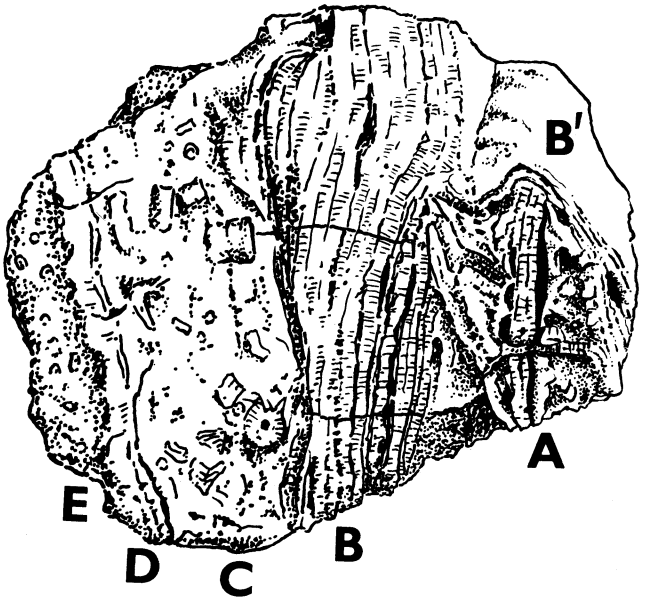

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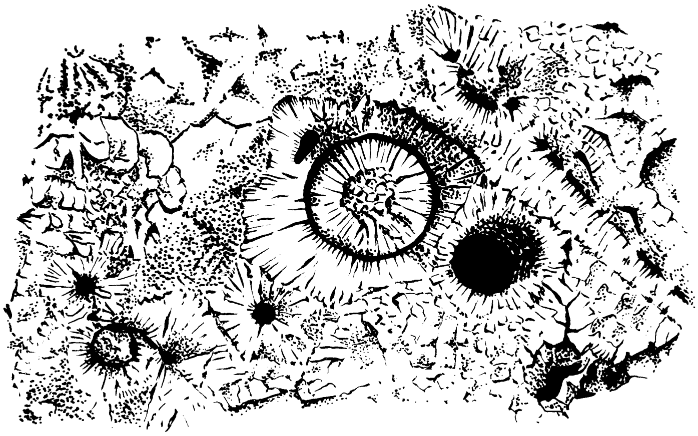
FIG. 1 Bands of secondary fibrous calcite (which, it is thought replace problematical reef-builders) alternating with calcareous sediment of varying fineness of grain. Erosion surface between segments (A) and (B).



X5

FIG. 2 Calcite fibres rooted on crinoid ossicles probably by **direct** precipitation from sea water.

they are organic is based primarily on his observations that the "closely spaced thin laminae which make up the ribbons are separated by short, closely spaced, vertical pillarlike structures" (1950, p.439). He is non-committal about the nature of the organisms; stromatoporoids or algae are mentioned(1950, p. 439) and he later states (1957, p. 247) that unless the *Stromatactis*-like forms are algal the sole reef-builders were all coelenterates. Stubblefield remarks in a general review of the Palaeozoic sessile marine organisms (1960, p. 231) that the evidence that algae were rock-formers in these Silurian reefs "is still far from conclusive".

R. G. C. Bathurst (1958, 1959) has studied in great detail the "reef tufa" in two knolls of C_2 age (Bellman Quarry, Clitheroe and Hall Hill, Whitewell in Bowland) and has concluded that it has all the important characteristics of the Devonian and Silurian *Stromatactis*. His views of the nature and origin of the Carboniferous "tufa" differ from those of both Tiddeman and Black; he considers that it is drusy mosaic which has formed in post-depositional cavities, and states that the lower surface of the *Stromatactis* layer or irregular mass is commonly smooth and rests on the surface of "internal sediment" coarser in grain than the primary calcite siltstone of the reef. He points out, in agreement with the observations of Dixon and of Black, that the upper surface of the cavity is normally irregular, the overlying siltstone being untidily embayed by digitate coarse mosaic (1959, p. 509 and Plates 1 and 2). Bathurst does not consider that the *Stromatactis* is associated with bryozoans as sediment-binders or frame builders; specimens he examined (sectioned by Dr. Alan Lees) from Feltrim, Co. Dublin, he considers to differ from *Stromatactis*, "since sediment is a minor component and does not enclose drusy mosaic" (1959, p. 517). Finally he suggests tentatively that the primary post-depositional cavities may have been moulds of an organism which had decomposed after burial. He came to no conclusion on the nature of the supposed organism, but commented on the apparent absence of algae from the Clitheroe knoll reefs.

"Tufa" bands are among the examples of knoll limestone examined petrographically from the Clitheroe knolls (Earp, et. al., 1961). The conclusion is reached (p. 40) that "some at least of the clear coarsely crystalline calcite has been chemically deposited from solution on internal cavity walls." Later narrow veins (up to 0.25 mm. wide) were also found which traversed both the coarse calcite and the fine-grained sediment which occupied the cavities.

Layered Calcite Fabrics from Dovedale

In his work on the Manifold Valley rocks, Prentice (1951) noted the presence in the reef limestone of layered structures to which he ascribed an algal origin, but he did not describe these features in detail. The structure described below from the neighbouring Dovedale knoll reefs are of various kinds and some of them appear to be of an algal nature.

The types of layered and fibrous calcite found in these reefs may be divided into four kinds:-

(a) Bands of fibrous and prismatic calcite sometimes showing the characteristic flat undersurface and irregular upper surface, separated by limestone which in some cases is of the nature of a calcite mud or silt, but in others is of a detrital material of moderately coarse grain. The fibrous bands are often bent or contorted and frequent truncations of one set of layers by later ones are seen. (Text-fig. 1).

(b) Fibrous calcite growing radially from the surfaces of fossils usually in a broken condition. The organisms involved in particular are fenestellids, crinoids and brachiopods. (Text-fig. 2).

(c) Laminae much thinner than the usual "tufa bands. Many of them have a crinkled or corrugated appearance and others appear to consist of a mat of very short prisms. There are characteristically from five to ten layers in one millimetre. These structures suggest *Collenia*-like stromatolites and some of them encrust fossils (Text-fig. 3).

(d) Intergrowths or successions of the (a) and (c) type bands (Text-fig. 4).

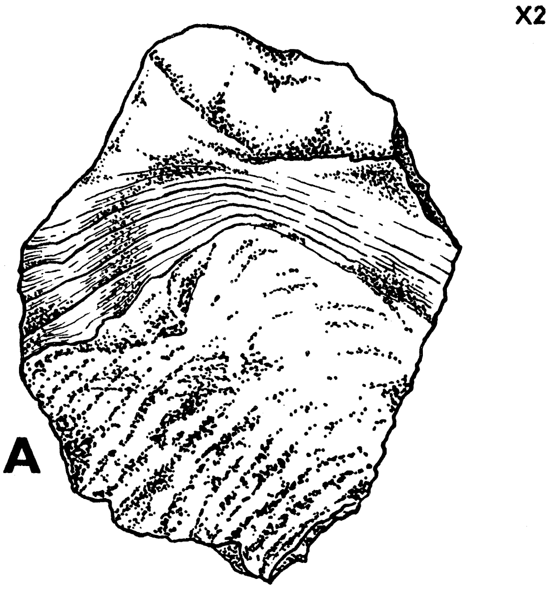


FIG. 3 Portion of Productus shell (A) encrusted by Stromatolite (?) (B).

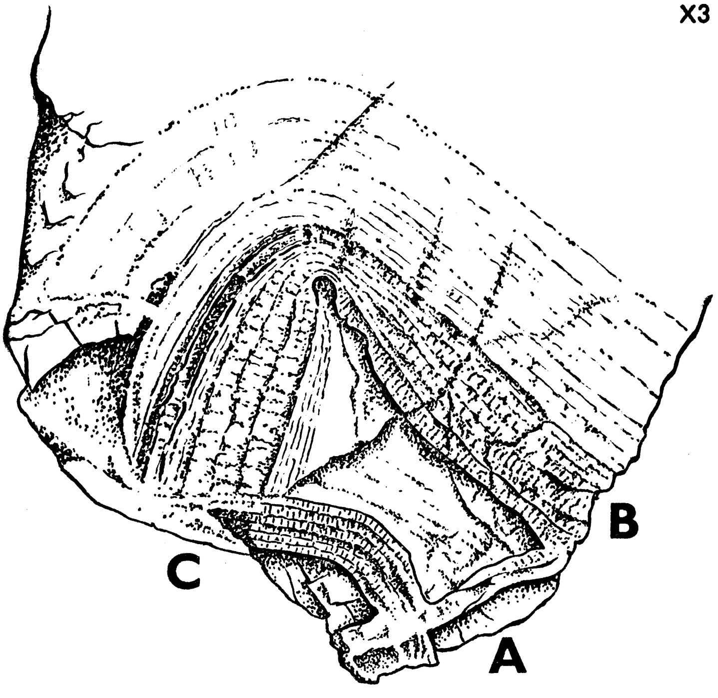


FIG. 4 Illustrating three stages of reef growth separated by two periods of erosion. Segment (A) and the upper part of (B) are of suggested algal origin. (C) and the lower part of (B) are thought to be secondary crystallisations occupying the sites of reef-builders.

It should be added that large portions of some of the knoll reefs, of which Thorpe Cloud may be cited in particular, are made of a porcellanous limestone which on close examination reveals a laminar texture.

The following remarks are based primarily on the examination of hand specimens and observations in the field, though some thin sections have been inspected. Well weathered hand specimens are in some respects more illuminating than micro-sections, since the structures can readily be observed in three dimensions.

Of the four types of texture enumerated above, (a) most nearly approximates to *Stromatactis* as interpretated by Bathurst (1959). In general the Dovedale-Manifold structures have a fresher appearance than the Clitheroe *Stromatactis* and the crystallisation is more obviously fibrous as seen in hand specimens, also the intervening lime silt is more transparent in thin section than in the Clitheroe-Bowland reefs. These particular mosaics resemble those described by both Black (1952) and Bathurst (1958, 1959) in being radial to depositional surfaces and in not encrusting organic material.

Both Black and Bathurst, though differing in their interpretation, state that the "tufa" bands are associated with the calcite siltstone which is a major constituent of the reef. In the Dovedale-Manifold country they are enclosed in sediment of from fine to coarse texture, as is shown in Fig. 1. This figure, like the others, has been drawn by a non-geologist with no preconceived ideas of what he ought to see and therefore no particular feature is exaggerated at the expense of the others, but not all that can be seen is shown. No attempt is made to orient the figures to indicate the original inclinations of the depositional surfaces.

The portion (A) of Fig. 1 is composed of fairly fine-grained crinoidal limestone traversed by a number of fibrous calcite layers; the largest divides into two, the divergent parts being evident in the diagram. The line running along the middle of the most prominent band is a deep groove from which the fibres radiate. A later generation of crystallisation is clearly shown by the thin prismatic layer crossing the area (A) and by the portion (B) which wraps round and truncates the edges of the portion (A). The rock has fractured along the surface of a fibrous band of the (B) generation in the area (B^1) which displays the "sugary" texture referred to by Black (1952, p. 196). The fibrous bands of (B) are not uniformly developed and are shown to thicken towards the top of the figure. The total thickness of radiating fibrous calcite in successive layers (which are not here separated from each other by primary or other sediment) is here about 13 mm. with one layer 4 mm. in thickness. The section (C) is a relatively coarse crinoidal limestone which is in contact with an irregular surface of (B). Along the upper surface of (C) is a band of fibrous calcite (D) of similar nature to those of (A) and (B). The portion (E) is a detrital limestone less coarse than (C).

It seems clear from the figure that (B) post-dates (A) after an interval, probably short, during which (A) suffered erosion. I consider that the bands of fibrous calcite crossing (A) are recrystallations of a small segment of the original framework of the reef and that the space between the frame-builders was filled by fine detritus. An alternative explanation is that suggested by Black, that the laminae are recrystallisations of the calcite silt. However, if these structures did in fact form before the influx of silt their configuration, if nothing else, indicates organic origin. The erosion surface between (A) and (B) which has a sharply bent and deeply indented profile, and the presence of a crack crossing (A), seem to indicate slight slumping during the erosion period. Lying on this surface the second generation of prismatic crystals forms the multiple band (B) and a thin fibrous layer penetrates the cavity in (A). There does not appear to be any essential difference between the (A) and (B) crystallisations. The thin band of fibrous calcite (D) is separated from (B) by a further influx (C) of detrital matter, mainly crinoidal, and much coarser than that filling (A). (D) is thought to be representative of a later frame-builder in the growing reef.

In the (B) type of structure the radial fibrous calcite grows direct from the surfaces of fossils, in particular fenestelloid polyzoans, but also crinoids, brachiopods and corals. In Fig. 2., the fibres are seen to radiate outwards from crinoid ossicles. In the same specimen, not shown in the figure, they are similarly associated with fenestellids. I agree with Bathurst that this type of structure is not *Stromatactis*. A specimen figured by Pray (1958, Fig. 4) from a Mississippian bioherm in Texas is interpreted by that author as consisting largely of sparry calcite which has grown inwards by open space crystallisation at a bryozoan frond which formed the wall of an original cavity in the rock. Pray's photograph resembles the type (b) material so closely that I have little doubt of the similarity of origin. In Fig. 2 of Pray's paper are coarse mosaics of a different type of structure which Bathurst compares with *Stromatactis* and comments on their flat bottoms and digitate tops.

Type (b) crystallisation is of common occurrence, though sporadically distributed, in the Dovedale reefs. I suggest that the radiaxial calcite was deposited directly in the voids of an original spongy network in the reef and that the voids were either in free communication with the sea and the calcium carbonate was precipitated from solution, or the precipitation was from evaporated water when the reef locally was above sea level. There seems no good reason why both operations should not have taken place, and therefore the tufa theory of Tiddeman might well offer the true explanation in some cases. Newell (1955) has argued that the bulk of the fibrous calcite in the Permian reefs of West Texas was deposited from solution in primary cavities "over the surfaces of frame-builders and older surfaces of calcarenite". He suggests precipitation from relatively clear turbulent waters in which all fine sediment remained in suspension...at a level a few inches below the surface of the growing reef" (p. 308).

The type (c) structure suggests an algal origin with some recrystallisation. The laminae form very thin sheets parallel to each other and to the depositional surfaces, they range from slightly undulating to crinkly. A fine-scale radial texture of very short prisms can often be seen in individual bands. In Fig. 3.,the banded material (B) which is suggestive of a *stromatolite*, encrusts the broken valve of a *Productus* shell (A). The dark lines of the illustration are shallow grooves which show up white in the rock itself. The details of the intervening texture are too fine to be shown in the figure.

Similar laminar textures to the one described above, but on a massive scale, cover large areas in the C$_2$ knoll reefs. In hand specimens some of them closely resemble the algal material reported by Wolfenden (1958) in the D$_1$ reef of Parkhouse Hill and elsewhere in West Derbyshire. Dr. F.W. Anderson, in a cursory examination of my material, recognised algal forms. He mentioned the difficulty of determining species because of the large degree of recrystallisation.

On the southern lower slope of Thorpe Cloud there is an outcrop many square yards in extent of an unbedded purply-blue porcellanous limestone which Dr. Anderson considered might indicate an algal origin.

Type (d) consists of alternations of the coarse fibrous *Stromatactis* layers and the fine stromatolitic-like layers, suggesting two kinds of organisms with much replacement of the original structure by secondary calcite. In Fig. 4. three generations of growth, separated by two periods of erosion, probably with some slumping, are recognisable. The first (A) is on too fine a scale for reproduction in the figure. It is finely lamellar, with the appearance of a gauze-like network. This could be of algal origin. The next generation (B) wraps round and trangresses the edges of (A). The lower (coarse) layers of (B) are radially prismatic, the higher ones, again suggestive of algae, not displaying much structure, though there is a suggestion as in (A) of a very fine network of short prisms normal to the boundary surfaces, some of which are straight and others slightly crinkled. The portion (C) is quite clearly seen to consist of six adjacent parallel prismatic bands which truncate (B) as well as (A), and in the specimen itself the first layer of (C) is seen to penetrate a narrow cavity in (B). The three generations of growth separated by two periods of erosion shown in this specimen are a common feature and as many as four have been noted.

An unusual deposit is seen in a small vertical exposure on Hamston Hill, Thorpe, consisting of a succession of parallel bands (of which 13 are visible) a few feet in length and for the most part straight, though some show undulations in the mass. Several occur close together to form one band and are separated from the next series of laminae by as much as an inch of detrital limestone. Some individual laminae display the characteristic corrugated texture and others appear to be finely punctate, the punctation being apparently a manifestation of short radial prisms. The appearance is suggestive of a succession of algal growths separated by influxes of calcite detritus in the growing reef.

It might be added that there are often seen in thin section innumerable tiny pellets,which though usually larger than the algal dust described by Wood (1941), could possibly be algal in origin. Their detailed investigation has not been attempted.

The Dovedale and Clitheroe Knoll Reefs ; Resemblances and Differences

The Dovedale-Manifold Valley knoll reefs resemble those of Clitheroe and Bowland in possessing depositional dips, much unbedded or obscurely bedded porcellanous limestone (siltstone according to Bathurst, 1959 and Earp et. al., 1961), a characteristic fauna and "reef tufa". The laminar "tufaceous" fabrics in the Dovedale-Manifold knolls are of greater variety and complexity than those in the Clitheroe knolls and are fresher in appearance, and in thin section the siltstone is more transparent. And whereas algae are not proved in the Clitheroe Limestone they are present (and may have been extremely abundant) in the Dovedale Limestone.

Now if the knolls of Clitheroe and Dovedale are of similar origin we should expect algae to be of importance in both regions. Although Bathurst suggested an organic origin for the Clitheroe Stromatactis he argued against an algal derivation. He stated (1959, p. 517) that the Derbyshire limestones are in the "same general state of diagensis as those near Clitheroe" in which algae are unrecorded. I would make the suggestion that the condition of the calcite mosaics in the Clitheroe reefs points to a somewhat more advanced state of diagenesis than those of Derbyshire, and I suggest further that this may possibly result-in part at least - from environmental differences between the reefs of the two areas. Those of Clitheroe were enveloped in basin rocks largely argillaceous, whilst the Dovedale reefs grew near the rim of the basin and the contemporaneous bedded limestone contains virtually no shale.

Whether or not algae were original constituents of the Clitheroe knolls, there is no doubt that in reefs where they are known to exist their skeletons are readily recrystallised. Newell and co-workers (1953, p. 109) refer to advanced recrystallisation of algal skeletons in the Pleistocene reefs of the Bahamas. The Silurian (Niagaran) reefs of North America provide an instance in ancient structures, now generally accepted as reefs, where the evidence of frame-building organisms is slight because of diagenetic processes, and as Black remarks (1954, p. 292) there are others in various parts of the world. Black, in fact, makes the interesting suggestion that the calcite mudstones (siltstones) of the Carboniferous reefs in the north of England might themselves be recrystallised algal skeletons. Although Bathurst (1959, p. 517) considers that the primary sediment was too coarse to provide algal precipitates, he does not altogether discount algal action.

In the Dovedale reefs there is much fine-grained unstratified limestone which on examination with a pocket lens reveals a closely spaced laminar texture. Other parts of the same apparently uniform mass of rock appear to be quite structureless. The general impression is one suggestive of an organism (probably algal) in progressive diagenetic change, which gives support to Black's suggestion. I believe with Bathurst that the Stromatactis-like structures were originally organic, but like him I have not proved their algal nature. However, in Dovedale some at least of the finer laminae, as distinct from the coarse mosaics, are apparently algal, and these often alternate with Stromatactis-like layers. The implication is that the Stromatactis-forming organisms decomposed more readily than the others. I suggest that in the Clitheroe knolls the diagenetic changes progressed so far as to obliterate completely not only the Stromatactis-forming organisms, but the more resistant finely lamellar algal frame-builders which are still preserved in the Dovedale reefs.

The diagenetic changes would appear to be of two main kinds; (1) decomposition of organic matter (Stromatactis) accompanying the formation of post-depositional cavities in which, as Bathurst believes, the drusy mosaics were precipitated, and (2) recrystallisation in situ of algal species different in character from the Stromatactis-like forms.

The view that a reef-builder,which decomposed rapidly,accompanied others with more resistant skeletons helps to explain why the calcite mosaics are often found to alternate rhythmically with fine-grained limestone (Bathurst's primary sediment) through a thickness of many yards, as can be seen for example in the dissected knoll of Knot (or Sugar Loaf) near Dunsop Bridge in Bowland, Yorkshire. The primary sediment itself would seem to have had to be supported originally by a frame-builder or sediment binder, otherwise it can hardly have contributed to the building of the reef. If it can be assumed that the reef-building in such circumstances was shared by algae and the problematic Stromatactis, the rapid disintegration of the latter would provide the sites of cavitation and account for the deposition of the coarse mosaics which, as Bathurst observes, would be precipitated not long after burial of the sediment in successive generations. Such a hypothesis is consistent with both Black's suggestion that the calcite siltstone of the reef consists in part of recrystallised algal skeletons and Bathurst's conclusion that the fibrous calcite itself is not recrystallised calcite siltstone as had been argued by Black. It should be added that Pray (1958, p. 265) considered that much of the lime mud in the American Mississippian bioherms was of algal origin, although distinct algal structures had not been recognised.

All this takes us a long way from Tiddeman's tufa and Dixon's direct precipitation from sea water and the common association of the tufa with fenestellids. There is, however, as noted in earlier pages, much evidence of direct precipitation in the Dovedale reefs of fibrous calcite on fossil surfaces, including fenestellids. Moreover, Pray (1958) considers the fenestrate bryozoans to be of major importance in the American Mississippian bioherms and there are other instances of bryozoan reefs. Bathurst shows that bryozoans are not associated with the structures he describes in the Clitheroe reefs, but in my view they were to some extent contributors to the reef framework both at Clitheroe and Dovedale. It is 40 years since I observed at Coplow, Clitheroe, before the knoll was levelled by quarrying, much fibrous calcite which in some cases was clearly rooted on a fenestellid; these observations were not followed up at the time. Fenestelloid polyzoans are common in the friable detrital calcareous mud (from which large numbers of crinoids representative of many species have been extracted) in the Coplow knoll, as well as in the surrounding shales. In contrast, bryozoans are apparently rare in the C_2 bedded cherty limestones in contact with the reef limestones of Dovedale and the Manifold Valley.

Conclusions

I consider that the evidence as a whole justifies the belief that reef-builders were present in the C_2 biohermal knolls of the North Midlands and the North of England. Of these organisms the fenestelloid bryozoans were subsidiary to the algal and Stromatactis forms. Algae may have been relatively less important in the Clitheroe limestone than in the Dovedale Limestone.

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