ASPECTS OF THE CARBONIFEROUS STRATIGRAPHY OF THE CASTLETON - TREAK AREA OF NORTH DERBYSHIRE

by

Donald Parkinson

Summary

This paper presents a discussion, in the light of recent research, of the ages of the reef and associated limestones, their relationship with each other and with the Viséan and early Namurian earth-movements, along the northern margin of the Derbyshire massif. The limestones of the reef-complex range in age from Lower B_2 to P_{1b} and in position from fore-reef to back-reef, the latter beds merging imperceptibly into the shelf limestones of the massif. Evidence of an earth-movement of Lower B_2/Upper B_2 age is reconsidered and amplified; it is argued that the upper algal reef and the fore-reef beds of Treak Cliff, and also the Beach-Beds of Castleton were deposited on an uplifted surface of the Lower B_2 reef limestone. The Beach-Beds, like the reef limestone (of Treak Cliff) north-west of them, contain an Upper B_2-P_{1a} fauna. Although the author's former views are modified, he still considers that the Beach-Beds are of sub-littoral origin and gives reasons for discarding a recent hypothesis that they were formed in a submarine channel passing from the shelf sea through the reef to the basin. Later crustal movements similarly involving simple vertical elevation along the boundary of reef and basin are attributed to successive ages P_{1a}/P_{1b} (Sudetian I), P_{1d}/P_{2a} (Sudetian II) and E_1/E_2 (Sudetian III).

Introduction

A few square miles of country along the northern edge of the Derbyshire "massif" of Carboniferous Limestone have been studied intensively by geologists during the last 70 years and varied conclusions on the succession of the sediments, their relative ages, modes of origin and relation to earth-movements have been published. The present communication presents the author's mature views on some important features of the stratigraphy of the Castleton area; it attempts a critical appraisal of his own work as well as that of others.

The district, which comes within the area of the Chapel-en-le-Frith Geological Survey Sheet 99, has recently been re-mapped and the memoir is awaited with interest. The writer is not familiar with details of the re-survey apart from what has been published in the "Summaries of Progress" from 1952 onwards, and in the recently issued Geological Survey Bulletin No. 21 (Eden et al., 1964) which describes about half a square mile of Carboniferous Limestone along the south side of Pindale and about three-quarters of a mile south-east of Castleton.

The Lower Carboniferous rocks under review are confined within the limits of the Dibunophyllum Zone (D_{1-2}) on the coral-brachiopod time-scale and the Upper Beyrichoceras (B_2) and Posidonia (P) Zones on the goniatite time-scale. The overlying Edale Shales of Namurian age are dealt with only so far as they bear on the question of earth-movements within the area.

Notes on the Faunal Sequence

The B_2 Zone (approximately equivalent to D_1) is characterised by a number of beyrichoceratid goniatites and by the Goniatites maximus Bisat group and the G. hudsoni Bisat group. Hudson and Cotton (1945a) define Lower B_2 as the subzone of Beyrichoceras vesiculiferum (De Koninck) and Upper B_2 as the subzone of B. delicatum Bisat. This sub-division seems justified, though there is overlapping of the goniatite faunas, as indicated in Hudson and Cotton's table (op. cit., p. 301) which shows a succession of five faunal assemblages. Faunas A and B represent the lower and C, D and E the upper subzone.

The overlying beds of P_1 age (with Hudson and Cotton's Fauna F at the base) contain the index forms Goniatites crenistria Phillips for the P_{1a} Zone and G. falcatus Roemer for P_{1b}. The P_{1c} and P_{1d} zones are apparently unrepresented as such in the Castleton district, but their lateral equivalents are present as part of the D_2 Zone in the back-reef areas.

The base of the P_{1a} Zone is defined by an association of Beyrichoceratoides truncatus (Phillips) and G. crenistria. These forms have been recorded from the highest beds of shell-reef limestone below the Edale Shales, near Odin Fissure at the foot of the northern slope of Treak Cliff, and they apparently follow the B_2 reef beds quite conformably. Where these two goniatite species are not found together, it is not possible on present evidence to map precisely the boundary between the two zones and therefore the Upper B_2 - P_{1a} beds are grouped together on the map (Text-Fig. 1). G. crenistria itself has in fact been recorded in the upper part of the B_2 Zone of the Clitheroe district (Earp et al., 1961).

The work of Ford (1952) in the natural caves and mine workings around Castleton confirmed conclusions (Parkinson, 1943, 1947, 1953) on the general equivalence of the reef and massif facies, but his discovery of Posidonia becheri Bronn associated with a goniatite "probably of the Goniatites maximus group" (Ford, p. 352) in the apron-reef (fore-reef) limestone of Treak Cliff Cavern, a considerable thickness below the unconformable junction with the Edale Shales, means that, unless P. becheri enters here earlier than in other areas, the limestones on the eastern slope of Treak Cliff are of later date than is shown on earlier maps (Parkinson, 1953, Figs. 1 and 2 - a paper written before the publication of Ford's paper). P. becheri ranges throughout P_1, but P. aff. becheri (a form smaller than typical) has been found in the higher beds of the B_2 Zone (Earp et. al., 1961, p. 181). It can be inferred that the highest beds on the eastern slope of Treak Cliff are of P_1 (probably P_{1a}) age. This substantially uniform slope of the hill has an angle approximating to 30° from the horizontal and the average dip at surface is nearer 35° than 30°; in the cave it ranges between 30° and 45°. The horizontal reef limestones (of B_2 age) of the summit ridge are therefore, it would appear, stratigraphically beneath the beds at the foot of the slope, the vertical difference being estimated at between 50 and 75 ft. (Fig. 2).

The reef limestones of Cave Dale, which are beneath the Cave Dale Lava, were attributed to

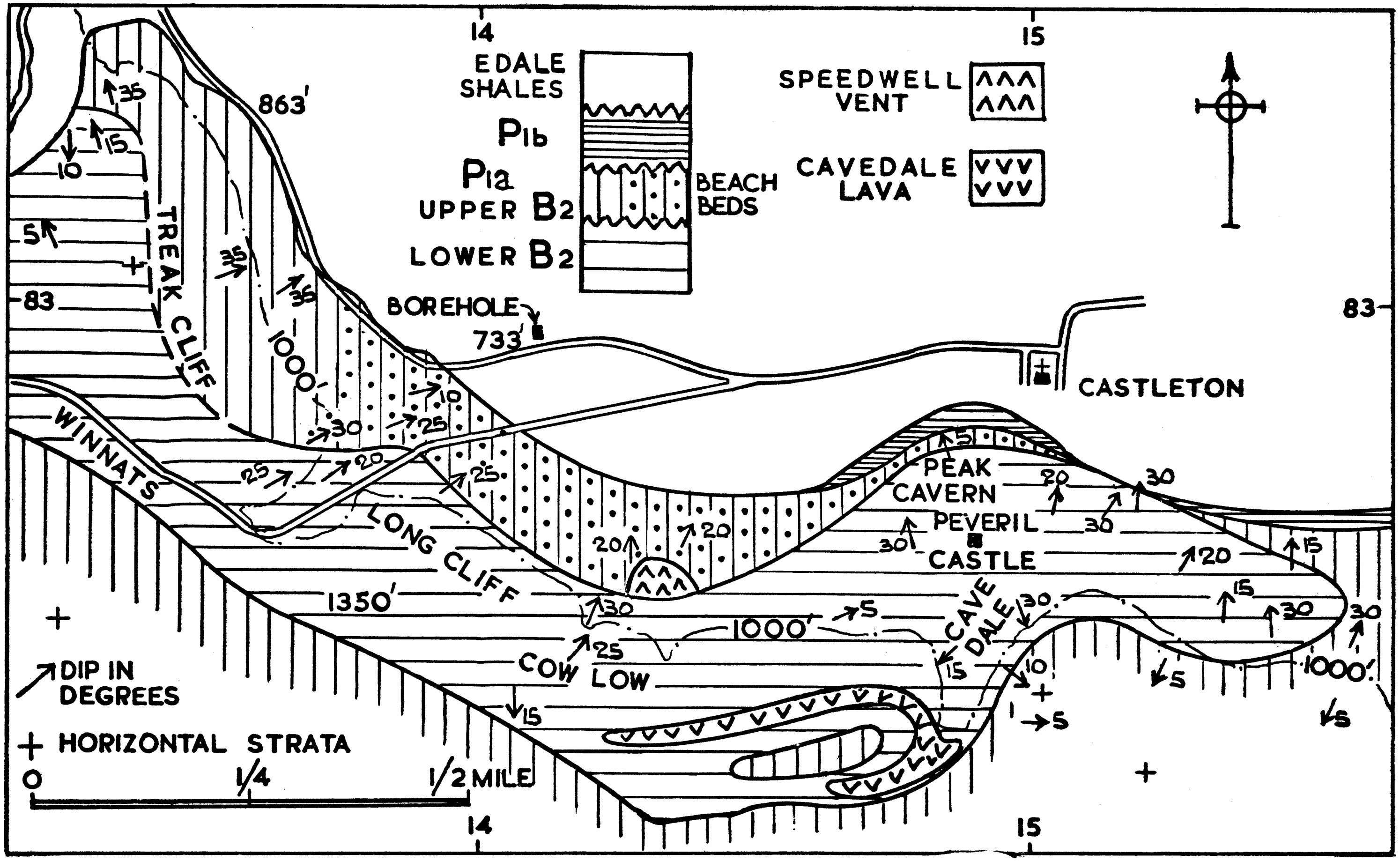

Fig. 1 Geological map of the Castleton–Treak Cliff area of North Derbyshire. It illustrates a reinterpretation by the author which takes account of the conclusions of other workers.

Lower B_2 by Hudson and Cotton (1945a), a view which received support from the work of the present author (1947) who also placed the limestone of Cow Low and the Winnats in the lower subzone. The well-known pocket crowded with goniatites in Cow Low Nick was thought by Hudson and Cotton to contain a drifted assemblage of their fauna A. This bed was recently described in detail by Ford (1965), who discussed alternative explanations of its origin and development. He amplified Hudson and Cotton's suggestion by aurguing that it formed a concentration of shells in an inactive surge channel. Ford's list of goniatites from this bed includes species not hitherto recorded, in particular Beyrichoceras rectangularum Bisat which occurs in Upper B_2 in the Craven reefs of Yorkshire and on Park House Hill, Derbyshire (Bisat, 1934, p. 295). This raises a doubt as to whether the deposit in question is in fact of Lower B_2 age. The writer, whilst agreeing with Ford as to the need for revision of the B_2 faunas, still considers that the Cow Low Nick goniatite bed should on stratigraphical grounds be placed in the Lower B_2 subzone. The bed is well below the upper surface of the reef limestone upon which rest Beach-Beds containing an Upper B_2 - P_{1a} fauna. (The Beach-Beds are fully discussed in later pages.) The Cow Low reef limestone itself forms the dip slope below the western end of the Cave Dale Lava, which is a flow of mid-D_1 age.

According to the work of Eden et.al. (1964) in the Pindale area, the lower apron reef beds of Nun Low Quarry are of D_1 (high B_2) age and pre-date the P_1 beds in the upper part of the quarry. All the beds of this quarry were formerly mapped as P_{1a} (Parkinson, 1947). The specimens of Goniatites crenistria (Jackson, 1925, p. 272) came from above the D_1 beds at a level of the quarry face now obscured by scree. The highest beds in the quarry face are un-bedded reef limestones containing Productus productus approaching hispidus Muir-Wood, of probable P_{1b} age (Eden et al., p. 91). They are approximately equivalent to the beds in Upper Jack Bank Quarry which have yielded both Goniatites striatus J. Sowerby and P. hispidus. The writer (Parkinson, 1947) assigned these strata to P_{1a}, partly because the beds below them were of B_2 age, partly because of a reported occurrence of Beyrichoceratoides sp. at Jack Bank and partly because at that time the precise horizon of G. striatus was in some doubt. However Bisat (1934) had referred the G. striatus beds to P_{1b}, a conclusion amply justified by later evidence from widely separated areas. The type form of this goniatite is characteristic of that horizon in Germany, and it is recorded from P_{1b} in the Alport boring where it is associated with Goniatites falcatus and Productus hispidus (Hudson and Cotton, 1945a, p. 269). Specimens are described by Hodson and Moore (1959) from P_{1b} of Dough Mountain, Co. Leitrim, Ireland, associated with Goniatites spirifer Roemer and G. falcatus.

Evidence that G. striatus might have entered earlier in some areas will now be considered. A single specimen "somewhat stouter than the holotype" (Bisat, 1934, p. 301) was found below the Bowland Shales west of the quarries on Swinden Knoll, near Cracoe, Yorkshire (see also Hudson and Cotton, op.cit.) and another one from quarry Q 12, near Burnsall, Yorkshire (Bisat, op.cit.) in reef limestone assigned by Bond (1950, p. 169) to the D_1 (B_2) Zone. There is a specimen in the British Museum collection from Crowdicote, West Derbyshire, and Dr. Bisat informs me (in litt.) that he suspects that the holotype in a similar "smooth ivory-like limestone" came from there. According to Hudson (1945a, Appendix II, p. 326) the shell-reef limestones of Crowdicote are of Upper B_2 and lower P_{1a} age; they are mapped by Wolfenden (1958) as B_2. Despite Bond's view of the D_1 age of the reef limestones from which G. striatus had been collected, Bisat, in his recent letter, expresses his belief that the Swinden Knoll specimen "came from behind and above the quarry and was probably a long way above the G. hudsoni horizon of the quarry". If, as the combined evidence strongly suggests, the horizon of G. striatus is everywhere P_{1b}, it seems necessary to postulate a major non-sequence within the reef limestones of both Derbyshire and the Craven district of Yorkshire.

Eden et al. (Figs. 1 and 2 and pp. 85, 90) demonstrate an angular discordance below the P_{1b} limestones of Jack Bank, with the removal of 22 ft. of strata, including the Lower Girvanella Bed characterising the base of D_2. In the apron-reef (or fore-reef) at Lower Jack Bank Quarry the higher beds of P_{1b} have suffered pre-Edale Shale erosion. In the Middle Bench of Earle's Quarry, in the back-reef area, the equivalents of the P_{1b} beds are represented by some 50 ft. of D_2 bedded limestones, including, near the top, a 3 ft. flat reef yielding Productus hispidus. The succeeding 250 - 275 ft. of back-reef beds constitute a series of bedded "shelf" or "standard" limestones (calcarenites) of texture ranging from fine (calcilutite) to coarse (calcirudite) which are interbedded and interdigitate with knoll-reef limestones. These deposits are all attributed by Eden et al. to the D_2 Zone.

From Siggate to the west of Castleton, along the foot of the reef limestone outcrop and separating it from the Edale Shales, is a thin development of black limestones, which have yielded the P_{1b} fossil Goniatites spirifer (Parkinson, 1947, 1953). These beds are presumably the basin equivalents of the G. striatus reef limestones of Jack Bank and Mich Low which they were formerly thought by the author to overlie. They do in fact overlie the reef limestones of Siggate and Cave Dale.

The Davidsonina septosa Beds.

The different interpretations of the Castleton reef limestones and associated beds have depended in part upon varying views of their relationship to the horizon of the brachiopod Davidsonina (Cyrtina) septosa (Phillips), which in widely separated areas has a rather restricted range in the middle and upper parts of the D_1 Zone; it is particularly characteristic of a faunal band in the north-west of England some 80 to 100 ft. below the summit limestone of the zone, and also in the "standard" succession of Derbyshire where it is about 25 ft. below the base of the Lower Lava in the Chee Tor Rock (about 150 ft. below the summit of the D_1 Zone). A similar band occurs locally some 10 to 15 ft. lower in the sequence (Cope , 1934, 1938). During the re-survey it was reported (1959, Summ. Prog. Geol. Surv. for 1958, p. 32) that D. septosa is found in a "well-defined bed 25 ft. below the top of the Chee Tor Rock and less commonly at two lower levels in that rock; it has also been found at many localities near the base of the Miller's Dale Beds." The latter strata rest on the Lower Lava where that flow is present. In the Castleton area, south of the reef complex bordering the massif, Shirley and Horsfield (1940) recognised two bands, the higher of which is probably that of the main band elsewhere.

A recent paper (Sadler, 1964b) deals with the conditions of sedimentation of the D. septosa Band in a number of localities in North Derbyshire. A list of associated corals and brachiopods is given by Dr. Sadler who suggests that the very fossiliferous concentration indicates a break in sedimentation.

In the reef and basin areas of England the occurrence of D. septosa is sporadic and it has not been mapped in a widespread band. Its position in the zonal sequence was discussed by Mitchell and Stubblefield (1941, pp. 210 - 11), who referred to a reported occurrence by Douglas (1909, p. 556) in D_2 of County Clare, Ireland. At Breedon Cloud, Leicestershire (Mitchell and Stubblefield, op. cit.) D. septosa occurs in a bedded breccia 3 ft. thick, of D_1 age. Overlying the breccia are 120 ft. of reef and bedded limestone of B_2 age, with D. septosa and a variety transversa (J.W. Jackson) in the lower beds. These authors suggest that var. transversa is indicative of a higher horizon than that of the normal D. septosa Band. Jackson (1922) recorded his variety from Narrowdale Hill, Staffordshire and elsewhere in B_2 reef limestone. The Narrowdale Limestone is of Upper B_2 age (Hudson, 1945a, p. 326; Parkinson & Ludford, 1964). Jackson also recorded var. transversa from the northern side of Middle Hill, two miles west of Castleton (Parkinson, 1947, p. 107). The level here, from field observations, appears to be higher than that of the quarry on the southern side of the hill, where Jackson (1941) cites D. septosa, typical form.

This evidence supports Mitchell and Stubblefield's view that the horizon of the transverse variety is higher than that of the widespread septosa Band, but it is evident also that the standard form ranges into higher beds in the Castleton area, as well as farther south. Thus it was recorded by Jackson (1941) from a nodular coral bed near the mouth of Pindale, about 50 ft. below the top of the D_1 zone. He correlated this bed with an oolitic and conglomeratic limestone described by Bemrose (1907) and referred to (Parkinson, 1947) as a tuff-bearing conglomerate. It occurs some 30 ft. above the Cave Dale Lava (op.cit., p. 104) and although D. septosa was not found in it there seems little doubt that it is the same - or very nearly the same - horizon as the Pindale coral bed. Shirley and Horsfield's observations (1940, p. 276) support such a view. They record a band 20 ft. above the lava with Lithostrotion aff. m'coyanum Edwards and Haime, together with other species of this genus, and correlate it both with the Pindale coral bed (also containing L. m'coyanum) and with the L. aff. m'coyanum bed in Miller's Dale just above the Lower Lava (Cope, 1933, p. 132). A pebbly limestone, 130 yds. south of Oxlow House east of Middle Hill, containing L. m'coyanum (Parkinson, 1947, p. 104) can with confidence be referred to the same horizon. This bed, referred to as an oolitic conglomerate (Parkinson, 1953, p. 261) is a little higher than the quarry referred to on the south side of Middle Hill as yielding D. septosa; it is presumably equivalent to the lower part of the Upper B_2 beds (with var. transversa) on the northern slope of the hill. The oolitic conglomerate is well exposed on the southern side of Windy Knoll and was described by Barnes and Holroyd (1897).

There is evidence from widely separated areas that about this time there was shallowing of the Lower Carboniferous sea with, in places, actual emergence into land. Local unconformities, non-sequences, or at least contemporaneous erosion are characteristic. Shirley and Horsfield (1940, p. 276) note a small angular discordance in Cave Dale causing overstep of the base of the Miller's Dale Limestone on to beds 30 ft. below the base of the lava. In the Castleton area, the evidence of uplift is of various kinds. In the well-known quarry on Windy Knoll, 1½ miles west of the village, D. septosa occurs just below a fissured surface of mid-D_1 limestone (Shirley and Horsfield, 1940, p. 290) and also, according to Ford (1952, p. 353), in boulders in the cavities. The erosion surface on Treak Cliff (Shirley and Horsfield, 1940, p. 280) shows Upper B_2 beds as unconformable on D_1 limestones with D. septosa. The basal Upper B_2 limestones with the oolitic and conglomeratic beds also contain D. septosa, and therefore the stratigraphical break, though important, as will be argued, was not of long duration.

In various parts of England and Wales the D. septosa Beds are associated with non-sequences and breaks in sedimentation. In the Cracoe Knoll area of Yorkshire, Bond (1950, pp. 171 - 2) adduces evidence of a non-sequence at the base of the D. septosa Beds in Swinden quarries. Hudson and Cotton (1945a, p. 304) refer to shell-reef limestones in Swinden quarries "with the pebbly oolitic conglomerate containing Cyrtina septosa at their base". In the basin deposits of the Dovedale district it is found in pebbly limestones above erosion surfaces (Alexander, 1940, p. 172). In the North Crop of the South Wales Coalfield (George, 1927, p. 47), D. septosa occurs 10 - 25 ft. below the summit of a condensed D_1 Zone in rubbly beds giving evidence of contemporaneous brecciation. At Breedon Cloud, Leicestershire (Mitchell and Stubblefield, p. 204) the base of the limestone with D. septosa is a bedded breccia. Cope (1938, p. 62 and Fig. 1) describes two surfaces with pot-holes 2 - 3 ft. deep a little below the D. septosa Band. Near Ribblehead, Yorkshire, Garwood and Goodyear (1924, p. 215) refer to a pot-holed surface "some 56 or 60 ft. above the Cyrtina-septosa Band." In Meal Bank Quarry, Ingleton, Yorkshire, the well-known patch of coal with its pot-holed under-surface is apparently 75 ft. below an exposure of the band. There is probably more than one band in this area, but there is also evidence of faulting and thrusting. Unless there is repetition of the beds, the limestones on Storrs Common within the range of D. septosa are 250 ft. thick. (op.cit., p. 216).

In north-east Staffordshire, evidence of a mid-D_1 unconformity not correlated precisely with actual exposures of D. septosa has been adduced by Ludford and the author (1964). Thus on Caldon Low, high D_1 beds with a conglomeratic base rest directly on C_2 limestones, and in the Blore-with-Swinscoe area, Upper B_2 shales are apparently transgressive over D_1 and S_2 limestones and are banked against C_2 knoll-reefs. In the Slaidburn district of Yorkshire, the apparent absence of a large part of the Beyrichoceras Zone (several hundreds of feet thick on Pendle Hill in Lancashire) was attributed by Earp et al. (1961) to restricted sedimentation and by the writer (1964a) to unconformity. These observations are relevant to the discussions in the following pages.

Notes on the Reef Limestones

The term "reef limestone" was restricted by Wolfenden (1958) to a rock which he considered to represent the rigid framework and which constitutes a very small part of the "reef complex". It is composed of calcareous algae, with encrusting colonies of fistuliporoid bryozoans and tabulate corals (op. cit., p. 874). The other parts of the reef facies are referred to "back-reef" and "fore-reef", the whole being named "reef complex limestones". The "reefs" described are from the marginal rocks between shelf and basin near Earl Sterndale in North-west Derbyshire and from the area now under review. They are instanced at two levels, one of Lower B_2 age just below the D. septosa band and the other of Upper B_2 age, above that band.

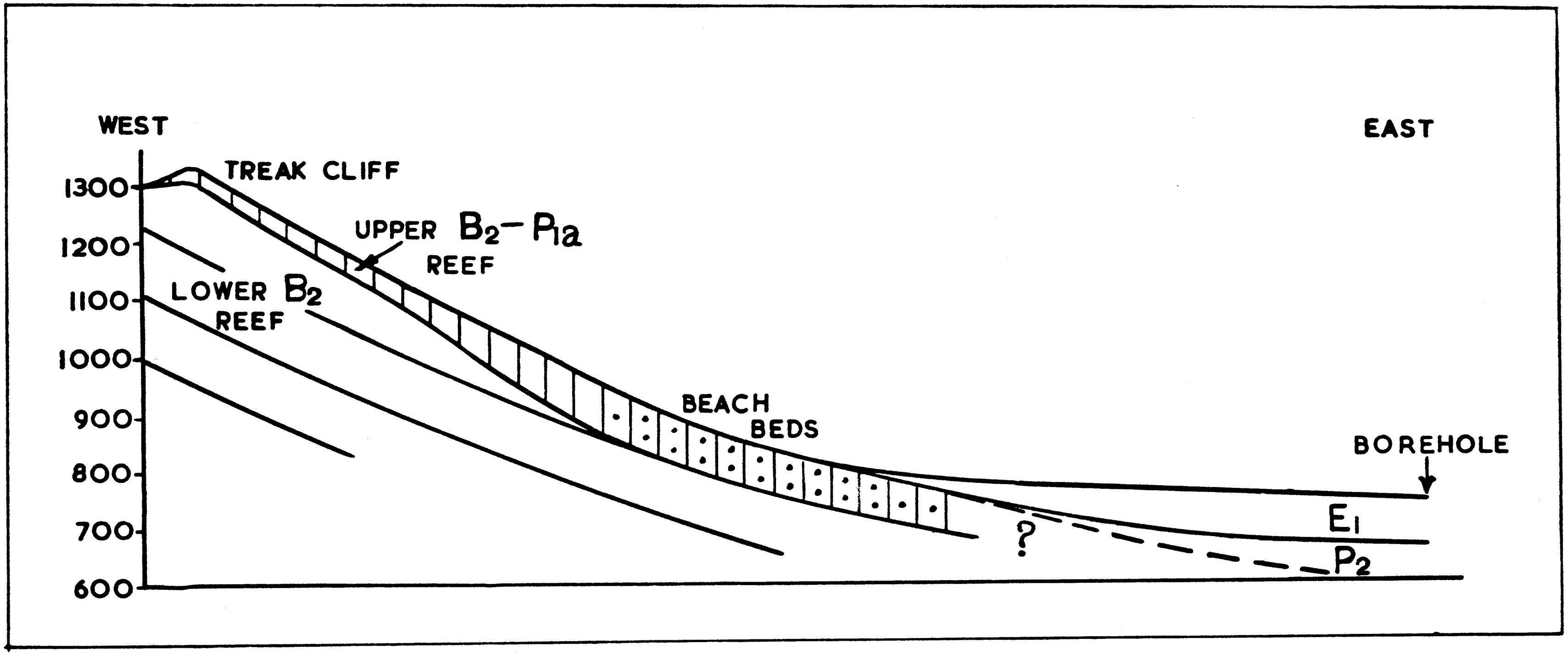

Fig. 2 Section to the same horizontal and vertical scale from Treak Cliff to the borehole. The P_2 shales and limestones in the vicinity of the boring rest on reef limestone of uncertain age.

There is much of interest and importance in Wolfenden's paper. A full discussion of its many aspects is not attempted here, but certain of them will be considered. The type of deposit which Wolfenden names "reef" is only one of many which together constitute a Viséan marginal reef as hitherto understood. His "reef" consists of an "organic framework constructed of stromatolitic algal deposits" which can be recognised in hand specimens and by which it can be distinguished from other limestones of the reef complex (op. cit., p. 882). The distinction implies that no other type of limestone can be designated "reef", and it further implies that no other parts of the reef complex have an organic framework. On this interpretation some sediments usually considered to be reefs actually contain no reef limestone. Even if it be admitted that algae form an essential part of the reef frame, it has been amply proved by various workers that algal skeletons are readily recrystallised, and reasons have been given for supposing that some of the calcite mudstone or siltstone, characteristic of reef limestones in the broad sense, can possibly be so interpreted. (Black, 1954, p. 292; Parkinson, 1964b). Moreover Bathurst, in an exhaustive study (1959), concluded that certain of the fibrous calcite fabrics (so-called reef tufa or Stromatactis), which are common constituents of both the C and the D zones, are drusy mosaics which have formed in post-depositional cavities. He suggested that some of these cavities may have been moulds of a decomposed frame-builder which left no trace of its original nature. The fabrics are not all of one kind and probably had different modes of origin but according to the writer (Parkinson, 1965) they appear to be manifestations of reef-building activity either as reef-builders or sediment-binders.

Owing to an oversight the author did not comment on Orme and Brown's detailed account (1963) of diagenetic fabrics in some Carboniferous Limestones, including reef limestones from the Pindale area. Orme and Brown show that the present appearance of these structures results from complex processes and urge caution in their interpretation. They conclude that most of the fibrous calcite is secondary, though some of it is simply drusy mosaic filling cavities by direct chemical precipitation from solution. They observe (p. 60) that "cavities examined from the Derbyshire apron reef commonly resemble the primary voids of Newell (1955). They have a basal layer of fine clastic calcite which resembles algal dust (Wood, 1941) containing skeletal fragments and a peripheral layer of fibrous calcite" which is interpreted as a diagenetic fabric. Quasi-cavities are also described which are associated with concentric spongiostromid layers.

Orme and Brown, in the discussion of their paper, suggested that spongiostromid structures and bryozoa probably formed the framework of the reefs in the Derbyshire area. Neither in this paper nor in the Geological Survey Bulletin No. 21, where Orme collaborates with Eden, Mitchell and Shirley, is there any mention of algae (except algal dust) in the Pindale reefs. It can be presumed that there is at least a possibility that stromatolitic algae were among the original rock formers but that their original nature has been obliterated by diagenetic processes.

In his account of the reefs in the Castleton district, Wolfenden does not refer to the existence of any "reef limestone" east of the Winnats, though he maps fore-reef beds to beyond Cave Dale. This emphasises the undesirability of restricting the term "reef" to a very small fraction of the reef complex. There is in fact often no discernible change in lithological character between the fore-reef sediments and the deposits behind them, as Wolfenden himself recognised. This is demonstrated by Ford (pp. 348 - 9) who, in describing the reef rocks both inside Peak Cavern and in the gorge leading to the entrance, concludes from a study of the bedding planes (nearly horizontal at the cave entrance, but increasing gradually to 40° near the mouth of the gorge) that the reef is composed of a series of overlapping shoals. The greater part of the rock is a "light grey calcite mudstone with few fossils and poorly developed lenticular bedding". The lenses vary in length from a few feet to one of 100 feet. Here then the fore-reef merges imperceptibly into the horizontal beds which (understandably) Wolfenden has not recognised as reef limestones.

In the following discussion Wolfenden's "reefs" will be referred to as algal reefs.

Wolfenden relates the lower and upper algal reefs to Hudson and Cotton's Lower and Upper B_2 respectively, but his goniatites are not localised and his maps do not differentiate between the two sub-divisions, nor is there any mention of the possibility of a stratigraphical break between them. The lower algal reef is stated to have grown almost vertically upwards, with a width of about 30 ft., and to be exposed on both sides of the Winnats Pass, where it is nearly 100 ft. high. It is also seen, according to Wolfenden, at the southern end of the depression between Middle Hill and Snels Low and is shown on his maps (Figs. 4 and 6) north-north-west of the summit ridge of Treak Cliff. The upper algal reef forms the summit ridge itself, where it is said to be exposed for 400 yds. and to be about 30 ft. wide and 50 ft. high. It is also stated to be present on Middle Hill and Snels Low.

On Treak Cliff the upper algal reef is shown, in Wolfenden's Fig. 6, as about 150 ft. in front of the lower algal reef. He states (p. 876) "Above the level at which this reef dies out, almost-horizontal shelf limestones pass gradually into reef-complex limestones. They gradually overstep the lower reef and come to rest above steeply dipping fore-reef limestones. The dip in the fore-reef limestones must therefore be depositional". A difficulty arises in explaining why the lower algal reef died out and, in this respect, Wolfenden quotes Newell et al. (1953, p. 106) that if "the rate of downwarping exceeds the growth potential of the reef, it will be drowned at comparatively shallow depths". Now if in fact there were two reefs, after the lower one was drowned there would have to be elevation of the sea floor before an upper reef could be initiated. Alternatively cessation of growth of the lower algal reef could have resulted directly from uplift. In either case upward movement of the sea bottom would, in the present author's view, have to be postulated.

The field evidence for a lower and an upper algal reef depends primarily upon the fact that the reefs are found at different altitudes in virtually horizontal strata. The palaeontological evidence rests partly in their relation to the D. septosa beds and partly on the goniatites in the equivalent fore-reef limestones, since the only goniatite recorded from the algal reefs themselves, either at Castleton or Earl Sterndale, is Beyrichoceras sp. D. septosa was stated to be found only at low horizons. It was recorded at 20ft. above the the top of the lower algal reef at the Winnats. But it has also been found on the summit ridge of Treak Cliff (Parkinson, 1953, p. 253) in the upper algal reef itself. However D. septosa, though common in Lower B_2, is also found in Upper B_2, and therefore its presence in the algal reef in itself does not mean that its age is Lower B_2. The writer believes with Wolfenden that the limestones of the summit ridge are higher than those designated "lower reef" at the Winnats.

In one locality - the northern slope of Treak Cliff - the fore-reef beds are of later date than the reef limestone behind them, which is mapped by Wolfenden as "lower reef". These fore-reef limestones constitute an apron of the well-known brachiopod beds. That they are of Upper B_2 - basal P_{1a} age has been amply demonstrated by the goniatite faunas (Hudson and Cotton, 1945a, p. 305; Parkinson, 1947, pp. 107, 110; 1953, pp. 257 - 8). They lie on a steeply inclined pot-holed surface of the lower algal reef and, locally at least, are banked against a few yards of its surface (Shirley and Horsfield, 1940, p. 280; Parkinson, 1943, p. 127).

On Middle Hill and Snels Low (Text-Fig. 3), both lower and upper algal reefs are mapped by Wolfenden, and his Fig. 7 (an idealised section) shows the upper reef, unlike those at Treak Cliff and Earl Sterndale, to be almost vertically above the lower one. He comments that the reason for this is unknown. However the evidence hardly justifies the view that there are here two algal reefs at two distinct levels. The "lower reef" is exposed in the shallow depression at its southern end between Middle Hill and Snels Low with the D. septosa band, south of the road in back-reef limestone, about 20 ft. higher. North of the algal reef the fore-reef limestones are stated to contain Lower B_2 goniatites (species not named). In this locality Shirley and Horsfield (1940, Pl. XVIII) map two septosa bands, the one noted by Wolfenden being the higher one, and probably equivalent to the main band of the standard succession. To judge from Shirley's map the lower band (which here as elsewhere is not so persistent as the upper one) is in the immediate neighbourhood 40 - 50 ft. beneath the upper one. It is shown on Shirley's map north of the road on the southern side of Snels Low at an altitude of about 1,275 ft. The average dip of the back-reef limestone is 5° N.W. and the summit of Snels Low is between 1,300 and 1,325 ft. The so-called "upper-reef" on Snels Low on this evidence is no higher than the level of the main D. septosa Band; and no fossil evidence has been produced that it is any higher than the lower algal reef elsewhere.

With regard to the three small outcrops on Middle Hill, the middle one is near the quarry mentioned earlier as containing D. septosa. The reef limestones in the quarry dip at 5° S.E. and presumably pass laterally into the algal reef limestones north of them. The dip of the beds in the quarry carries them beneath beds of massif facies, with sporadic exposures of the oolitic conglomerate which marks the base of Upper B_2. This (algal) reef therefore, like the one on Snels Low, is apparently of Lower B_2 age. The upper algal reef, if it exists in this locality, should be found behind the steeply dipping Upper B_2 fore-reef limestones on the northern and north-western slopes of Middle Hill and Snels Low.

On the sketch-map (Text-Fig. 3) the approximate position has been drawn, where the evidence permits, of the top of the reef-front in both Lower B_2 and Upper B_2 times. Between Perryfoot and Windy Knoll, the line of the Lower B_2 crest follows that of the algal reefs, the positions of which, as drawn by Wolfenden, are indicated. It should be noted that the reef limestones, where seen in front of this line, dip at low angles, whereas the fore-reef limestones of Upper B_2 age north of Bull Pit and at Snels Low and Middle Hill are inclined at high angles towards the basin. A substantial component of these dips is probably depositional. From Treak Cliff to the Winnats the evidence, so far as it goes, supports Wolfenden's view that the top of the fore-reef in Upper B_2 time was in front of its position in Lower B_2 time. Between the Winnats and Cave Dale the top of the Upper B_2 reef front has been removed, according to the writer's interpretation, by recent (and in part by late Viséan and sub-Namurian) erosion. Between Siggate and Nun Low the Lower B_2 fore-reef beds or their equivalents are buried. The approximate position of the summit of the Upper B_2 - P_1 reef-front is indicated by the dip configuration on the assumption that the dips towards the basin are partly primary. Another line drawn on Fig. 3 represents the approximate position where the back-reef beds merge into the shelf limestones. This line must be regarded as quite arbitrary; it may have moved forwards with time, like the reef-front.

Volcanic Rocks

The Cave Dale Lava was demonstrated by Shirley and Horsfield (1940) to be equivalent to the Lower Lava of D_1 age of the Wye Valley region farther south. The tuff bed, formerly exposed in the Pindale area and later encountered in boreholes, is now known to be also of D_1 age (Eden et al., pp. 76 - 7). The top of this tuff, forming an elongated mound in the Lower Bench of Earle's Quarry, was recognised by Shirley and Horsfield as marking the site of a volcanic vent. Eden et al. correlate it on geometrical grounds with the pillow lavas and associated calcareous agglomerate and tuff of the Hope borehole (Fearnsides and Templeman, 1932) a quarter of a mile east of the mouth of Pindale. The agglomerate of the Speedwell Vent, which penetrates the Beach-Beds, is probably another manifestation of the same volcanic activity. A quarry within the Beach-Bed series near the entrance to Peak Cavern contains a thin tuff bed which can be correlated approximately with the tuffaceous limestone conglomerate above the Cave Dale Lava (Bemrose, 1907; Parkinson, 1946, p. 109).

The Beach Beds

The Beach-Beds of Castleton, so-called by Barnes and Holroyd (1896), have recently been studied in detail by Sadler (1964a). They form a varied group, including limestones with abundant water-worn shells, and Dr. Sadler has done valuable work in describing the different lithologies and recording the extensive fauna. Her views as to age and mode of origin can, however, be criticised on various grounds. Because of the occurrence of Davidsonina septosa and Goniatities hudsoni, she attributed to them a mid-B_2 (D_1) age, rather older than the assessments of earlier authors, which ranged from Upper B_2 (high D_1) to P_{1b}. However D. septosa ranges into Upper B_2 and the one goniatite recorded (a poorly preserved specimen from the lower part of the series), although characteristic of Lower B_2, is also found in higher beds, specimens very close to the holotype having been collected from Upper B_2 (Moore, 1941, pp. 253 - 4; Hudson and Cotton, 1945a, p. 285).

Also noted in the Beach-Beds is the readily recognised productid Striatifera striata (Fischer) (Sadler, p. 363) which Eden et al. (1964, p. 90) cite as a P Zone fossil and record from quarries east of the Beach-Bed outcrop at Lower Jack Bank (P_{1a}) and Nun Low (P_{1a} or lower P_{1b}). It was found in P_{1a} in the Edale borehole (Hudson and Cotton, 1945b, p. 22). The writer does not recall ever seeing it below very high D_1 and has listed it in both P_{1a} and P_{1b} assemblages from the Slaidburn district of Yorkshire. It is common in P_{1a} on the Derbyshire side of the River Dove, west of Thorpe village and in high D_1 (possibly P_{1a}) on Caldon Low, Staffordshire. (Parkinson and Ludford, 1964).

This evidence suggests for the Beach-Bed group as a whole, the maximum thickness of which may exceed 80 ft.,an Upper B_2 - P_{1a} age. The discrepancy between this assessment and Dr. Sadler's is not large, but is important because of her hypothesis of origin. She does not agree that the deposits are indicative of a sub-littoral environment and considers them to result from submarine current action. She postulates (p. 369) "a channel cutting through the reef-complex in D_1 times, down which currents could sweep abundant fossil remains from the warm shallow water of the shelf sea behind the reef to the deeper and colder water at the foot of the fore-reef slope". The suggested position of this channel is the present dry gorge of the Winnats. Her idealised section (p. 365) shows the channel as about 1,000 ft. long with a slope of 25°. This is evidently based on Wolfenden's estimate (1958, pp. 880 - 883), approximating to the writer's (1953), of a surface relief of about 400 ft. on the reef front. It is difficult to believe that such a mechanism operating down a short steep slope would be adequate to have worn down the productid shells to their present smooth and rounded shapes.

Dr. Sadler's section (p. 365) does not accord with her map (p. 362). The section illustrates Beach-Beds thinning out against the fore-reef at a level just above the top of Wolfenden's lower algal reef (Lower B_2) and lying about 100 ft. below the upper algal reef (Upper B_2) on the summit of Treak Cliff. Her map, like the maps of earlier authors, can be interpretated either as Beach-Beds passing laterally north-westwards into the fore-reef limestones of the same general age as the upper algal reef or as resting on top of them. They cannot in their entirety lie below them,as indicated in her section.

Dr. Sadler does not discuss the evidence of a correlation of the Beach-Beds with the oolitic tuffaceous conglomerate and associated deposits of the back-reef area (Parkinson, 1947, 1953) and the evidence of unconformity below them. These back-reef limestones, as noted earlier, can be correlated with the lower part of the Miller's Dale Beds of high D_1 age, whereas the lower part of the Beach-Beds,as argued above, are of Upper B_2 age. Thus there is good reason to correlate the Beach-Beds with the oolitic conglomerate: and in fact Barnes and Holroyd regarded the two deposits as synchronous. In further support of such correlation, it should be noted that the base of the Beach-Beds in the Speedwell Mine is marked by a thin bed of clay with limestone pebbles, stated by Ford (1952, p. 357) to resemble those in the Cave Dale conglomerate.

On the question of unconformity Dr. Sadler merely asserts (p. 369) that "there is no evidence of unconformity below or within the 'Beach-Beds'." A critical appraisal of earlier work would have enhanced the value of her paper. Some of the evidence for earth-movement, not only in the Castleton district, but in widely separated areas elsewhere, has been noted in earlier pages, and this clearly shows that although interpretations of certain of the observed facts might differ, there was widespread elevation of the Lower Carboniferous sea floor in the middle part of the D_1 Zone, which,it might be added, corresponded in Derbyshire with the early period of volcanic activity.

A further point to be noted is that,in the absence of direct evidence, there seems no reason to suppose that the fossils in the Beach-Beds were transported from the shelf sea. The brachiopods recorded are nearly all reef forms and most of the named species have been listed from the nearby Treak Cliff fore-reef limestones. However, Dr. Sadler's conclusion that the fossils are not derived from previously consolidated limestones can be accepted; and she has demonstrated that the Beach-Beds proper are inter-bedded with occasional fore-reef limestones. But it does not follow that they accumulated at the bottom of the fore-reef hundreds of feet below sea level. If they formed, as the writer believes, at and a little below sea level, after elevation some original reef material might well be present as subsidiary sediment.

Some of the evidence of prior uplift is based on estimates of transgression by the Beach-Beds down the reef front. These estimates assume that the original thickness of the fore-reef beds along a given cross-section did not change much along the dip, which admittedly is an assumption that may not be fully justified, though actual attenuation of the strata down dip has not been demonstrated. The overstep down the Winnats gorge was estimated to have removed not less than 150 ft. thickness of rock (1953), but a reconsideration of all the available facts suggests that this figure, which depends upon an average dip of the fore-reef limestones of about 20°, may be too high. Dips locally along the slopes of the Winnats of 10° (Shirley and Horsfield, 1940), 15° and 25° (Parkinson) and an overall value of 25° (Wolfenden, 1958) have been recorded. The following estimate is based on an average dip of the Lower B_2 beds of 25°. The altitude of the base of Upper B_2, marked by small exposures of the oolitic pebbly limestone at the top of the cliff on the southern side of the Winnats, is about 1,350 ft. From this point, in the direction of strike, the limestone at the bottom of the gorge outcrops at an altitude of 950 - 975 ft., so that assuming a dip of 25° the limestone from the bottom to the top of the gorge is approximately 350 ft. thick along the strike. Down the gorge in the direction of dip to the base of the Beach-Beds, the thickness, again based on an inclination of 25°, approximates to 250 ft. Assuming no decrease in original thickness down the reef front over a distance of less than 300 yards Upper B_2 strata (Beach-Beds) are transgressive over Lower B_2 to a depth of about 100 ft.

This figure must be regarded as no more than a rough approximation, and from the point of view of the present discussion it could be much less than 100 ft. However, some support is given to this estimate from a consideration of the dips of the Upper B_2 - P_{1a} fore-reef beds of Treak Cliff. Evidence at the surface, coupled with Ford's observations in Treak Cliff Cavern, suggest an average of 33 - 35°. If it be assumed that the buried Lower B_2 rocks at Treak Cliff dip at an average angle of 25°, as at the Winnats, an overstep down the reef front of approximately 100 ft. follows, as is illustrated by the section (Text-Fig. 2) which runs eastwards from Treak Cliff to the borehole at the foot of the hill.

An alternative explanation which should be considered is that the Beach-Beds pass laterally up the gorge into fore-reef limestone, but the fossil evidence does not favour this interpretation and stratigraphical considerations make nonsense of it, since it means that along the strike to the north-west the Beach-Beds assume a fore-reef character of Upper B_2 - P_{1a} age, and across the strike they become fore-reef limestone of Lower B_2 age. Nevertheless such an interpretation follows from Dr. Sadler's hypothesis, unless her alleged channel was cut through limestone of later date than that of the Winnats Pass. Now the fore-reef limestones along the dip slope of Long Cliff and Cow Low constitute a lateral extension of the higher beds of the Winnats and their extension downwards was examined by Ford (1952) in the Speedwell Mine. Ford's section (p. 351) shows basal Beach-Beds (Upper B_2) overlying the reef limestones. If the Beach-Beds arose in a submarine channel cut through the Upper B_2 reef (and there is no direct evidence of such a channel) what has become of the <u>in situ</u> fore-reef limestone of that age in the area occupied by the Beach-Beds? Was the reef itself eroded away, leaving virtually only the products of the channel? This difficulty does not arise if the Beach-Beds are sub-littoral deposits resting on the Lower B_2 reef.

Earth - Movements

<u>Lower B_2/Upper B_2</u>. Whatever the relationship between the Lower and Upper B_2 sediments it is evident that the hiatus between them is confined within the limits of the range of <u>Davidsonina septosa</u> since this species is found in both subzones.

An attempt to understand the nature of the proposed uplift involves a consideration of the dips of the fore-reef limestone and Beach-Beds. The argument in the author's 1953 paper assumed that the dips on the reef front are substantially primary, and it was then further assumed that the Beach-Beds post-dated the steeply inclined rocks on the eastern slope of Treak Cliff. There is now good evidence to support the view that the fore-reef limestone of Treak Cliff, with an average dip of around 35°, is synchronous with the Beach-Beds, which dip at an average of approximately 20°. The Beach-Beds lie on the Lower B_2 reef limestone, of variable dip, averaging 25° or rather less at the Winnats and not much more at Cow Low. Evidence in the field does not indicate that the Beach-Beds are banked against or overlap on the reef (except possibly to some extent near the entrance to Peak Cavern, where the Beach-Beds dip at a much lower angle than the uppermost reef limestones - Ford, 1952, p. 347). This suggests at least the possibility that the Beach-Beds were laid down on a surface not steeply inclined, and in fact their character indicates very shallow water throughout the series. It seems to follow that they have a large component of tectonic dip and, if so, the underlying reef rocks are only in part depositional. It seems reasonable, in order to assess the component of primary dip of the reef limestone, to deduct the amount of tectonic dip of the Beach-Beds - say 15°. This would make the depositional dip of the limestone at the Winnats no more than 10° and at Cow Low probably less than 15°. A conservative estimate suggests a surface relief of the Lower B_2 reef front at the time of uplift of between 100 and 150 ft., and, if the reasoning is sound that 100 ft. of limestones were overstepped down the Winnats gorge, the position of maximum uplift would seem to have been to the east and to have involved a vertical movement of some 200 - 250 ft.

The axis of uplift, if the term is appropriate, was probably along the rim of the basin and would be expected to follow the boundary of reef and basin along the foot of Treak Cliff and to swing round from north-west to south-west near Odin Fissure. Sedimentation would be renewed as the reef sank again and the down-warp would be greater north of the Winnats, where the Upper B_2 reef was forming, than in the Beach-Bed area to the south-east. It is presumed that the Beach-Beds accumulated on the surface of the Lower B_2 reef, which had been raised above sea level and still formed a small area of low-lying land on the inside edge of the Beach-Bed outcrop. At the same time the Upper B_2 reef of Treak Cliff was growing, with an average depositional dip of the fore-reef beds of 20°, a figure again based on a tectonic dip of 15°. This would make the original surface relief on the reef front about 250 - 300 ft. as compared with earlier estimates of 400 ft.

P_{1a} / P_{1b}. In Castleton village the thin outcrop of black limestones of P_{1b} age rests on Beach Beds. Eastwards along the foot of Siggate the black limestone lies on fore-reef limestones, including broken shell beds. Basal P_{1a} goniatites have been recorded from beds on the dip slope of the hill (Parkinson, 1947, p. 110). The limestones actually in contact with the P_{1b} basin deposits may be a little below P_{1a}. The field relations suggest that they are approximately equivalent to the high D_1 beds at the entrance to Pindale and in Lower Jack Bank Quarry, which Eden et al. (p.90) show to be unconformable below P_{1b}.

The unconformity below P_{1b} has removed the higher deposits of P_{1a} along much of the line of the reef apron. Limestones high in P_{1a} may be present in Nun Low Quarry (Eden et al.; localities 13, 14; pp. 91, 104). In the Edale borehole, two miles north-west of Treak Cliff (Hudson and Cotton, 1945b, pp. 21 - 2), the strata are of basin facies and P_{1a} is well developed. P_{1b} was found in the borehole between 493 and 512 ft. with *G. falcatus* at the top. The 19 ft. of beds below it are of a sub-littoral character and occasional beds are "made up entirely of water-worn fragments of productid shells from one to three inches long in a calcareous matrix" (op.cit., p. 21). In character they resemble the Beach-Beds. Hudson and Cotton suggest a correlation of the beds between 493 and 530 ft. with beds from 298 to 348 ft. in the Hope borehole (Fearnsides and Templeman, 1932, Fig. 1, p. 102). The Hope limestones yielded *Lonsdaleia duplicata* (Martin) and a number of reef facies forms. The authors suggest the possibility that these very variable ashy and brecciated limestones may have accumulated on the sloping flank of the submarine volcano. They describe (p. 106) a "bed of rounded limestone pebbles at 312 feet which dips with the beds above at about 10°. Its floor at 313 feet dips more steeply - at fully one in three - and is pot-holed and irregular. The beds beneath that irregular surface are more compact and massive", without breccia and conglomerate and with a dip of 20°. The lowest part of the series is a breccia composed of several kinds of darker and lighter nodular and massive ashy limestones, which at 348 feet rest upon an irregular pockety nodular surface of a 3 - foot bed of pinkish tuff. This tuff lies on the uppermost of the three flows of pillow lava. The occurrence of *L. duplicata* in the limestones of the borehole indicates D_2 rather than D_1, and their age, as suggested by

Hudson, could well be P_{1b}. They apparently rest with a pronounced break on the D_1 volcanic rocks.

It is significant that, in the vicinity of Pindale and Jack Bank, P_{1b} oversteps D_1 limestones above the tuff-bed down the reef front; these limestones may all have been removed near the site of the Hope borehole. The uplift, like the earlier one, presumably followed the line of the basin rim. In the Edale borehole there is no evidence of unconformity, but the position of the break is indicated by the water-worn shell bed. A similar "Beach-Bed" is found in low D_2 of Earle's Lower Bench (Eden et al., p. 86). This unconformity coincides with the Sudetian I earth-movement of Hudson and Mitchell (1937 - See also Hudson and Cotton, 1945b, p. 32). The uplift was apparently of sufficient magnitude to bring the bottom of the reef front to near sea level. In the subsequent sedimentation period, downward movement was restricted and elevation was soon renewed.

P_{1c-d}/P_{2a}. In the back-reef area between the non-sequence at the bottom of P_{1b} and the Upper Girvanella Band at the base of the upper part of D_2, three erosion surfaces representing non-sequences were demonstrated by Eden et al. The pebble bed at 312 ft. in the Hope borehole may represent one of these breaks, suggesting the possibility that the limestone between 293 and 313 ft. may be of somewhat later age than P_{1b}.

Strata of the P_{1c} and P_{1d} Zones have not been recorded from the fore-reef area, but a borehole east of Treak Cliff (1953, Summ. Prog. Geol. Surv. for 1952, p. 27) revealed shales and thin limestones of Upper Posidonia (P_2)age above reef limestone of unstated age. It seems unlikely that these reef limestones are higher than P_{1b}, and, unless a fault intervenes between the borehole and the limestone outcrop, they are presumably of B_2 (probably Lower B_2) age. This is indicated in the section (Fig. 2) which is drawn to true scale. The absence of P_{1a} (and maybe Upper B_2) can be explained by the P_{1a}/P_{1b} uplift and of the $P_{1b,c,d}$ beds by crustal movement of P_{1d}/P_{2a} age (Sudetian II, Hudson and Cotton, 1945b, p. 32). The P_2 beds are apparently overlapped out on the reef front.

E_1/E_2. In the marginal belt between massif and basin, the Edale Shales both overlap on and overstep the reef and associated limestones. Within the Edale Valley and elsewhere, however, there is no break between Viséan and Namurian, as was shown both in the Alport and Edale borings through the basin sediments; and even in the marginal area, where in the Treak Cliff borehole the beds of Eumorphoceras (E_1) age, with Cravenoceras leion Bisat at the base, are apparently conformable on the P_2 deposits. In the Hope borehole, the local base of the Namurian at 298 ft. was shown to rest directly on limestone of D_2 age with every indication of conformity (Fearnsides and Templeman, p. 105). Hudson and Cotton (1945b, p. 14) gave reasons for placing the base of the Namurian at Hope at the horizon of the beds designated E_{1d} in the Edale bore, which suggests that the whole of P_2 and nearly all of E_1 were not present in the Hope borehole. It seems likely that argillaceous limestones excavated near Mich Low (Hudson and Cotton, 1945b, p. 30) represent some of the beds missing from the bore. Near the top of the Treak Cliff borehole Cravenoceras malhamense (E_{1c}) was found in a greatly attenuated E_1 sequence.

The combined thickness of the zones E_{1a}, E_{1b} and E_{1c} in the Edale borehole is about 340 ft; this has dwindled to about 80 ft. in the Treak Cliff borehole. The lowest Namurian beds in the Hope borehole contained no specifically diagnostic fossils; the E_{1d} fauna of the Edale borehole was not very distinct and might equally well have been placed in the E_{2a} Zone (op. cit, p. 11). In the Eyam district of Derbyshire, Shirley and Horsfield (1945, p. 293) refer to outliers of Edale Shales on the limestone surface. From the largest outlier at Wardlow Mires, the E_2 Zone fossil Eumorphoceras bisulcatum Girty was recorded. On this evidence the time of uplift along the edge of the massif was that of the faunal change from E_1 to E_2 (Sudetian III) and like the earlier movements it was epeirogenic in character. Erosion associated with this and the earlier uplifts locally denuded the rocks down to the level of Lower B_2 (about the middle part of D_1). Transgression and overlap of the Edale Shales on the limestone surface continued until R_1 times (Hudson and Cotton, 1945a, Pl. XIX; 1945b, pp. 13 - 14).

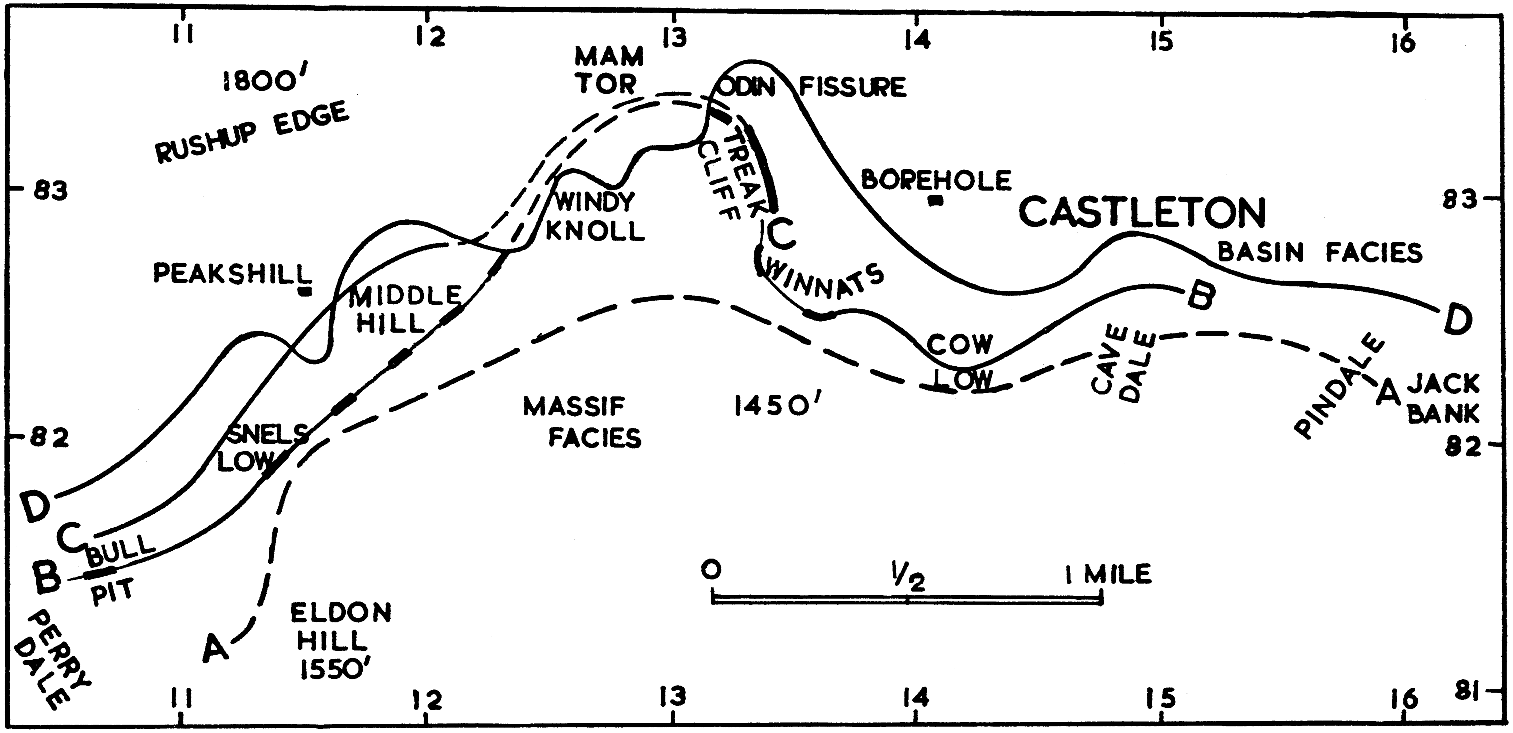

Fig. 3. Sketch-map of the reef complex between Perry Dale and Pin Dale. The line A-A approximates to the inner boundary of the reef, which is quite arbitrary since the back-reef facies pass imperceptibly into the massif facies. The line B-B attempts to show the position of the top of the fore-reef in Lower B_2 time, and the line C-C similarly illustrates the top of the reef front in Upper B_2 time. The thick portions depict the algal reefs as interpretated by Wolfenden (1958). The line D-D is the present boundary of the Carboniferous Limestone and Edale Shales.

Fissures in the Limestone

The "Neptunian Dykes" in the limestone of the quarry on Windy Knoll contain infillings of two distinct kinds. The limestone breccia-filled pockets,as noted by Shirley and Horsfield (1940, p. 290), appear to be continuous with the Upper B_2 beds over the top of the quarry, which in neighbouring exposures, including the oolitic conglomerate, have yielded Hudson and Cotton's fauna C (1945a, p. 305). The other type of infilling consists of Edale Shales, the base of which near Windy Knoll and Peakshill approximates to the base of the R_1 Zone, and in fact Reticuloceras has been collected from one of the shale pockets in the limestone (Hudson and Cotton, 1945b, p. 14).

At first sight it might seem rather remarkable that, in the same small quarry, cavities in the limestone surface should be filled with deposits of widely different ages. The interval spans the period represented by strata of P, E and H age. However the phenomena are in keeping with the view of alternating periods of elevation and depression along the margin of the massif. Moreover similar fissures are reported from below Jack Bank (Fearnsides and Templeman, pp. 115 - 6) and in Treak Cliff Cavern (Ford, 1952, pp. 352-4).

As at Windy Knoll, the Treak Cliff fissures are filled with two distinct kinds of deposit. One consists of "angular and subangular boulders of limestone in a matrix of shaly and bituminous limestone and are thus closely similar to the well-known 'dykes' at Windy Knoll" (Ford 1952, p. 353). The other type consists of black Edale Shales, the basal layers of which contain large rounded and corroded boulders of crinoidal limestone constituting, as Ford observes (p. 352), a basal Namurian conglomerate. In the absence of any evidence to the contrary, Ford suggested that the two types of "Neptunian dyke" might be of similar age. However, it seems at least possible that the limestone infillings are associated either with the Sudetian I or the Sudetian II earth-movement. They are of later date than the limestone infillings of Windy Knoll if, as seems probable, the immediately underlying rocks on Treak Cliff are of lower P_1 age. They could possibly be, as Ford observes, of similar age to the Edale Shale pockets, but if so the absence of shales of Edale type seems rather surprising.

The Edale Shale cavities in Treak Cliff Cavern and the nearby surface exposures have not yielded any diagnostic fossils, but they are probably of E_2 age. Their location is roughly half way between the Treak Cliff borehole and the gully north of Odin Fissure, where the shales near their base are of E_{2b} age (Hudson and Cotton, 1945b, p. 13), whereas at the top of the borehole they are of E_{1c} age or a little higher.

Fearnsides and Templeman (pp. 115 - 6) described an extensive "channelled and water-worn surface of a single bed or post of limestone" which was uncovered in 1931-2 in preparation for quarrying below Jack Bank. The "uppermost six or eight feet of limestone is a coarse-textured crinoidal composite breccia, with many different kinds of limestone in a matrix of ill-graded unbroken and broken shells and limestone paste". Joints in the limestone had sagged and been widened by solution to grike-like fissures to a depth of many feet and were filled with black shale. There was no evidence of transgression of shales over the limestone surface, no fossils were recorded from the shales and, in contrast to the Treak Cliff pockets, there were no loose pieces of limestone in the basal layers of shale. Jackson had earlier (1925) described the pot-holed surface between the Carboniferous Limestone and Edale Shale in Nun Low Quarry. The age of the basal shales in the Pindale-Nun Low area according to Eden et al. (p. 90) is "known to belong to either P_2 or E (Low Namurian)."

It is concluded that the fissuring of the limestone surface was not the result of one episode but that it accompanied successive crustal movements. So far as can be judged by the available evidence, the pockets and grikes were filled with later deposits, the approximate ages of which are Upper B_2 (Windy Knoll), P_1 or low P_2 (Treak Cliff), P_2 - E_1 (Jack Bank-Nun Low), E_2 (Treak Cliff) and basal R_1 (Windy Knoll.)

Conclusions

The considerable body of research that has been carried out in this small area is indicative of the complex nature of the problems involved. Some of the controversial issues have now been resolved, but disagreement remains on others, notably the origin of the Beach-Beds, their relationship to the reef limestones and to crustal movement between massif and basin. Uncertainty still exists on the delimitation of the lower and upper parts of the B_2 Zone.

The following conclusions seem to be justified on the available evidence.

(a) The reef limestones of Cave Dale, Cow Low, the Winnats, part of the flat between Treak Cliff and Windy Knoll, and parts of Middle Hill and Snels Low are of Lower B_2 age.

(b) The fore-reef limestones of Treak Cliff, Middle Hill and Snels Low are of Upper B_2 - P_{1a} age. The back-reef beds are mostly of higher D_1 (Upper B_2) age.

(c) The term "reef-limestone" should have a wider connotation than that which restricts it to an algal reef framework.

(d) Earth-movement involving simple uplift separates the Upper B_2 sub-zone from the Lower B_2 sub-zone. The resulting unconformity is confined within the limits of the range of Davidsonina septosa.

(e) The Beach-Beds are sub-littoral deposits resting on the elevated Lower B_2 fore-reef limestones and passing laterally into the B_2 - P_{1a} fore-reef limestones.

(f) The P_{1b} limestones are unconformable on lower beds as a result of crustal movement of Sudetian I age.

(g) Absence locally of Upper P_1, P_2 and E_1 sediments is attributed to the Sudetian II and III uplifts.

(h) The successive upward and downward earth-movements produced fissures in the limestone surface which were filled with deposits ranging from Upper B_2 to R_1 age.

Donald Parkinson, D.Sc., Ph.D.,
6, Clowes Avenue,
Southbourne,
Bournemouth

References

ALEXANDER, G.B. 1940. Report of field meetings for 1939. Proc. Yorks. Geol. Soc., vol. 24, p. 172.

BARNES, J. and HOLROYD, W.F. 1896. On the occurrence of a sea-beach at Castleton, Derbyshire, of Carboniferous age. Trans. Manchr. Geol. Assoc., vol. 25, pp. 119 - 132.

BATHURST, R.G.C. 1959. The cavernous structure of some Mississippian Stromatactis Reefs in Lancashire, England. J. Geol., vol. 67, pp. 506 - 21, 2 plates, 4 figures.

BEMROSE, H.H. ARNOLD 1907. The Toadstones of Derbyshire: their field relations and petrography. Quart. J. Geol. Soc. Lond., vol. 63, pp. 241 - 281.

BISAT, W.S. 1934. The Goniatities of the Beyrichoceras Zone in the North of England. Proc. Yorks. Geol. Soc., Vol. 22, pp. 280 - 309, 8 plates, 1 figure.

BLACK, W.W. 1954. Diagnostic characters of the Lower Carboniferous knoll-reefs in the North of England. Trans. Leeds Geol. Assoc., vol. 6, pp. 262 - 297, 1 plate, 6 figures.

BOND, G. 1950. The Lower Carboniferous reef limestones of Cracoe, Yorkshire. Quart, J. Geol. Soc., Lond., vol. 105, pp. 157 - 188, 1 plate, 4 figures.

COPE, F.W. 1933. The Lower Carboniferous succession in the Wye Valley region of North Derbyshire. J. Manchr. Geol. Assoc., vol. 1, pp. 125 - 145, 6 figures.

1936. The Cyrtina septosa Band in the Lower Carboniferous succession of North Derbyshire. Summ. Prog. Geol. Surv. for 1934, pp. 48 - 51, 1 figure.

1939. The Mid-Visean (S_2 - D_1) succession in North Derbyshire and North-West England. Proc. Yorks. Geol. Soc., vol. 24, pp. 60 - 66, 1 figure.

DOUGLAS, J.A. 1909. The Carboniferous Limestone of County Clare (Ireland). Quart. J. Geol. Soc., Lond., vol. 65, pp. 538 - 586.

EARP, J.R., MAGRAW, D., POOLE, E.G., LAND, D.H., and WHITEMAN, A.J. 1961. Geology of the country around Clitheroe and Nelson. Mem. Geol. Surv., IX, 346 pp., 12 plates, 22 figures.

EDEN, R.A., ORME, G.R., MITCHELL, M. and SHIRLEY, J. 1964. A study of part of the margin of the Carboniferous Limestone 'massif' in the Pin Dale area of Derbyshire. Bull. Geol. Surv. G.B., No. 21, pp. 73 - 118, 4 plates, 2 figures.

FEARNSIDES, W.G. and TEMPLEMAN, A. 1932. A boring through Edale Shales to Carboniferous Limestone and pillow lavas at Hope Cement Works, near Castleton, Derbyshire. Proc. Yorks. Geol. Soc., vol. 22, pp. 100 - 121, 2 figures.

FORD, T.D. 1952. New evidence on the correlation of the Lower Carboniferous reefs at Castleton, North Derbyshire. Geol. Mag., vol. 89, pp. 346 - 356, 5 figures.

1965. The Palaeoecology of the Goniatite bed at Cowlow Nick, Castleton, Derbyshire. Palaeontology, vol. 8, pp. 186 - 191, 1 plate.

GARWOOD, E.J. and GOODYEAR, E.
1924. The Lower Carboniferous succession in the Settle District and along the line of the Craven Faults. Quart. J. Geol. Soc., Lond., vol. 80, pp. 184 - 273, 12 plates, 2 figures.

GEORGE, T.N. 1927. The Carboniferous Limestone (Avonian) succession of a portion of the North Crop of the South Wales Coalfield. Quart. J. Geol. Soc., Lond., vol. 83, pp. 38 - 95, 1 plate, 6 figures.

HODSON, F. and MOORE, E.W.J.
1959. Goniatites striatus and related forms from the Visean of Ireland. Palaeontology, vol. 1, pp. 384 - 396, 6 plates, 3 figures.

HUDSON, R.G.S. and COTTON, G.
1945a. The Lower Carboniferous in a boring at Alport, Derbyshire. Proc. Yorks. Geol. Soc., vol. 25, pp. 254 - 330, 1 plate, 6 figures.

1945b. The carboniferous rocks of the Edale anticline, Derbyshire. Quart. J. Geol. Soc., Lond., vol. 101, pp. 1 - 36, 1 plate, 3 figures.

HUDSON, R.G.S. and MITCHELL, G.H.
1937. The Carboniferous geology of the Skipton anticline. Summ. Prog. Geol. Surv. for 1935 (2), pp. 1 - 45.

JACKSON, J.W. 1922. On the occurrence of Daviesiella llangollensis (Dav.) in Derbyshire. Geol. Mag., vol. 59, pp. 461 - 468.

1925. The relation of the Edale Shales to the Carboniferous Limestone in North Derbyshire. Geol. Mag., vol. 62, pp. 267 - 274.

1941. Description of a Carboniferous Limestone section with Girvanella in North Derbyshire. J. Manchr. Geol. Assoc., vol. 1, pp. 239 - 246.

MITCHELL, G.H. and STUBBLEFIELD, C.J.
1941. The Carboniferous Limestone of Breedon Cloud, Leicestershire, and the associated inliers. Geol. Mag., vol. 78, pp. 201 - 219, 1 figure.

MOORE, E.W.J. 1941. Sections in the Bowland Shales west of Barnoldswick. Proc. Yorks. Geol. Soc., vol. 24, pp. 252 - 258, 1 figure.

NEWELL, N.D. 1955. Depositional fabric in Permian reef limestones. J. Geol., vol. 63, pp. 301 - 309, 8 plates.

NEWELL, N.D., RIGBY, J.K., FISCHER, A.G., WHITEMAN, A.J,. HICKOX, J.E., and BRADLEY, J.S.
1953. The Permian Reef Complex of the Guadalupe Mountains Region, Texas and New Mexico. XIX + 236 pp. 32 plates, 85 figures.

ORME, G.R. and BROWN, W.W.M.
1963. Diagenetic fabrics in the Avonian limestones of Derbyshire and North Wales. Proc. Yorks. Geol. Soc., vol. 34, pp. 51 - 66, 7 plates, 1 figure.

PARKINSON, D.
1943. The age of the reef-limestones in the Lower Carboniferous of North Derbyshire. Geol. Mag., vol. 80, pp. 121 - 131, 1 figure.

1947. The Lower Carboniferous of the Castleton district, Derbyshire. Proc. Yorks. Geol. Soc., vol. 27, pp. 99 - 124, 1 plate, 1 figure.

1953. The Carboniferous Limestone of Treak Cliff, Derbyshire, with notes on the structure of the Castleton reef-belt. Proc. Geol. Assoc., vol. 64, pp. 251 - 268, 3 figures.

1964a. The relationship of the Bowland Shales to the Pendleside Limestone in the Clitheroe, Slaidburn and Sykes anticlines. Geol. J. vol, 4, pp. 157 - 166, 3 figures.

1964b. Problematic fabrics in the Carboniferous Limestone of Dovedale. Mercian Geologist, vol. 1, pp. 49 - 57, 4 figures.

PARKINSON, D. and LUDFORD, A.
1964. The Carboniferous Limestone of the Blore-with-Swinscoe district, North-East Staffordshire, with revisions to the stratigraphy of neighbouring areas. Geol. J., vol. 4, pp. 167 - 176, 1 plate, 2 figures.

SADLER, H.E.
1964a. The origin of the "Beach-Beds" of Castleton, Derbyshire. Geol. Mag., vol. 101, pp. 360 - 372, 4 figures.

1964b. Conditions of sedimentation of the Cyrtina septosa Band in the Lower Carboniferous of Derbyshire. Mercian Geologist, vol. 1, pp. 15 - 22, 1 figure.

SHIRLEY, J. and HORSFIELD
1940. The Carboniferous Limestone of the Castleton-Bradwell area, North Derbyshire. Quart. J. Geol. Soc., Lond., vol. 96, pp. 271 - 299, 1 plate, 2 figures.

1945. The structure and ore deposits of the Carboniferous Limestone of the Eyam district, Derbyshire. Quart. J. Geol. Soc., Lond., vol. 100, pp. 289 - 308, 1 plate, 3 figures.

WOLFENDEN, E.B.
1958. Paleoecology of the Carboniferous reef complex and shelf limestones in Northwest Derbyshire, England. Bull. Geol. Soc. Amer., vol. 69, pp. 871 - 898, 12 figures.

WOOD, A.
1941. "Algal dust" and the finer grained varieties of Carboniferous Limestone. Geol. Mag., vol. 78, pp. 192 - 200, 2 plates.

(Manuscript received 20th May, 1965)