THE LOWER CARBONIFEROUS CORAL ENVIRONMENTS OF DERBYSHIRE AND ADJACENT AREAS.

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by

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Summary

A comparison is made between recent and Lower Carboniferous coral faunas from morphological and stratigraphical aspects. The environment of recent corals is summarised and comparisons and contrasts made of this environment with that of the Lower Carboniferous, deduced from a study of Derbyshire rocks and fossils. It is considered that the Lower Carboniferous corals lived in an equatorial warm water marine environment developing mainly as patch reefs, just below sea level, with an associated fauna. Outer barrier reefs, knoll limestone, possibly controlled by abundant crinoid growth, with or without algae and generally devoid of coral, separated the coral patch reefs from the surrounding deeper water. Land areas would be restricted to small, low islands lying to the south, the remnants of an earlier more extensive St. Georges Land. The possibility that the main Derbyshire limestone area subsided as a result of an ancient volcanic platform, floundering, allowing the accumulation of over 2,500 feet of limestones, is investigated.

Introduction

Much has been written about coral ecology since the voyage of the Beagle and Darwin's (1837, 1842) essays on coral reefs. There is a similar volume of literature on British Lower Carboniferous (Avonian) palaeogeography, summarised in the papers of George (1958, 1962, 1963). Recent and Carboniferous corals and reefs are usually mentioned by writers on these subjects. The corals and associated faunas with their sediments have not been used to any great extent to deduce detailed Lower Carboniferous environments. Using Sir Charles Lyell's 'Principle of Uniformitarianism' - 'the present is the key to the past' - as a working hypothesis, comparisons are here made between modern and Carboniferous coral occurrences to add details to the palaeogeography of Derbyshire so far illustrated by other authors.

For the description of the ecology of modern corals I am indebted to the work of J.W. Wells, (1956, 1957), D.R. Stoddart (1966) and contributors to a coral symposium held in London in September 1970, to be published shortly. The ideas on the Lower Carboniferous palaeogeography of Derbyshire are based on the summaries of Professor T.N. George and other Carboniferous workers acknowledged in the text, and also on my own studies of Derbyshire corals and rocks since 1953.

There has been little published on the palaeoecology of the Carboniferous coral beds. Rayner (1946) has described an occurrence near Settle, Yorkshire, and Hill (1948, 1956) has written on the palaeoecology of Palaeozoic corals, considering them to form the framework of reefs in conditions similar to those of the present day. The small solitary corals are thought to have lived in deeper water and the large solitary corals in an intermediate depth position.

There is no clear indication of the depth of water involved and little can be learned from the literature about the environment in which these corals and their associated fauna lived.

If the principle of 'Uniformitarianism' is accepted, the first step to be taken in attempting to deduce Lower Carboniferous coral environments would seem to be a study of those of recent corals. Before this is done, however, I would like briefly to review morpholigical, ontogenetic and stratigraphical evidence which might suggest that there are sufficient character differences to render the hypothesis that recent and Lower Carboniferous coral environments are the same, invalid.

Coral Morphology

It is not intended to describe in detail the skeletal structure of the various groups of corals, the modern Scleractinia, and the Palaeozoic Rugosa and Tabulata, but to draw attention to the clear differences of skeletal structure that do exist which may be the result of different environmental conditions. Three examples, concerning the form of the coral, the septal plan and the original mineral composition of the skeletal material, are discussed below.

A first assessment might suggest that there are many growth habits or forms of coral common to all three groups. This statement applies particularly to the common fasciculate and massive colonial corals. Certain forms are restricted to only one or two of the groups. There are no acknowledged solitary Tabulate corals and the slipper shaped *Calceola* and rectangular *Goniophyllum* of the Rugosa have no counterparts in the Scleractinia. Many modern solitary corals, such as the fungids, have no outer protective wall (epitheca), a feature unknown in the Lower Carboniferous. The meandroid colonies, as developed by *Meandrina* or *Mancinia* of the Scleractinia are restricted to that group, the nearest equivalent being the cateniform or chain corals exhibited by *Halysites* of the Tabulata. These distinctions are due to different methods of colony formation, the result of polyp increase producing a large number of individuals grouped together as a colony. The different methods, may well be a fundamental distinction.

The septal plan, seen in transverse sections of the coral skeleton, is determined by the mode of septal development. Modern corals possess a septal plan which is characterised by six long septa reaching to the centre of the coral, dividing the circle of septa into equal 60^{o} sectors. These six sectors are bisected by six shorter septa and the resulting twelve sectors are themselves bisected by twelve shorter septa. Depending on the size of the coral there may be a further set of septa, twenty-four if fully developed, again shorter than the pre-existing septa. A distinctive radial septal plan is thus a common feature of scleractinid corals. The rugose corals developed their septa in a different manner, resulting in the alternating long and short septa characteristic of their septal plan. Tabulate corals are often without septal structures and when they do occur they are seen as small spines, usually twelve in number, (Hill, 1956; Wells, 1956). These differences are once again fundamental.

Micro-structures in the septa of corals are known from both modern and Carboniferous corals. The aragonite skeleton of the Scleractinia often changes to calcite, the more stable form of calcium carbonate, with the resulting loss of the microstructure. Further recrystalisation may result in the complete destruction of the coral, leaving only a mass of large calcite crystals. The fact that microstructures can still be found in the calcite skeletons of Carboniferous corals, or Silurian corals for that matter, suggests that calcite, rather than aragonite, was the original mineral deposited. Aragonite is more commonly formed in a warm marine environment and calcite in cooler areas at the present time. (See also Sorauf 1971)

Other examples could be given but these three illustrations alone are sufficient to show that there are fundamental, skeletal differences between the three groups of corals and it would not be surprising to learn that these reflect differences in the respective environments.

Evolution and Geological History

Historically, there is no continuity between Palaeozoic and Mesozoic coral faunas. Rugose corals are known from Upper Permian strata, represented by the small solitary coral populations of Timor and Armenia. No tabulate or scleractinid corals of this age are known. The first small colonial corals of the Middle Trias are all thought to be scleractinids and claims of rugose corals from the Lower Triassic rocks have still to be substantiated. There are no clear morphological similarities between the last rugose corals and the first scleractinids and Hill (1960) claims that there is no certain evolution of the modern corals from the rugose corals.

The scleractinid corals have had a long existence commencing at the beginning the Middle Triassic, on present estimates (Harland, 1964) over 215 million years ago. During this time environmental changes could occur accompanied by, or independant from, any adjustments of scleractinid physiology. The group is extremely successful at present, as successful as the Rugosa were at the close of the Lower Carboniferous.

Skeletal differences have purposely been emphasised but corals of all ages are placed within the same phylum, the Coelenterata, indicating the essential similarities that are also common to all groups. It is generally accepted that the composition of sea water has changed little over the last 600 million years, a constant environmental factor. It still seems worth while to consider modern coral environments as a key to those of the Lower Carboniferous.

Modern coral environments

All modern corals are marine organisms living in saline water with an optimum of 33 to 36 parts of dissolved salts per thousand. They are intolerant of any degree of dilution or concentration outside the range 27 to 40 parts per thousand. Breaks in continuous coral growth occur beyond these limits.

The corals are sessile organisms and require that all materials necessary for life be brought to them, and that all toxic waste products be removed. They live, therefore, in regions of moderate to strong current activity.

Other ecological conditions are less stringent and allow modern coral faunas to be divided into two main groups, the warm water, so-called reef corals, and cold water, non-reef, solitary coral faunas.

The colonial corals flourish in a warm water environment with optimum temperatures between 25^{o} and 29^{o}C. Another factor said to facilitate skeletal secretion is strong sunlight. The reason for this is a little obscure as the polyps are most active with reduced illumination, feeding especially at night. The environmental restriction may be imposed by the zoanthellae (algae), which are considered to be an important symbiant in the coral tissue and would require sunlight for photosynthesis. It follows, that coral growth is most active between the low-tide mark and a depth of about 20 metres.

Solitary corals also thrive in the conditions outlined above but are more tolerant of variations in temperature and light. They can live in much cooler situations with temperatures down to $4{\cdot}5^{o}$C and in depths down to 500 metres or more. Strong sunlight is not an essential condition and these corals are without zoanthellae. Deposition of calcium carbonate in the skeleton is much slower and no large masses of coral are formed.

Geographically, warm-water reef corals are restricted to a zone approximately 30^{o} north and south of the equator with variations where warm water currents will allow growth at higher latitudes and cold currents will restrict growth even in equatorial regions (Wells, 1957, Pl.9). The main areas of modern reef development are the central Pacific islands, the Gulf of Arabia, the Red Sea, Indonesia and the Caribbean (West Indies), covering in all an area of over 68 million square miles.

Solitary corals live in the same areas and extend beyond them into higher latitudes, including the North Sea and the Western Isles of Scotland, but coral populations in these higher latitudes are insignificant.

The distribution of corals in the warm-water areas takes one of the following forms:

(a) Fringing reefs, immediately off-shore, below low-water mark.

(b) Barrier reefs, usually separated from the fringing reefs and the shore-line by a lagoon.

(c) Atoll reefs, developing on the flanks or crater of a subsiding volcanic caldera.

(d) Patch reefs, found in any shallow water region, but covered at low-tides.

(e) Isolated coral development, frequently made up of single large colonies or solitary corals, sited in the path of a favourable current.

Atoll reefs frequently attain great thickness, with growth of the coral keeping pace with subsidence. Exploration at Eniwetok Atoll (Ladd, 1953) has proved corals down to depths of over 4,000 feet, the corals remaining unaltered at that depth and the lowest ones being of Eocene and Miocene age. There are basaltic foundations to the atoll and the sediments show shallow water characteristics throughout. Darwin's (1837) subsidence hypothesis seems now to be proved.

Other reefs are usually much less thick. With the surface of the sea restricting growth upwards, development of the reef is outwards and horizontally, with steep faces towards areas of maximum water movement.

The corals are just one factor of the reef populations. Of equal importance are the calcareous algea, which bind the various consistuent parts of the reef together. Other organisms, including foraminfera, echinoderms, molluscs and fish, live in sheltered crevasses or cavities in the developing reef. All these organisms provide a wealth of small food particles for the coral polyps, particularly eggs, larvae, spat and other small fragments. It is now doubted whether plankton is the only food source as it is relatively scarce in areas where currents and waves are strong.

Debris derived from the break-up of the reef during storms, or when the reef building organisms are killed, contribute in a large way to the amount of limestone in and around the reef area.

Despite the attacks of predators, including the much publicised star-fish (*Acanthaster planci*), the Scleractinia are remarkably successful and since the Miocene at least, have contributed much to the life of the warm water oceans. Their remains are to be found, either fragmented or complete, in many thousands of feet of limestone sequences.

Next to be considered, are the Lower Carboniferous coral environments, as they might have developed in the North Midlands (Derbyshire) area.

The Derbyshire Lower Carboniferous coral environments

General conditions and situation

The present location of the British Isles, despite the favours bestowed upon the country by the warm Gulf Stream oceanic current, precludes the growth of reef corals around its shores. The occurrence of large colonial corals now preserved in limestones of Wenlock, Middle Devonian, Lower Carboniferous and Jurassic ages has always created a problem concerning their environment. Before the idea of continental drift became acceptable, it was necessary to consider changing the positions of the poles and equator, ameliorating climatic conditions generally over the globe or assume that Palaeozoic corals were more tolerant to adverse conditions than those of the present day. The occurrence of fossil corals has been used as circumstantial evidence in favour of continental drift. Recent ideas on continental drift and polar wandering, derived from palaeomagnetic data, independantly allow the British Isles to be placed within the 0^{o} - 30^{o}N position during the Permian Period, as accepted by Holmes (1965, p.1231) and the same author (p.1232) does not think that the position would be greatly changed during the Lower Carboniferous. With the possible existence of a warm-water current and with the restricted volume of a much reduced 'Atlantic Ocean' the geographical position of the 'British Isles' could be a little further to the north to achieve substantially the same climatic conditions. Warm-water marine conditions are thus envisaged right across the present British Isles, during Lower Carboniferous times, extending into Europe on the one side and North America on the other.

The lack of coarse terrigenous detritus (siltstones and sandstones) in the Lower Carboniferous sediments of the Derbyshire area, suggests the absence of large deltas originating from land surfaces (St. George's Land) with high relief. Small islands are acceptable, possibly less than 100 feet high, separated by channels in which limestone could be deposited. Eunson (1884) has described Carboniferous limestone from bore-holes near Northampton, south of the postulated islands. They form part of St. George's Land, a land area extending from East Anglia to Wales, and can be positioned in the open channel depicted on the Visean palaeogeographical maps of Wills (1951) or Rayner (1967). The deposition of mud, either with or without calcium carbonate was often extensive and requires a source area, the nearby St. George's Land or further afield.

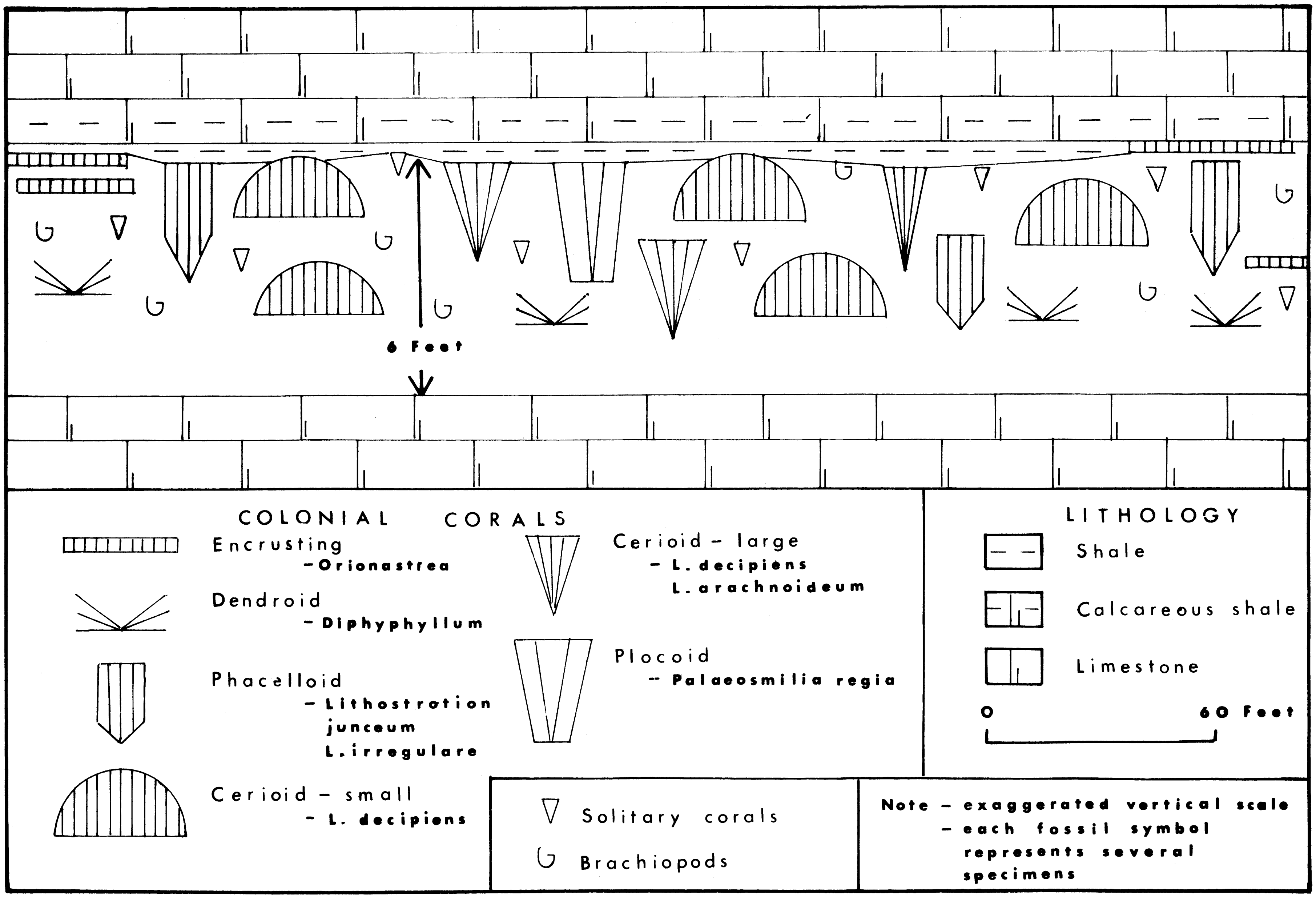
High temperatures are envisaged not only from the tropical position of the islands but also from the development of minerals in some areas. These minerals include any chemically precipitated calcite and dolomite in the limestones. The less porous, more compact dolomitic limestones of south Derbyshire and north Leicestershire suggest almost immediate dolomitisation. Dolomitisation of Carboniferous limestone in this area is complicated by the later cover of Permian and Triassic beds and the consequent addition of magnesium ions to the Carboniferous limestone from the Permo-Triassic sediments resulting in the highly porous rocks now seen near Brassington at the Harboro' Rocks and Rainstor Tor. Finally, the discovery of anhydrite in a bore-hole near Hathern, Leicestershire (Llewellyn and Stabbins, 1970) indicates intense evaporation in part of the area at least during the late Tournasian, early Visean times.

The details of the marine environments of the Derbyshire area can be studied commencing with the coral beds, which appear to be situated centrally, and then bordering environments can be briefly examined, as these appear to have an effect on the distribution of the coral populations.

The coral patch reefs

The evidence for the details of this environment is obtained from a study of the Derbyshire Lower Carboniferous coral beds and associated rocks. For structural and erosional reasons, it is not possible to trace a single coral bed over the entire Derbyshire limestone area, but some of the coral and other fossil beds do have considerable lateral extent. The *Davidsonia septosa* brachiopod and coral bed can be traced discontinuously over many square miles, (Cope 1936, Sadler 1964) and the *Orionastraea* coral-brachiopod bed likewise has been mapped over much of the northern and eastern part of the Derbyshire limestone outcrops (Shirley and Horsfield, 1940, 1945; Shirley, 1959). This horizon is of great interest as in many places the corals can be found in their original growth positions. Other coral beds, including most of those containing only solitary corals appear to have been disturbed before preservation, though the lack of attrition of the corals suggests that they have been moved only a short distance.

A well developed example of a Carboniferous coral reef can be seen at Coomsdale (SK 222743) (text-fig.1). On the flanks of the reef, encrusting colonies of *Orionastraea* sp. only a few mms. thick can be seen. They are generally associated with fasciculate colonies of *Diphyphllum* sp. with branches arranged almost horizontally. Adjacent to these colonies, on the sheltered side towards the centre of the reef, more upright fasciculate colonies are to be found including *Lithostrotion irregulare*, *L. junceum*, *Syringopora* sp. and *Lonsdaleia duplicata*. Moving further towards the centre of the reef, are the small massive colonies of *Lithostrotion decipiens* and *Lonsdaleia floriformis*. In the centre of the reef, mud is rarely seen and the limestone matrix is light coloured. The largest colonies seen are examples of *Palaeosmilia*



Text-fig.1. - Diagrammatic section across a Lower Carboniferous coral patch reef, based on the exposures of such a reef in Coombsdale, Derbyshire, zone D_2.

regia over one metre high but, in the centre of the reef, colonies of *Lithosotrotion decipiens* and *Thysanophyllum* sp. also approach this size. A section through the coral bed is illustrated in text-fig. 1.

Elsewhere, comparable sections of coral reef can be seen near Bakewell, Monsal Head and Crich. Despite the absence of *Orionastraea* in some of these localities, the occurrence of other corals and their stratigraphical position near the top of the Carboniferous limestone suggests that the corals beds at these localities are of the same age.

Associated with the colonial corals are solitary ones both large and small. They are subordinate to the colonial corals and include members of the Clisiophyllidae and the Zaphrentacae. There are abundant brachiopods, mainly gigantoproductids and spiriferids. Foraminifera are frequently found in the darker coloured limestones at the margins of the patch reefs and there are usually abundant crinoid columnals.

Occasionally it is possible to see the development of a new colony on the remains of another but the development of hundreds of feet of continuous coral growth, as in modern coral atolls is unknown in the Carboniferous.

It is concluded that the corals grew mainly in patches, subcircular in outline and separated by channels. Broken and uprooted corals show that the reefs were frequently eroded, thus contributing to the accumulation of limestone beds and accounting for the incomplete preservation of the patches.

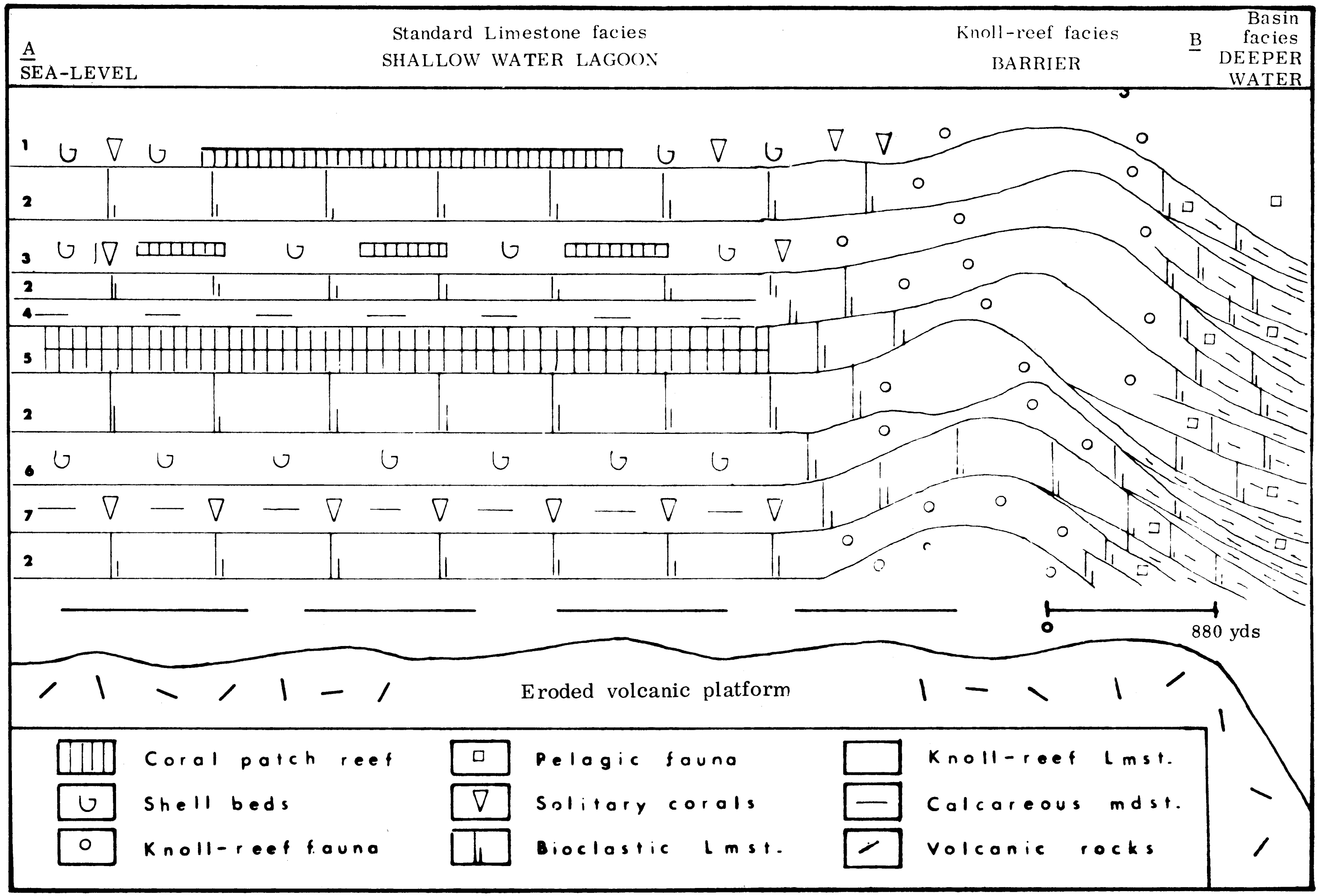
Away from the coral patch reefs, the sea floor was in places crowded with brachiopods. It is thought that these shells, mainly productids, originally lived in the areas bordering the channels and that they frequently became detached and collected in shell banks.

Elsewhere, deposition of mud results in the formation of shaley limestones. The calcareous mud seems to have been an ideal habitat for small solitary corals, *Zaphrentites* and *Cythaxonia* and for brachiopods, including the smaller productids and *Martinia*. Inarticulate brachiopods and trilobites may be an important part of the fauna. The introduction of increasing quantities of mud frequently killed off the corals and they are now located in the lowest layers of the shale horizons. The source of this mud is uncertain but it occurs repeatedly throughout the Lower Carboniferous. The fauna associated with the small solitary corals suggests that the depth of water has not increased very much, rather it is the sediment which controlled the character of the fauna. The distribution of these three environments (coral patch reefs, brachiopod lenses, solitary coral patches) is shown diagrammatically in plan view on text-fig. 3, and in section at the top of text-fig. 2, together with the various rock types (numbers 1 to 7) which may be found (See also p. 91). Isolated coral occurrences may be found between the patches mentioned above (text-fig.3).

Undoubtedly, the optimum time for patch coral reef development in the Derbyshire limestone area was in the D. zone. There is preserved at this time a much greater variety of colonial corals than at any other. Before the D. zone, the patch reefs are smaller with the centres of the coral reefs made up of the larger massive *Lithostrotion* colonies and the large clisiophyllid corals. The smaller solitary corals continue to be found in the areas of mud deposition.

The Carboniferous barrier reefs

The patch reefs described above eventually give way laterally to mound shaped masses of limestone (text-fig.2) which have been described as knoll-reefs by Black (1954) and Parkinson (1957) or knoll limestone by Whiteman (1961). Their occurrence in Derbyshire has been described by many authors, including Wolfenden (1958) from the north and west, Parkinson (1950), Prentice (1951) and Ludford (1951) from the west; Shirley and Horsfield (1940, 1945), Shirley (1959) and Smith and others (1967) from the east, and in the south there is the work of Mitchell and Stubblefield (1941) from the Breedon area. The distribution of the knoll-reef limestone has recently been reviewed by Ford (1968) and illustrated by maps for different



Text-fig.2. Section along the line A - B, text-fig.3, showing the range of variation of the Standard Limestone facies, nos. 1-7, and its relationship with other facies and with the basement, at depth. Not drawn to scale.

1. Developing coral patch reef and associated fauna at the surface.
2. Bioclastic limestones, the result of erosion of 1.
3. Incomplete preservation due to partial erosion.
4. Mud or fine volcanic ash covering 5.
5. A well preserved coral patch reef.
6. is a well preserved shell bed, with only occasional corals.
7. Small solitary corals preserved in dark muddy limestones or calcareous shales.

times during the Lower Carboniferous. Combining all the known Derbyshire knoll reef occurrences on a single plan emphasises the marginal characteristics of these knoll limestones in relation to the coral patch reefs (standard limestone facies) and is the starting point for text-fig.3. The separate maps (Ford 1968) show that the distribution is at present dependant on the subsequent erosion of the limestone, which now outcrops in the areas indicated. The correlation of the knoll - reefs with adjacent coral patches is also subject to the availability of the necessary faunal evidence, often scarce.

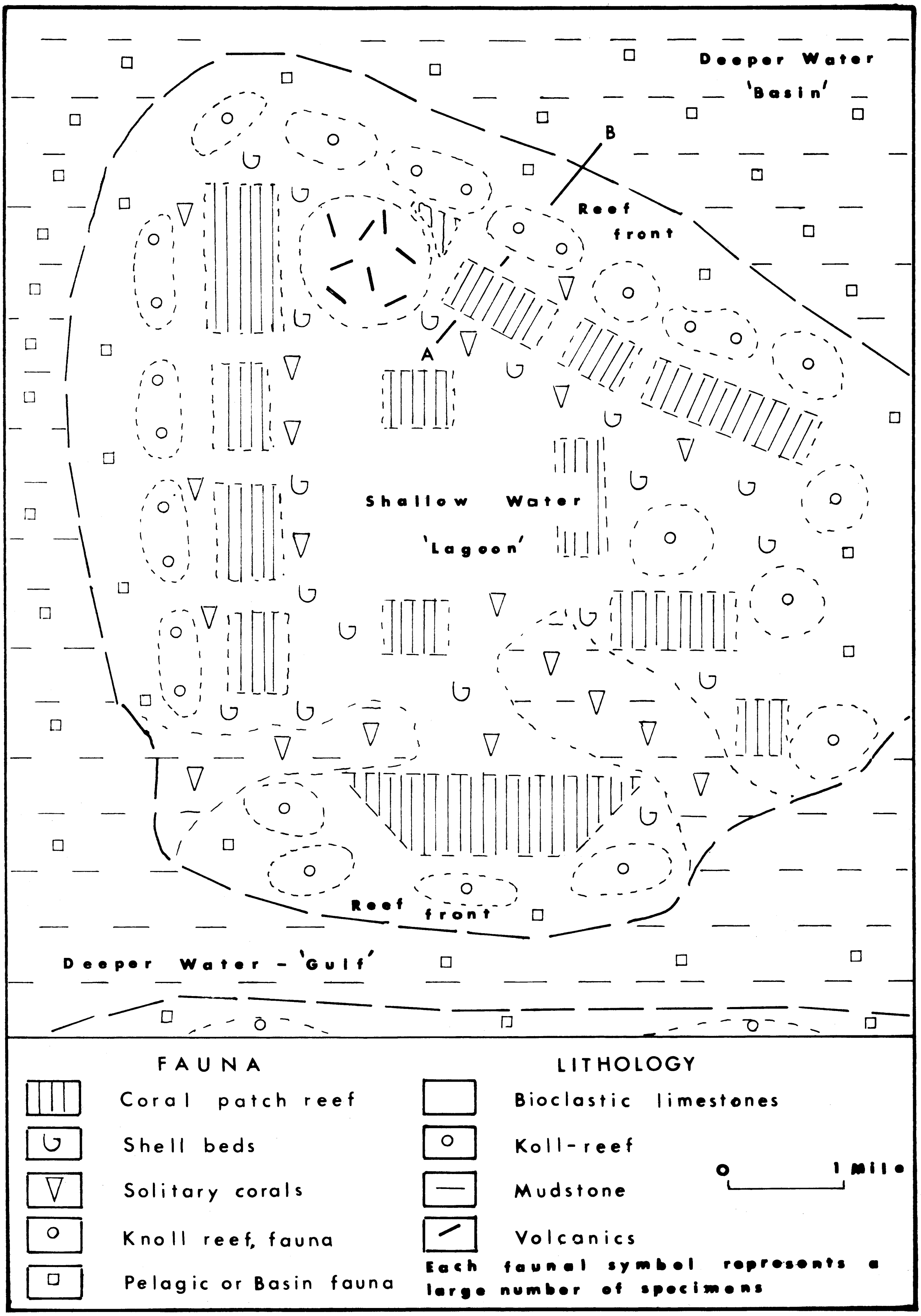
The Derbyshire knoll-reefs appear to vary in character, although the published details make comparisons difficult. In the north-west, Wolfenden describes the knoll-reefs as long, narrow ridges, the result of algal growth and accretion. Elsewhere, many knoll reefs are subcircular or elliptical in shape. Both can rise to over 100 feet from their bases, gradually being built up and at any one time a little above the adjacent coral patch sea floor (text-fig.2). In origin these mounds have been compared with those at Clitheroe, where Black and Parkinson consider them to have been developed by organic means, either algal or some other unknown bonding organism. Whiteman (1961) on the other hand, with his experience of the Guadelupe reefs of Texas and New Mexico, is convinced that the Clitheroe knoll-reefs are lime banks accumulated by currents. These views have recently been reiterated (Parkinson, 1969; Whiteman, 1968). Whatever their origin, the knolls are considered to be marginal, on the one side to the 'shelf' or 'lagoon' conditions and, on the other to the deeper water of the 'basin' or 'gulf'.

Many animals found these knoll-reefs suitable for colonisation. Many species of foraminifera, brachiopods, mollusca, trilobites, goniatites, bryozoans, crinoids and fish have been recorded from them. The brachiopod faunas are far more varied here than amongst the coral-patch reefs. The most notable absentees are the corals. Occasional ones, both solitary and colonial are found, such as the large specimens of *Lithostrotion* from Treak Cliff, Castleton, but information regarding the orientation of such corals is lacking. *Amplexus coralloides* is often recorded from the Clitheroe knoll-reefs but seems to be rare in Derbyshire. The tabulate coral, *Michelinia* is a much more frequent find. The presence of algae in the knoll-reefs is still a debatable point, with most of the evidence in Derbyshire being composed of trace fossils, structures said to be of algal origin. These structures consist of laminated patches of limestone, '*Collenia*', or nodules made up of concentric layers of laminated limestone, '*Girvenella*'. Fragments of shells and other fossils may be coated with concentric layers of the same limestone.

It is here envisaged that these mounds and ridges were marginal to the coral patch reefs and that there were channels through the reefs, possibly of considerable depth (Sadler, 1964a). The mounds and ridges could well have broken the surface of the sea at low-tide and, in any case, separated the coral patch reefs from somewhat deeper water beyond. They would therefore perform the function of present day barrier reefs, even if their organic origin is debatable. The flanks of these reefs are always associated with prolific crinoid debris. The crinoids must have lived in close proximity to, if not on the reef itself, in miriads. Perhaps the occurrence of these organisms as reef builders was responsible in some way for the knoll-reef development. The main mechanism would be to provide an area free from current activity which would allow calcite mud banks to accumulate.

Deeper water basin or gulf environment

Becoming more remote from the coral environment, but added here to complete the immediate picture of Derbyshire Lower Carboniferous environments, are the slopes leading away from the knoll-reefs to somewhat deeper water. Beyond the bioclastic limestone comprising the 'reef-front' or 'reef apron', on the deeper side of the reef, the limestones become more shaley and are comparable in lithology to the solitary coral facies described earlier. These shaley limestones lack corals or other fossils which would indicate shallow water littoral type conditions, but possess the free swimming pelagic faunas, the goniatites, free swimming bivalves and fish. In Derbyshire, limestones of this facies have yet to be described satisfactorily. Many limestones said to be of basinal facies contain solitary corals, articulate and inarticulate brachiopods, trilobites and crinoid debris, suggesting that they were developed in a shallow water environment. Ford (1968) has commented on the lack of evidence for depth of water in basin type limestones. The existence of the outer reef slopes, however, cannot be doubted in



Text-fig.3. - Map illustrating possible distribution of marine environments, in an area to the north of St. Georges Land, based on evidence available from D. zone coral beds of Derbyshire.

some areas, particularly around Castleton. It is considered that, however the reef-knolls are developed, deeper water with free oceanic circulation may be found comparable with the areas found beyond modern barrier reefs. The occurrence of the barrier-reefs facing in all directions at various times during the Lower Carboniferous suggests that deeper water not only occurs to the north and south, the Lancashire Trough and the Widmerpool Gulf (Falcon and Kent 1960) respectively, but at certain times may well have been present to the east and west.

Fringing coral reefs

In the Derbyshire area there is no direct evidence of the St. George's Land coast line situated in the south Midlands. Small islands may well have been present and, if this is the case, fringing reefs might have developed adjacent to the coast.

Preservation of the coral beds

Coral beds occur at infrequent intervals in limestone sequences. Much of the Carboniferous limestone is made up of fragments of fossils, broken and eroded or even fragmented to single crystals. Current bedding testifies to the existence of currents. Unconformities separate all Shirley's (1959) major groups of limestones indicating major erosion surfaces. Minor ones, channels, variations in bed thickness, all point to movement of sediment. Only occasionally were conditions suitable for the preservation of the fauna living at the time, on any large scale. The conditions were usually catastrophic, including the sudden influx of mud into the area (text-fig.1) which killed off the living fauna and preserved the skeletons as fossils in the top beds of the limestones. Volcanic debris was also shot into the area from a number of vents, located in the Derbyshire area through the work of Bemrose (1907) and Smith (1967). A vent is shown diagrammatically in text-fig.3. The result of the volcanic activity was the outflow of lava, ash and fine dust, covering and preserving the fauna in some cases, for example the *Davidsonina septosa* bed in the Via Gellia, near Cromford.

Text-fig.2 is a diagrammatic section through about 20 metres of limestone showing (1) the development of coral reef at the surface; (2) limestone formed by erosion of the reefs; (3) eroded, incomplete, coral-brachiopod bed; (4) mud or fine volcanic ash covering (5) a well preserved coral bed; (6) is a well preserved shell bed with occasional corals, preserved by excessive limestone sedimentation and (7) solitary corals preserved in dark coloured limestones beneath calcareous muds. All these limestones are adjacent to the developing barrier reef with its abundant crinoid and other reef faunas.

A Derbyshire atoll or atolls

Using the modern coral environments, so far, coral patch reefs, isolated coral occurrences, fringing reefs, and barrier reefs have all been discussed. There remains the possibility of a Derbyshire atoll. The information available is meagre and obscured by subsequent erosion of the limestones and earthmovements altering their disposition. The possibility of caldera subsidence is suggested only by the encircling knoll-reefs as shown in text-fig.3, the result of combining barrier reefs of all ages on one plan, with shallow water in the centre and deeper water around. However attractive this idea might be it must be stated that the marginal reefs which occurred throughout the Lower Carboniferous in Derbyshire may well have existed only in the positions fortuitously preserved at the present day. The one bore hole which has pierced the base of the limestone (Cope, 1949) records volcanic rocks said to be comparable with those of Charnwood Forest and thus of Pre-Cambrian age but they could be younger than this.

It is concluded that there was gradual, but irregular subsidence of a much eroded volcanic platform, which has allowed the accumulation of over 1000 metres of limestones during the Visean, with some renewal of volcanic activity during the time.

Lower Carboniferous cherts

High accumulations of silica, forming nodular, and tabular masses, both concordant and discordant with the bedding, are commonly seen in the highest limestones, particularly in close proximity to the mineral veins. The mineralisation and silicification of the limestones, for the purpose of this address, are considered to be subsequent to original deposition and have not been taken into account in this study.

Conclusions

Certain comparisons can be made between modern and Lower Carboniferous coral reefs. The geographical position of the reefs may have been similar with corresponding climatic and depth characteristics. Although there are morphological differences, the corals would be subject to the same hazards of life. The corals are associated with other forms of life. There are coral patch reefs and isolated coral occurrences at both times.

In contrast the Carboniferous corals never took advantage of the knoll-reefs (barrier-reefs) as do the modern corals, their place being taken by brachiopods and other organisms including possibly crinoids. The Carboniferous massive corals tend to occur as patch reefs, protected from the extremes of their environment by fasciculate coral populations and by the incomplete outer knoll reefs.

The possibility that the Derbyshire shallow water limestones were deposited within the lagoonal area of a large atoll is discarded in favour of the hypothesis that the shallow water was the result of slow irregular subsidence of a 'stable' area, possibly a much eroded volcanic platform.

There are always associated faunas, although vastly different at the two times. Modern brachiopod populations are relatively insignificant compared with those of the Carboniferous. The reverse is true of the mollusca.

What would keep the corals off the knoll-reefs during the Carboniferous? One can only speculate - a privilege of a Presidential Address. Perhaps trilobites and goniatites were able to feed on the coral polyps, as the 'crown of thorns' starfish does at the present time. The crinoids, in close proximity to the knoll-reefs, may well have prevented the settling of the coral larvae, or the accumulation of lime mud may have been too great for the developing corals.

It is clear that the evolution of corals and adaptation to their environment since the Carboniferous has resulted in the greater success of modern corals, but the morphological changes prevent an exact environmental comparison.

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