THE CARBONIFEROUS LIMESTONE OF MONSAL DALE, DERBYSHIRE

by

Nicholas J.D. Butcher and Trevor D. Ford

Summary

The sequence of the Carboniferous Limestone Beds of the D_2 subzone, occurring above the Millers Dale Beds, is described and mapped in detail for the first time. The sequence consists largely of two divisions, the Monsal Dale Group below, totalling some 660 feet (200 m), and the Ashford Beds above, totalling 145 feet (44 m). Both thin south eastwards. The Monsal Dale Group is redefined to include the Station Quarry Beds of Cope (1933) which are not separable from the overlying beds over much of the area. The Upper Millers Dale Lava is thus within the lower part of the Monsal Dale Group. This lava is correlated with the Upper Fin Cop Lava of Bemrose (1907). The Monsal Dale Group contains several marker coral beds at Upperdale, Hob's House and White Cliff, and the Rosewood Marble Bed provides another useful marker. The Ashford Beds are thought to be equivalent to the Eyam Limestones. Within the Monsal Dale Beds some limestones with abundant *Gigantoproductus* are shown to be slumped or turbidite horizons of little value in correlation. Numerous other slumps and turbidites are noted, in a quasi-basinal environment. Scattered *Lingula* valves in these "basinal" limestones are thought to have originated from an epi-planktonic environment. Sedimentological and structural notes are included and an appendix provides a guide to the sections seen in the abandoned railway cuttings.

Introduction

Although Monsal Dale is visited by numerous geological parties, and the section therein was part of the "type" section described by Sibly (1908), no detailed geological map he published of the Dale and the details of the sequence published by various writers leave many discrepancies. The present paper attempts to fill the gap. The field mapping was carried out by the first author, under the guidance of the second, as part of his undergraduate course at the University of Leicester, during 1969 and 1970. Thus presented here for the first time are a detailed geological map of Monsal Dale (Fig. 1) and a statigraphical correlation and lithofacies chart (Fig. 2).

Monsal Dale lies on the eastern flank of the "Derbyshire Dome" of Carboniferous Limestone. It forms part of the valley of the River Wye, here incised some 500 feet (150 m) below the plateau. The hillsides are thickly covered with Pleistocene screes, and often densely vegetated, whilst the plateau is almost entirely covered by a drift of residual soils, chert gravels and occasional patches of till. The only reasonably continuous section in the area is that along the railway cuttings (Fig. 4) which, until abandonment a few years ago, were effectively inaccessible.

Previous Research

The "current" Geological Survey map of the area is Old Series Sheet 81SE, published in 1852 and revised in 1867. The Institute of Geological Sciences are currently remapping the area and the sheet and memoir immediately to the north have recently been published (Sheet 99; Chapel-en-le-Frith; Stevenson and Gaunt 1971). Subsequent to the Old Series map and Memoir (Green 1869 and 1887), Bemrose (1907) gave a comprehensive description of the

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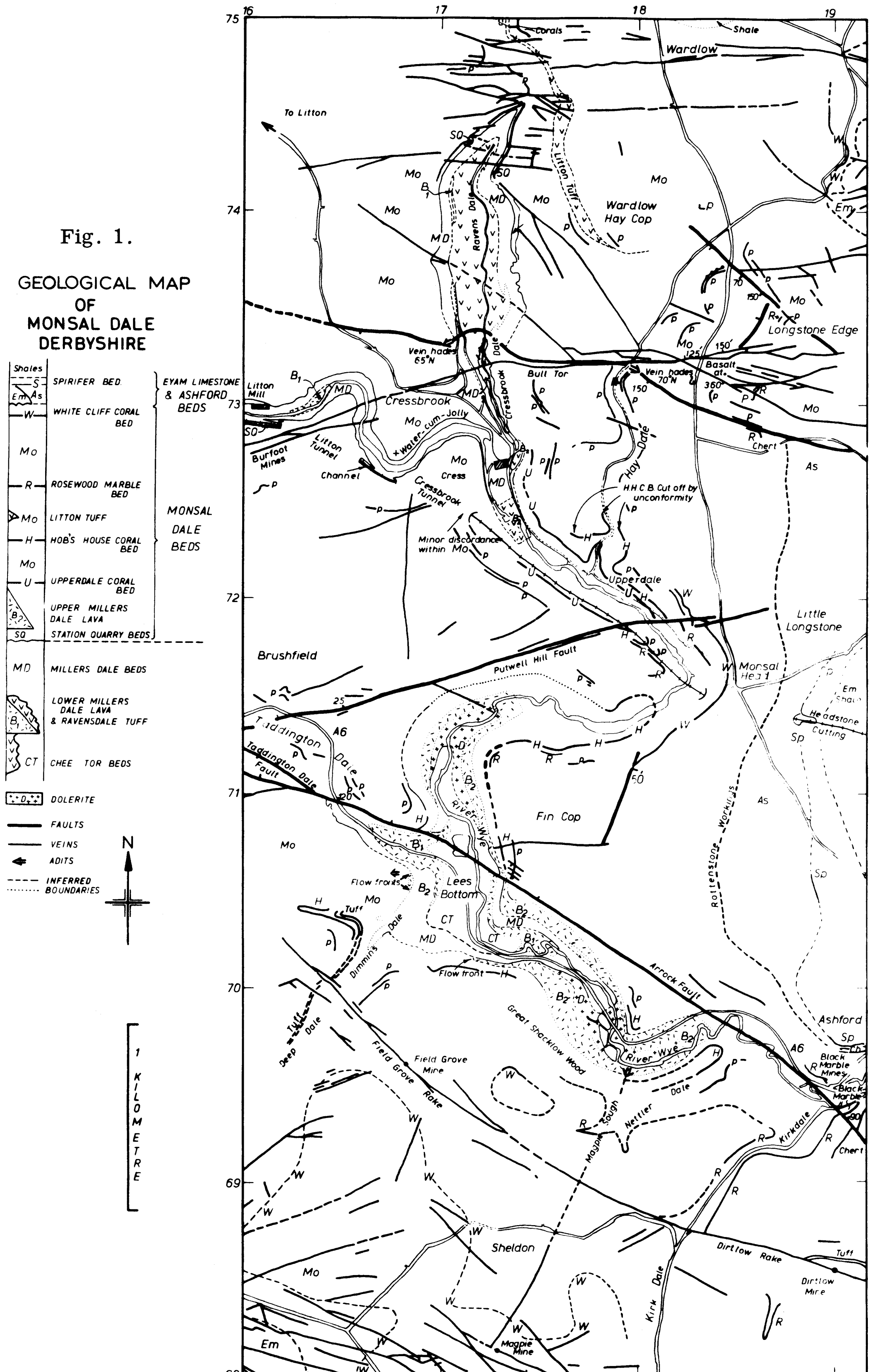
Fig. 1.

GEOLOGICAL MAP OF MONSAL DALE DERBYSHIRE



distribution and petrography of the igneous rocks, though he left some outcrops uncorrelated. Sibly (1908) used the Wye Valley, including Monsal Dale, to establish sub-divisions of the Dibunophyllum Zone, D_1, D_2, and D_3. Following this, Cope (1933, 1937) described a 'standard' Wye Valley succession with sub-divisions named from the Millers Dale area. Shirley and Horsfield (1945) described and gave a detailed map of the succession in the Eyam area to the north-east, and Shirley (1958) has described the Monyash area to the south. Stevenson and Gaunt (1971) have included descriptions of the sections at the head of Cressbrook Dale, on the northern margin of the present area, and the mineralogy of some of the clay wayboards

Thus Monsal Dale lies in between areas with detailed maps. Although the sequence has been outlined by the above, by Eden (1954) and again by Cope (1958 and 1967), there are differences between the accounts, particularly in the placing of certain coral marker beds. For example, Cope placed the Hob's House Coral Band at less than 100 feet above the Upper Lava whilst Eden placed it 200 feet above; Cope's estimate of the thickness of the Monsal Dale Beds was less than 400 feet, whilst Eden's estimate was 500 feet.

Unpublished work by Taylor (1957) and Cockbain (1957) has added some detail on the corals and sedimentology. More recently Walkden (1970) has described the sedimentology of some sections along the railway, and the mineralogy of some of the clay wayboards (Walkden 1972).

The Stratigraphic Succession

The formational names introduced by (Cope 1933, 1937 and 1958) are retained herein, though with some revision of thicknesses and boundaries as discussed below. The full succession is:-

			Thickness
P_2	Eyam Group	Viséan Shales	...?...
		Ashford Beds	145 feet (44 m)
		Monsal Dale Beds	500 feet (150 m)
D_2	Monsal Dale Group	Upper Millers Dale Lava	0-100 feet (30 m)
		Station Quarry Beds	0- 63 feet (20 m)
		Millers Dale Beds	75-150 feet (23-45 m)
D_1	Bee Low Group	Lower Millers Dale Lava	0- 80 feet (24 m)
		Chee Tor Beds	.....

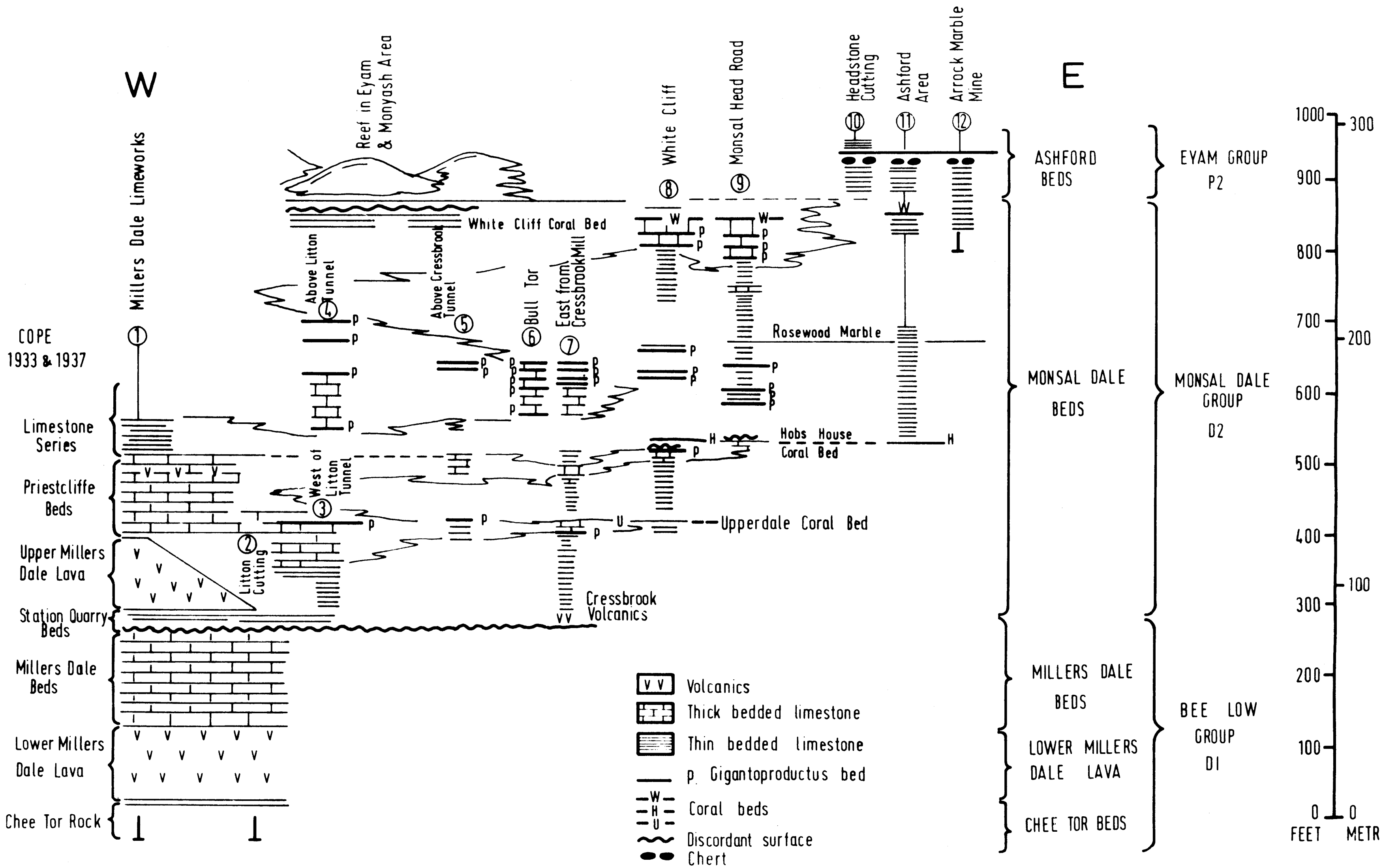
The Bee Low Group

The Millers Dale Beds and Lavas. The Millers Dale Beds rest on the Lower Millers Dale Lava in Millers Dale, indifferently exposed near Litton Mill. The lava was correlated by Shirley and Horsfield (1945), on rather insecure evidence, with the Ravensdale Tuff in the upper part of Cressbrook Dale. New exposures have now been located, which show basalt resting on tuff with intercalated limestone beds at SK 171741; exposures at SK 171734 and SK 172741 are among landslips which have slid on thin tuff horizons.

The Millers Dale Beds are massive cliff-forming limestones with poorly developed bedding except at the top, where a coral bed with abundant *Lithostrotion junceum* (Fleming) is present. Overlooking Water-cum-Jolly a mound-like structure is present (SK 165729) and although difficult of access, it appears to be made up of bioclastic debris, presumably the result of current action. An abrupt lithological change from the massive limestones of the Millers Dale Beds to the thinly bedded Station Quarry beds was taken as the top of D_1 by Cope (1933) and this horizon was also noted in Cressbrook Dale by Shirley and Horsfield (1945).

The Millers Dale Beds dip eastwards beneath the valley floor near Cressbrook Mill but reappear in the Lees Bottom inlier as cliffs around the foot of Dimmins Dale and in Lower

Fig. 2. SUGGESTED STRATIGRAPHIC AND LITHOFACIES CCOMELATION IN THE MONSAL DALE AREA



Taddington Dale. Indifferent exposures in faulted ground at the foot of Fin Cop show two lava flows and a dolerite sill. The lower flow is clearly seen to occur beneath massive Millers Dale Beds and is thus tentatively correlated with the Lower Millers Dale Lava. It appears to die out southwards, with a flow front exposed immediately north of the mouth of Dimmins Dale (SK 170704). Detailed mapping has shown that much of the flat ground here is not, as previously thought, underlain by basalt, but by limestones of the Chee Tor Beds. In the absence of the Lower Lava the Millers Dale Beds rest directly on Chee Tor Beds.

The Millers Dale beds are here approximately 75 feet (23 m) thick, in contrast to 150 feet (45 m) in Millers Dale itself.

<u>The Monsal Dale Group</u>

The Station Quarry Beds. Described from Millers Dale Station yard by Cope (1933, p. 134) these thinly bedded limestones with *Saccaminopsis* bands are about 25 feet (8 m) thick, and rest non-sequentially on the Millers Dale Beds. The top of the Station Quarry Beds was here taken at the base of the Upper Millers Dale Lava, but the lava dies out eastwards, and the Station Quarry Beds are then indistinguishable from the upper part of the Monsal Dale Group.

In the Litton tunnel (east) railway cutting (SK 166727) the channel noted by Cope (1933, p. 132) shows Station Quarry Beds unconformably lying on Millers Dale Beds with a bed with frequent *L. junceum* at the top. A lens of limestone pebbles in a pyritic green clay lies at the bottom of the channel. However, near Cressbrook Mill, horizontal thin-bedded limestones without *Saccaminopsis*, rest directly on Millers Dale Beds. Much further to the north, in upper Cressbrook Dale (SK 173745), Station Quarry Beds with *Saccaminopsis* are seen to be 63 feet (20 m) thick, more than double the thickness in the type section. Along the east side of Cressbrook Dale, the Station Quarry Beds can be seen to thin from 63 to 40 feet (20-13 m) southwards. Dip readings taken above and below the Station Quarry beds along the Dale suggest that they thin out and may be banked against an incipient Longstone Edge monocline.

Some difficulty has been encountered in relating the above observations with the sections described by Cope (1933, 1937) in the Litton railway cutting (SK 157730) and east of Taddington (SK 153712). In the former, a study by Walkden (1970) has confirmed Cope's opinion that the flow front of the Upper Millers Dale Lava rests on top of Station Quarry Beds, and has basal Monsal Dale Beds banked against it. This seems to be the case near Taddington also, though the Station Quarry Beds are insufficiently exposed for definite conclusions to be drawn.

In the Lees Bottom inlier it has not been possible to differentiate the Station Quarry Beds from the overlying part of the Monsal Dale Beds owing (a) to the absence of *Saccaminopsis* bands, (b) to the absence of the normally intervening Upper Millers Dale Lava along most of the south-west side of the inlier, and (c) to the very indifferent exposures at this general horizon, with considerable scree cover. If present, the Station Quarry Beds, sensu stricto, can be no more than a few feet thick.

As the Station Quarry Beds can thus only be mapped and recognized as a distinct unit over a small area, the present authors agree with Stevenson and Gaunt (1971) that henceforth they should be regarded as no more than a sub-unit at the base of the Monsal Dale Beds. The Upper Millers Dale Lava thus occurs at an horizon within the lower part of the Monsal Dale Beds.

The Upper Millers Dale Lava. Although the lava was over 60 feet (18 m) thick in the type area, Cope (1933) described sections which appeared to show that this lava died out eastwards near Litton Mill (SK 157730) and in Taddington Dale (SK 151712). To the north the flow is present in Tideswell Dale but not in Cressbrook Dale. These observations allow an apparent eastern boundary to the flow to be drawn showing a lobate extension down the Priestcliffe syncline. Only two feet of tuff are seen at the appropriate position in the western mouth of Litton tunnel (SK 162729) but vesicular basalt and tuff totalling 20 feet (6·5 m) appear, resting directly on the Millers Dale Beds, at the mouth of Cressbrook Dale (SK 173726). Either these are a flow unrepresented elsewhere, or they cut out the Station Quarry Beds to rest conformably on Millers Dale Beds. In view of the thickness variations of the Station Quarry Beds in Cressbrook Dale, the latter alternative seems much more likely, and the Upper Millers Dale Lava is thus regarded as having been cut out by unconformity in the Litton tunnel area. The green clay filling the channel in the Litton Tunnel east cutting thus appears to be a relic of the lava.

In the Lees Bottom inlier, the Upper Fin Cop Lava of Bemrose (1907) appears at a position equivalent to the Upper Millers Dale Lava. It is seen to be 38 feet (11·5 m) thick on the south-western spur of Fin Cop. North-west of Black Rock Corner (SK 177700) the lava rests directly on the Millers Dale beds, but at the Corner itself a dolerite sill some 60 feet (18 m) thick appears. The contact between dolerite and basalt is a crumbly altered horizon, suggestive of subsequent intrusion, rather than a coarsely crystalline core to a flow. Both sill and lava die out westwards along the south side of the inlier, in Shacklow Wood, which contains an exposure inferred to be a flow-front facing westwards (SK 172702). The flow makes a brief re-appearance on the spur between Taddington and Dimmins Dales (SK 168705), with flow-fronts to both north and south. The flow and sill are both seen again in the northern margin of the inlier (SK 172714).

The three flow-fronts which together could be taken to indicate an irregular flow margin across the south-western part of the Lees Bottom inlier and the observations described above around Cressbrook Mill allow a new distributional analysis of the Upper Millers Dale Lava to be made; it can be inferred that a tongue, or complex of tongues, of this lava extend from Millers Dale to Lees Bottom under the Brushfield plateau. Furthermore, observations in old lead mines to the south of Lees Bottom, beneath Sheldon, allow a further extension of this flow to be outlined. At Field Grove Mine (SK 170695) the flow is absent, but in Sheldon Shaft (SK 176688) the flow (and sill?) are at least 138 feet (42 m) thick. The Magpie Sough (drainage level) (SK 176690 to 178696) was driven through basalts dipping gently northwards, but in the Magpie Mine Shaft (SK 172682) only a thin tuff at 480 feet (148 m) depth appears at the appropriate position. A rise in the True Blue Mine (SK 178680) penetrated the base of the flow. The flow was also seen, 110 feet thick (33 m), in Mogshaw Mine (SK 196678) and it appears to be the lowest of the three flows seen in Dirtlow Mine (SK 190685) still further east.

Neither the old mining records, nor the mines themselves, permit the recognition of the Station Quarry Beds sensu stricto, so that the Upper Fin Cop Lava, herein correlated with the Upper Millers Dale Lava, may either rest on these, or may be unconformable on the Millers Dale Beds. Alternatively, the Upper Fin Cop Lava may be a separate flow at the horizon of the unconformity recognized further west between the Station Quarry Beds and the Millers Dale Beds. The field evidence is incomplete but the present authors prefer the first alternative, the correlation with the Upper Millers Dale Lava.

The Monsal Dale Beds. Cope (1937) described the sequence above the Upper Millers Dale Lava in Millers Dale as composed of two units, the moderately thickly-bedded Priestcliffe Beds below, about 120 feet (36 m) thick, and a Cherty Limestone Series, nearly 400 feet (120 m) thick above. In Monsal Dale, however, it has not been possible to separate these two divisions, as thinly-bedded cherty limestone make up the bulk of the succession of some 500 feet (150 m) of beds. There is ample field evidence around the Brushfield plateau that there is a gradual change of lithofacies, with massive non-cherty limestones inter-fingering with the thin cherty beds. This is indicated diagrammatically in Fig. 2. A number of well-known coral and Gigantoproductid horizons in Monsal Dale form good marker beds, but most die out westwards and only by projection of their horizons, using strike and dip, can their approximate position in the Millers Dale succession be estimated. Some are of limited lateral extent within Monsal Dale as well. Defining the relationship of these bands is made more difficult by the absence over part of the area of the Upper Millers Dale Lava and also by the Station Quarry beds being generally indistinguishable from the rest of the Monsal Dale Beds. A more easily defined horizon from which to measure is the top of the Millers Dale Beds.

Recently, Stevenson and Gaunt (1971) have separated the Monsal Dale Beds into Upper and Lower divisions with a boundary at an Upper *Girvanella* Band or at the top of the Litton Tuff where the former is absent. No *Girvanella* Band has been found in the present study and the Litton Tuff can only be followed for a short distance so that such a subdivision is impractical in the Monsal Dale area.

At about 130 feet (42 m) above the Millers Dale Beds is the Upperdale Coral Bed, consisting of 3 feet (1 m) of massive limestone with abundant silicified *Lithostrotion junceum* and, less frequently, *L. martini* Edwards and Haime and *Diphyphyllum lateseptatum* McCoy. This is well exposed at track level in the cutting immediately west of the old Monsal Dale station (SK 177720), and is well seen below the lip of the lowest scarp in Hay Dale (SK 178722). A similar but less crowded bed occurs at the top of the Millers Dale beds where they are cut into by the channel at the east end of Litton tunnel. At the east end of the Cressbrook tunnel (SK 172724) the Upperdale Coral Bed has apparently slumped and has become mixed with the normally underlying Gigantoproductid bed, with discordant junctions both above and below the combined bed.

60 to 80 feet (18–24 m) higher is the more widely developed Hob's House Coral Bed, 8 feet (2·5 m) thick and crowded with large *Dibunophyllum bipartitum* (McCoy) and less common *Diphyphyllum lateseptatum*, *Lithostrotion martini* and *L. junceum*. This can be traced all round that part of Monsal Dale below Monsal Head, but it is cut out by an unconformity west of Hay Dale at SK 177723. It re-appears above the Litton Tuff at the head of Cressbrook Dale, apparently being interrupted by slight upwarping of the Longstone Edge monocline. Near Monsal Dale station the Hob's House Coral Band is seen in the cutting close to the fault at SK 179718, but westwards it is lost beneath the scree on the hillside. From the Hob's House landslip the coral bed can be traced along the face of the Fin Cop escarpment. It is lost in places beneath scree but re-appears some 50 feet (12 m) above the Upper Millers Dale Lava at Black Rock Corner. The Hob's House Coral Bed is also exposed in the western part of Shacklow Wood (SK 172701) and at the foot of Nettler Dale (SK 184696). At several of these localities the contact with the beds above is an angular discordance, though it has not been possible to demonstrate the nature of the unconformity suspected. On the basis of thicknesses, this horizon seems to be equivalent to the change from the Priestcliffe Beds to Cherty Limestones in Millers Dale. About the middle of the Monsal Dale Beds is the thick Litton Tuff. Although 100 feet (30 m) thick at Litton, this has thinned to 42 feet at the head of Cressbrook Dale, and is last seen on the western slopes of Wardlow Hay Cop (SK 178738). As it is about 200 feet (60 m) above the Millers Dale Beds, its relationship to the Hob's House Coral Bed becomes of importance. A coral bed a few feet above it on Litton Edge and at Peters Stone, just beyond the northern margin of the present area, was correlated with the Hob's House Band by Taylor (1957) and by Stevenson and Gaunt (1971) but the fauna contains a much higher proportion of colonial corals and some uncertainty must remain as the bed cannot be traced along the length of Cressbrook Dale.

At the head of Cressbrook Dale, a layer of basalt some 6 feet (2 m) thick, occurs some 30 feet (9 m) below the Litton Tuff, but it cannot be traced into the present area, although Stevenson and Gaunt (1971) have shown that it thickens rapidly northeastwards, beneath Wardlow Mires (SK 185755).

Although neither the Litton Tuff nor the Cressbrookdale Lava can be traced at outcrop in the Monsal Dale area, it is of interest to note that two volcanic horizons are known in the sub-surface in the south of the area. In the Dirtlow Mine Shaft (SK 192684) there are two "toadstones" each about 30 feet (9 m) thick, one of which makes a brief outcrop east of the farmhouse. These volcanic horizons have also been seen in shafts on Mogshaw Rake (SK 192678 and 195678) and clay-wayboards (degraded volcanic horizons) at about the appropriate position are known in the Magpie and True Blue Mine shafts (SK 173682, 178680). A thin tuff was noted near the top of the Priestcliffe Beds above Millers Dale by Cope (1937, p. 181). The true relationships of these scattered volcanic horizons are uncertain and correlation must depend on further underground mine exploration. Although no tuff is visible, the foot of the Hob's House landslip is at about the Litton Tuff horizon and a clay-wayboard at this horizon could well be the weakness causing the landslip.

In Monsal Dale itself, the Rosewood "Marble" (or Laminated Limestone) is the next higher marker bed in the Monsal Dale Beds. The Rosewood Marble is a slumped horizon about 3 feet thick. The thin laminae show a great variety of convolutions, overthrusts and minor folds, all on a miniature scale. Preliminary examination shows the orientation of the slumps to be highly variable, though there is a suggestion of movement down the present dip, i.e. into the Priestcliffe syncline. Further study of these is needed. The Rosewood Marble is 140 feet (42 m) above the Hob's House Coral Band in the cutting west of the viaduct (exposed at SK 182716) but only 85 feet (26 m) higher in the Hob's House landslip scar (SK 176713) a quarter of a mile to the south. The distinctive lithology can be traced southwards by means of fragments in the scree round Fin Cop into Ashford-in-the-Water (SK 189695), on the Arrock (SK 188691) and into Nettler Dale (SK 177693), where it was mined for ornamental purposes in the 18th and 19th centuries (Ford 1964). Northwards however, the Rosewood Marble Bed appears to die out. It is exposed near the foot of the road down into Monsal Dale (SK 183717) and scree fragments indicate its presence in the lower end of Hay Dale, but its only other known occurrence is in a faulted area at the western end of Longstone Edge (SK 187734).

About 180 feet (55 m) above the Rosewood Marble bed is the White Cliff Coral Bed. Strictly two beds, a few feet apart, these have abundant corals including *Lonsdaleia duplicata* (Martin), *Palaeosmilia regia* (Phillips), *Diphyphyllum lateseptatum* and *Orionastrea placenta* (McCoy). The latter allows correlation with the *Orionastrea* band in the Eyam area to the north-east (Shirley and Horsfield 1945), Stevenson and Gaunt 1971). Taylor (1957) distinguished two *Orionastraea* bands close together. In Monsal Dale, however, the two beds are only a few feet apart in White Cliff, and they can be followed along the top of the slopes around Monsal Head and north of Fin Cop but they have not been seen elsewhere. The White Cliff Coral Bed is not seen to extend much to the west beyond the fault above the Hob's House landslip, and it is too high stratigraphically to outcrop on the Brushfield plateau.

At Crossdale Head Quarry (SK 183831) an isolated exposure of a coral bed with abundant *Dibunophyllum bipartitum* may be equivalent to the White Cliff Coral Bed, but it is in faulted ground and its fauna is dominated by Clisiophyllids. Both Cope (1933) and Taylor (1957) correlated this bed with the Hob's House Coral Bed, but later Cope (1958, 1967) referred it to the White Cliff Coral Bed, though Stevenson and Gaunt (1971) appear to accept Cope's earlier suggestion (1933).

A number of scattered localities have the same appearance and contain the same corals on the plateau south of Monsal Dale, around Sheldon. Although the band cannot be traced directly in the field, scattered blocks in walls suggest that its outcrop is much as shown on the map (Fig. 1).

The total thickness of the Monsal Dale Group, if the Upper Millers Dale Lava and the Station Quarry Beds are included, reaches 660 feet (200 m) but there is thinning in a south-easterly direction and between Lees Bottom and Ashford the total thickness is probably not more than 400 feet (120 m).

<u>The Eyam Group</u>

The Ashford Beds. Definition of the top of the Monsal Dale Beds and the base of the Ashford Beds raises problems. To the north-east of the present area the Monsal Dale Beds are covered unconformably by the Eyam Limestones, of crinoidal mound and flat-reef facies (Shirley and Horsfield 1945); Stevenson and Gaunt 1971). These are a small but variable distance generally about 30 feet (9 m) above the *Orionastrea* band and in places cut it out by unconformity on the western end of Longstone Edge, according to Shirley and Horsfield. This "reef" facies of the Eyam Limestones has not proved to be present around Monsal Head and no unconformity has been seen. The lower slopes of Longstone Edge do, however, show an apparent transition from one lithofacies to the other, in much faulted ground. The crinoidal mound facies reappears in the extreme south-west of the area, between Sheldon and Monyash, though neither an unconformity nor the *Orionastrea* band has been detected before Lathkill Dale is reached (Shirley 1958). The intervening area contains a thin-bedded "basinal" equivalent, with two marker horizons. These basinal beds were referred to as the Ashford Beds by Cope (1958) though at present no basal boundary to these can be mapped and the line on the map has been inserted purely on the geometrical relationships of the marker beds.

The Ashford Beds contain a distinctive bed crowded with *Spirifer trigonalis* (Martin), exposed in the Headstone cutting (SK 188714) and on the Arrock at Ashford (SK 192694). Rarely more than a few inches thick, this bed can be traced across the dip slope of Fin Cop by blocks in walls, and it is exposed briefly in Little Lane (SK 189705). It can also be traced along the strike to the north of Great Longstone, east of the area under consideration. The bed is generally less than 8 inches (20 cm) thick but crowded with single valves of *S. trigonalis* and other less common brachiopods, such as *Martina glabra* (J. Sowerby), *Productus productus* (Martin), and *Camarotoechia pleurodon* (Phillips).

By geometrical construction the Spirifer Bed is 280 feet above the Rosewood Marble, in Headstone cutting (i.e. 100 feet (30 m) above the White Cliff coral bed which is not exposed owing to the railway tunnel). On the Arrock, at Ashford, it is 240 feet (73 m) above the Rosewood Marble. On this basis the base of the Ashford Beds must lie in the 100 feet (30 m) of beds above the White Cliff Coral band, which can only be traced over a limited area in Monsal Dale. By projection, however, the base of the Ashford Beds is approximately equivalent to the Black Marble Beds in the Arrock Mine (Ford 1964). Only about six feet thick, the Black Marble Beds can be traced for a limited distance around Ashford, but on the adjacent higher ground their outcrop is marked by rottenstone (Ford 1967) and a line of workings can be traced largely by blocks in the walls, across Pennyunk and Greengate Lanes on the dip-slope of Fin Cop. Other occurrences of rottenstone in the walls and turf are around Dirtlow Farm (SK 187687) and near Mogshaw Mine (SK 182676). The base of the Ashford Beds is accordingly drawn just above this horizon.

The Black Marble beds at Ashford are crowded with small corals of the Cyathaxonid phase. Used to define a D_3 zone by Sibly (1908), these are here regarded only as a special faunal phase of upper D_2. The corals have been studied by Cockbain (1957).

A few feet below the Spirifer Bed is another distinctive marker, a thick bed of chert. Generally around 6 to 10 feet (2-3 m) thick, this has a lithology identical to the better-known Bakewell Chert, mined 2 miles to the east. The thick Chert has been both quarried and mined on the Arrock (SK 194695) and in the top of the Rookery Plantation (SK 192697). The Bakewell Chert is thought to be the same bed, and it is notable that a bed with *Orionastrea* was noted below it in the Endcliff at Bakewell (SK 213699) by Cockbain (1957) indicating the same relationship with the base of the Eyam Limestones as in the Ashford area. The Chert bed is poorly developed in the Headstone cutting and not seen to outcrop elsewhere in the Monsal Head area. It has not been traced on to the higher ground southwest of Ashford, but it is present again near Green Cowden Farm to the south-east (SK 199678).

The chert formerly worked at Chertpit Plantation (SK 187729) is in fact a crystalline quartz rock associated with mineralization and is in no way related to the Bakewell Chert.

Some 15 feet (4·5 m) beneath the Chert in the Headstone cutting there is a distinctive limestone conglomerate, with small limestone pebbles up to half an inch long. The conglomerate is about 3 feet (1 m) thick but it has not been seen elsewhere. A bed with scattered rootlets and coaly markings is present high in the tunnel mouth, and may be the equivalent of the Coombsdale Quarry coal near Stoney Middleton (SK 233748).

The Ashford Beds are thus taken as 100 feet (30 m) thick up to the Spirifer bed and a further 45 feet (14 m) of limestones are seen above this in the Headstone Cutting below thick shales, giving a total of 145 feet (44 m).

Viséan Shales: At the eastern end of the Headstone cutting, the highest limestones of the Ashford Beds are seen to be interleaved with and overlain by shales. The highest shale within the limestones is about 10 feet (3 m) thick and it yields many crushed fossils including abundant *Chonetes* sp., trilobites, ostracods and goniatites including *G. granosum* diagnostic of the P_{2a} subzone (Cope 1967, p.3). The shales overlying the limestones are seen to a thickness of some 20 feet (6 m) and yield a more sparse fauna. As no discordance is visible it seems that these too are of upper Viséan age. No definition of the top of the Viséan is possible owing to the drift cover of higher beds.

Regional Correlation

Correlation of the Monsal Dale succession with that to the west in Millers Dale, has already been discussed. To the north the Monsal Dale Beds have been mapped by Stevenson and Gaunt of the Geological Survey on the 1 inch to 1 mile Sheet 99. Their correlation charts and discussion only serve to show the difficulties inherent in attempting correlation within a complex of highly variable facies. Lithological types, Gigantproductid beds, coral beds and volcanic horizons are all impersistent and lenticular. Correlations are too often liable to be little more than of similar lithofacies rather than continuous horizons. As Taylor (1957) noted, it is unwise to make too emphatic a correlation until a full sedimentological analysis has been done. The only marker beds which seem to be reasonably secure between Monsal Dale and The Eyam-Stoney Middleton area are the Hob's House Coral Band and the *Orionastrea* Band, and of these even the former raises some doubts as discussed earlier in this paper. The two coral bands between these recognized in the Eyam area containing *Londaleia duplicata* and *L.floriformis* have not been recognized in Monsal Dale, though scattered corals occur in limestones at about this level. The Rosewood Marble Bed of Monsal Dale has not been seen in the area to the north.

As with the Monsal Dale Beds, detailed correlation of the Ashford Beds with the limestones of the Eyam Group in the area to the north is not possible. No single horizon seems to be common to both Monsal Dale and to the sections described by Stevenson and Gaunt (1971). To the south, a broad correlation may be made with the succession in the Lathkill Dale and Monyash area as described by Shirley (1958), though much detailed work remains to be done. Broadly, the Monsal Dale Beds appear to be equivalent to the Lathkill Limestones of Shirley (1958) and the Ashford Beds may be equated with the Cawdor Beds. Apart from the coral bed with *Orionastrea placenta* mapped high in the Upper Lathkill Limestones by Shirley, no marker beds have been found to be common to both areas and correlation is largely on lithological types and the similarity of the facies interdigitation in both Lathkill and Monsal Dales.

Sedimentological notes on the Monsal Dale and Longstone Beds

As indicated on Fig. 2 and discussed briefly in the foregoing, there is a gradual facies change from the more massive Priestcliffe Beds and the Cherty Limestones in the west to the thinly-bedded Monsal Dale and Ashford Beds in the east. This is seen largely as an inter-fingering of thick limestones with abundant *Gigantoproductus giganteus* (J. Sowerby) with the thin fine-grained limestones and shale partings. Attempts at correlation within the region by Shirley and Horsfield (1945), by Taylor (1957) and by Cockbain (1957) all using *Gigantoproductus* bands have led to contradictory results. In the present study, wherever such a band was found its position in relation to the nearest marker bands was carefully plotted and thicknesses of inter-vening beds were measured. These observations have shown that there is in fact a variable number of lenticular *Gigantoproductus* beds. The railway cutting west of the Monsal Dale viaduct (SK 181717) shows two such beds, and in this clear section both are seen to be part of slumped horizons.

The *Gigantoproductus* valves are frequently separated and they are randomly orientated in a calcarenite matrix, which shows some evidence of grading. The base of the beds are channeled into the underlying thin dark limestones. These too show small channels at the base. The aspect of such beds is one of turbidite deposition. To the west in Millers Dale the equivalent beds are full of *Gigantoproductus* in life position, and all variants from life position to turbidite disorientation can be seen along the southern slopes of Monsal Dale, opposite Cressbrook, as noted by Walkden (1970). Shirley and Horsfield (1945) noted similar "Broken shell" horizons in the Eyam area to the north.

Slumped horizons which do not involve *Gigantoproductus* are also common, one large slump is just outside the east end of Cressbrook tunnel (SK 172724). The Rosewood Marble is a thin, slumped horizon of wide extent discussed earlier. The lower part of the Ashford Beds in the Headstone cutting show frequent slumps near the tunnel mouth. Among these are slumps which are deformed round apparently early-formed chert nodules. A slumped bed is also present in the roof of the Arrock Black Marble Mine. A full study of these slumps still needs to be made, but the impression gained is one of movement into the Priestcliffe syncline from all sides, but particularly from the west, i.e. down the plunge.

A number of the thin dark limestones of the Monsal Dale Beds contain *Lingula* or less commonly, *Orbiculoidea*, usually as single valves and certainly not in life position. These beds are well exposed in the roadside quarry below Monsal Head (SK 183717). As these are unlikely to be benthos of a turbidite environment and are equally unlikely in the more turbulent waters of the nearby massive flanking facies with *Gigantoproductus*, it seems possible that they represent epi-plankton which have fallen from drifting sea-weed.

Apart from the slumps and channels, the Monsal Beds show a number of marker coral beds. As already noted these have discordances above them, and these too may represent the onset of turbulent conditions and bottom-scouring after the deposition of the corals. The large solitary corals in the coral beds, particularly in the Hob's House Coral Bed, are lying prone, not in life position, and their epithecae are frequently abraded, so that an element of transport, possibly in turbid conditions, from adjoining shallow waters may be deduced. The solitary corals are sometimes seen to lie on top of colonial corals apparently in life position, though a hunt will still reveal a few colonies inverted, again suggesting transport. The coral beds also show sharp bottoms in places, supporting the concept of bottom-scouring before deposition, though commonly the corals are only in the top part of a massive bed a few feet thick. This is taken to suggest that the corals may have "floated" in the upper part of turbidity currents. Collectively there is a suggestion of cyclicity; with members developed in upward sequence:- (1) dark thinly-bedded limestone; (2) light massive limestone; (3) coral bed; (4) scoured surface; and return to member 1. This type of sequence is only to be expected in such circumstances and it is doubtful if any regional significance can be attached to it.

The facies changes described above indicate that the regional distinction between the reef facies of the Eyam Limestones and the thin limestones of the Ashford Beds seen in the latest Viséan were already being manifest in earlier D_2 times, and that the area of the Priestcliffe syncline was an area of relatively deeper water at the time of deposition. Taylor's unpublished work (1957) suggests that there may be similar "transported" facies in the down-warped area of Coombs Dale, to the north of the Longstone Edge monocline.

Diagenetic changes in the thinly-bedded limestones differ from those of the surrounding massive limestones in the much greater abundance of chert. Nodular and lenticular masses of black chert are developed throughout the thinly bedded limestones of both Monsal Dale and Ashford Beds. Silicification in the coral beds is different, being largely metasomatic replacement of the coral tissues. In the *Gigantoproductid* beds silicification is shown mainly by beekite sheaths around the brachiopod valves. The Bakewell chert is a silicification complex which requires a separate study. Nodular and metasomatic phases are present, and many vughs have a chalcedonic lining (cf. the chert at Ashford described by Orme and Ford, 1971). Apart from these, most of the Bakewell chert is laminated, with quartz layers of differing grain sizes apparently reflecting original depositional layering. The various types of chert and silicification are well displayed in the old railway cuttings.

Structure

Three main structural elements are depicted on the structure contour map (Fig. 3). From north to south these are the east-west Longstone Edge monocline, the Priestcliffe syncline, and the Taddington-Bakewell anticline. The first of these, the Longstone Edge monocline, has been described by Shirley and Horsfield (1945) and need not be described further so far as the north-east of the area is concerned. From Cressbrook Dale westwards, however, this monocline is replaced by the Ravensdale Fault, with a downthrow to the south of 200 feet (60 m) in Cressbrook Dale. The fault also terminates the outcrop of the Tideswell sill further west. The sinuous course across Cressbrook Dale clearly indicates that it is a reversed fault dipping northwards, at angles between 50° and 65°, showing the same sense of movement as the monocline. On the western end of Longstone Edge the fault splits into a number of lesser faults, but no evidence has been found for the north-south fault mapped by Shirley and Horsfield (1945).

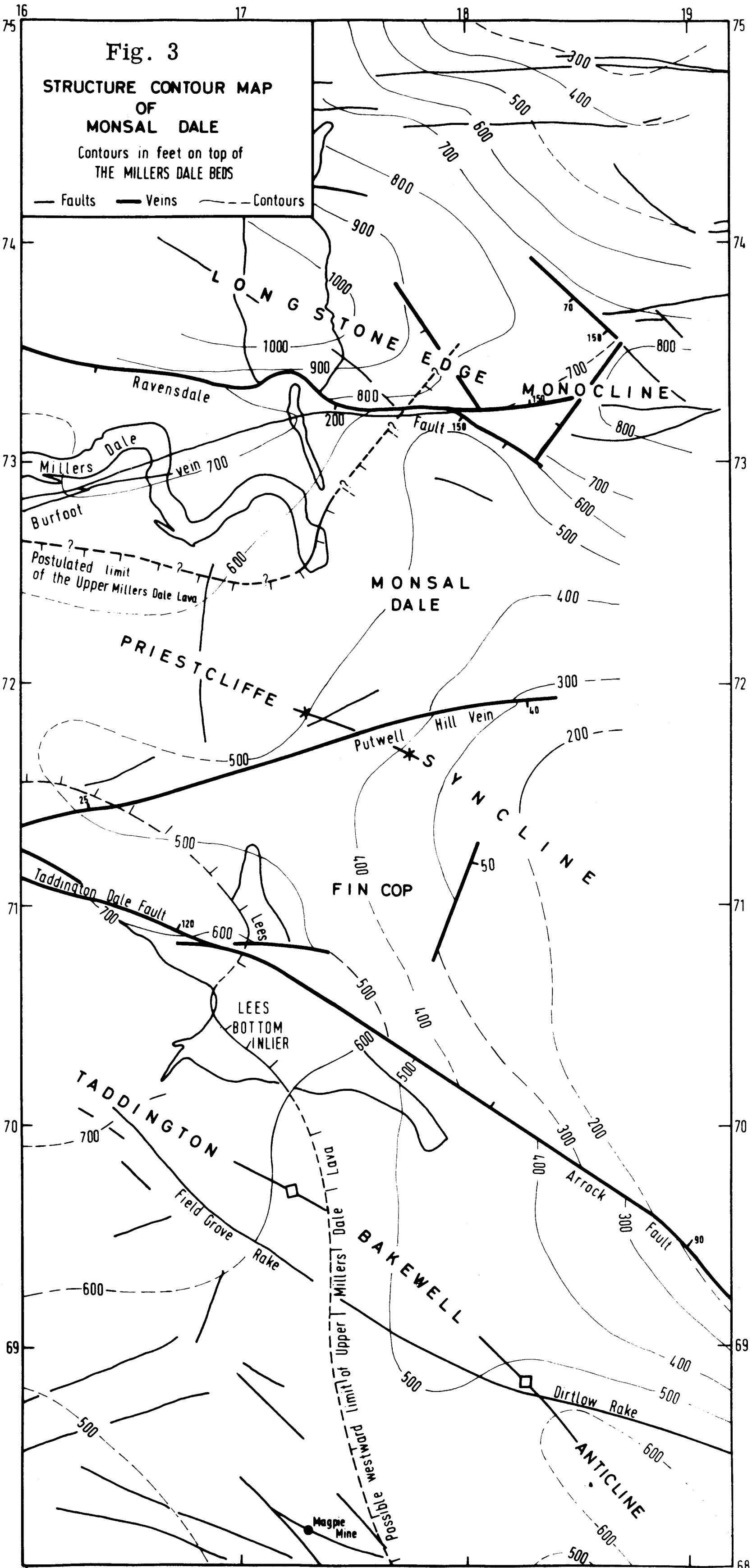


Fig. 3

STRUCTURE CONTOUR MAP OF MONSAL DALE

A small area of upper Monsal Dale Beds is faulted down into the monocline on Rolley Low (SK 186735), and this is bounded to the north-west by a fault downthrowing south-west 150 feet (45 m). All these faults are mineralized, indicating a phase of tensional opening subsequent to the compressional reversed fault phase. Horizontal slickensides indicate a phase of wrench faulting also.

The Priestcliffe syncline proper lies to the west of the Monsal Dale area and appears to pass eastwards into the Chatsworth syncline affecting the Millstone Grit around Baslow and Calver. The name "Priestcliffe syncline" is here extended to include the Monsal Dale area. It has also been called the Bakewell syncline, but this name is inappropriate as an upwarp at Hassop station lies between the syncline and Bakewell.

The Priestcliffe syncline is crossed by a number of faults. The most northerly of these is the Putwell Hill vein which crosses the dale near Monsal Dale station with a WSW trend. Here it has a southerly downthrow of some 40 feet (12 m) but when traced westwards to Brushfield (SK 165714) it has a northerly downthrow of 25 feet (8 m). A SSW fault on Fin Cop (SK 174716) downthrows eastwards by 50 feet (16 m). The main fault crossing the syncline is that trending north-west from the Arrock at Ashford (SK 191693) for $2\frac{1}{2}$ miles towards Taddington. The downthrow is about 90 feet (18 m) to the north-east on the Arrock and about 100-125 feet in the same direction in Taddington Dale. It splits south of Brushfield and is less easy to define. The structure contours suggest a slight monoclinal flexure along the Arrock Fault, and there is some evidence indicative of thinning towards this flexure. Several parallel minor faults are to be found on Fin Cop. The fault is mineralized through most of its length. About half of a mile to the southwest, the parallel mineral vein system including Dirtlow and Fieldgrove Rakes is probably a fault, but the throw cannot be determined owing to the lack of marker beds. The veins around Magpie Mine also show evidence of faulting but again the throw cannot be determined, though it is apparently small.

The Priestcliffe syncline is diversified by a slight doming in the Lees Bottom inlier. The crest of this has almost horizontal beds in the mouth of Dimmins Dale (SK 169703), and the dying out of the Upper Millers Dale Lava flow here suggests that the dome was syndepositional. A more prominent structure occurs in an analogous position east of the present area, near Hassop station.

West of the present area, Cope (1937) described the Taddington anticline but this soon becomes indistinct and merges into the Taddington Dale fault and the domed Lees Bottom inlier. The Priestcliffe syncline is flanked to the south by a broad upwarped area forming part of the Bakewell anticline, which falls away southwards into the Lathkill syncline.

The structure of the area has been depicted on a structure contour map constructed for the only horizon clearly recognizable throughout the area, the top of the Millers Dale Beds. Although with limited outcrop in the south, its position can be estimated within insignificant limits from marker beds in the Monsal Dale Beds and from mine-shaft sections.

As has been indicated above, there is considerable evidence for the incipient phases of these structures having effects on contemporary deposition. The dying out of some lavas and the thinning of the Monsal Dale Beds appear to take place as structural highs are approached. For example, the Lees Bottom inlier shows slight doming which appears to have controlled the south-west flank of the Upper Millers Dale lava flow. The eastward thinning of the Monsal Dale Beds may reflect the direction of transport of the turbidite phase, with the thick proximal part in Monsal Dale itself, and the distal part around Ashford. Further studies of the sedimentology are needed.

The incipient tectonic phases may be summarized thus:-

(a) Post D_1 - pre D_2; as shown by the slight unconformity beneath the Station Quarry Beds. A gentle upwarping of the Longstone Edge monocline affected the distribution of these, the subsequent Upper Millers Dale Lava and some of the coral bands.

(b) Post D_2 - pre P_2; as shown by the unconformity beneath the Eyam Limestones in the northern extremity of the area, though no unconformity has been detected in the Monsal Dale area. Some evidence of slight emergence is shown by the rootlet markings and the limestone pebble bed in the Headstone Cutting.

No evidence of a post P_2 - pre E_1 phase of movement has been found.

Following the incipient stages, the main tectonic phases have been the Armorican movements, responsible for the main folding along east-west trends and presumably also responsible for the compressional reversed phase of the Cressbrook Dale fault. Compressional, wrench faulting followed by a tensional phase allowed mineralization, though there is ample evidence that this was poly-phase and overlapped with repeated movements in a lateral sense. There is no direct evidence for the age of mineralization though it is generally regarded as being of Triassic date (Ford 1969).

The mineral veins are largely seen on the anticlinal areas where crestal tension may have been a factor, though the apparently poor development in the syncline is perhaps illusory owing to the relatively poor exposures.

N.J.D. Butcher, B.Sc.,
T.D. Ford, B.Sc., Ph.D., F.G.S.,
Geology Department,
University of Leicester,
Leicester, LE1 7RH.

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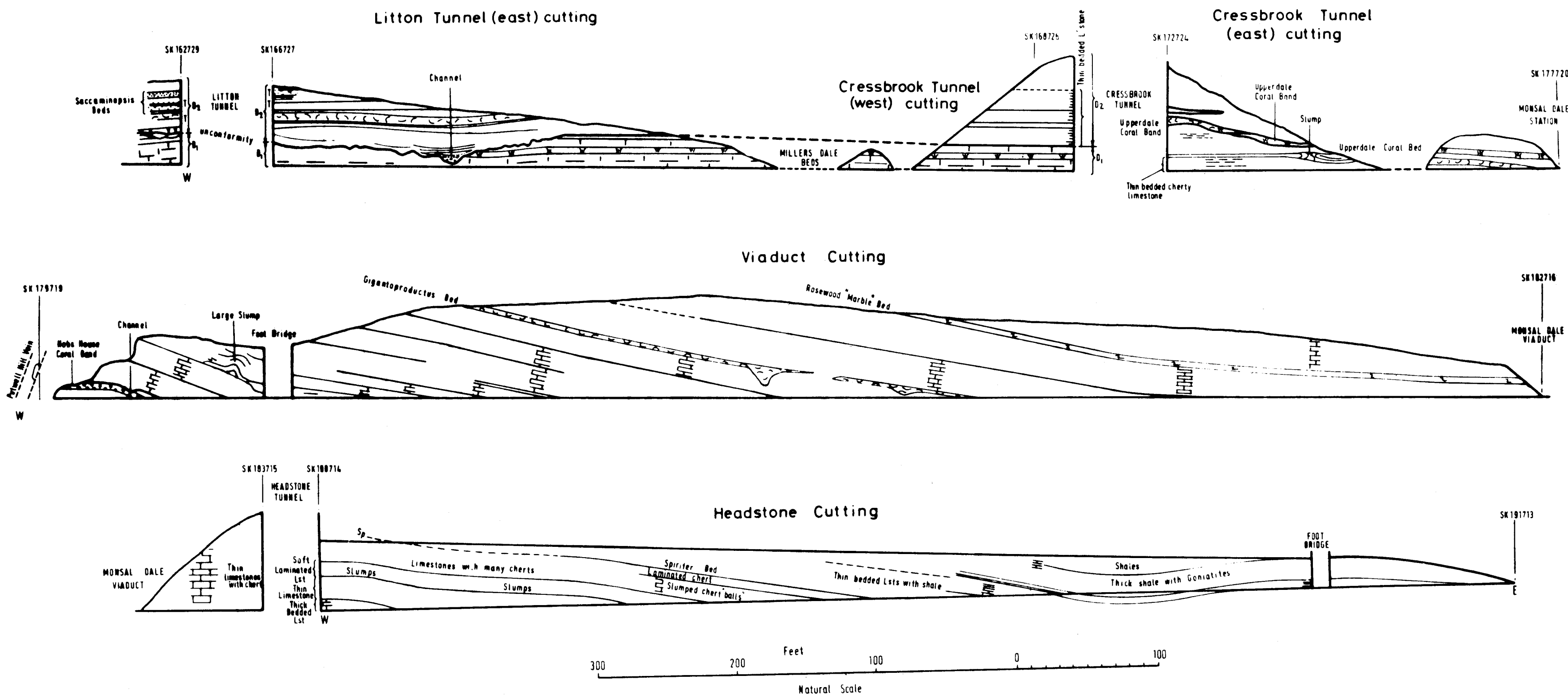
Appendix

Monsal Dale Cuttings Excursion

With the abandonment of the railway through Monsal Dale, the cuttings provide sections which make a most instructive excursion (fig. 4). The regional eastward dip allows the sections to be approached from either end, working downwards going west from Monsal Dale, or upwards going east from Millers Dale. The three railway tunnels are brick-lined, so that there are gaps in the succession. Each of the tunnels is about 500 metres long so that lighting is desirable to walk through; otherwise they must be passed by footpaths on the surface. The profiles illustrated in Fig. 4 are compounded from both north and south walls of the cuttings. The beds illustrated are present in both walls but are sometimes best seen on the south and at other points best seen on the north.

The Headstone Cutting (SK 191713 - 188714) may be reached by a footpath from Little Longstone. In it there are exposed about 145 feet (44 m) of Ashford Beds. At the extreme eastern end there are shales with calcareous nodules, and some evidence of mineralization. Under the bridge the first limestone beds roll through a small shallow syncline and a few yards to the west some 10 feet (3 m) of shale appears. The basal part of this yields many crushed fossils, mainly brachiopods and ostracoda, with some goniatites. About half-way

Fig. 4.



Litton Tunnel (east) cutting
SK162729
SK166727
Saccaminopsis Beds
LITTON TUNNEL
unconformity
Channel
W
MILLERS DALE BEDS
Cressbrook Tunnel (west) cutting
SK168726
Thin bedded L'stone
CRESSBROOK TUNNEL
Cressbrook Tunnel (east) cutting
SK172724
Upperdale Coral Band
Slump
Upperdale Coral Bed
Thin bedded cherty limestone
SK177720
MONSAL DALE STATION
Viaduct Cutting
SK179719
Hobs House Coral Band
Channel
Large Slump
Foot Bridge
Gigantoproductus Bed
Rosewood "Marble" Bed
SK182716
MONSAL DALE VIADUCT
Headstone Cutting
SK183715
SK188714
HEADSTONE TUNNEL
MONSAL DALE VIADUCT
Thin Limestones with chert
Soft Laminated Lst
Thin Limestone
Thick Bedded Lst
Slumps
Limestones with many cherts
Spirifer Bed
Laminated chert
Slumped chert 'balls'
Thin bedded Lsts with shale
Shales
Thick shale with Goniatites
FOOT BRIDGE
SK191713
E
Feet
300
200
100
0
100
Natural Scale

along the cutting is the Spirifer Bed, about 8 inches (20 cm) thick, and below it the rather inconspicuous Bakewell Chert, some 4 feet (1·2 m) of laminated siliceous rock. Many layers of black nodular chert occur in the beds below and on the north side of the cutting ball-shaped masses of chert show deformed slumps around them. The lowest beds seen are rather crumbly limestone with numerous small slumps. Fallen blocks around the tunnel mouth show rootlet markings.

Headstone Tunnel West cutting (SK 18715). The short cutting shows thin-bedded limestone alternating rapidly with layers of black chert over a thickness of some 50 feet (16 m) of the Monsal Dale Beds. The White Cliff Coral Bed may be found high above the tunnel mouth, almost at the lip of the escarpment.

The Monsal Viaduct cutting (SK 182716 - 179719), west of the viaduct, shows a most interesting section in the middle part of the Monsal Dale Beds. Almost the first bed seen on the south side is the Rosewood Marble Bed. About 3 feet (1 m) thick, it is somewhat hidden in the undergrowth, but rises gently along the cutting and its convolutions and slumps make a distinctive feature. About halfway along the cutting, a lenticular bed with many disoriented and separated valves of *Gigantoproductus* is seen to fill a channel on the north side of the cutting, and opposite it there are two small channels at the bases of thin dark limestones, presumably of turbidite origin. A little further along, a second channel with *Gigantoproductus* is seen on the north wall. Beneath the bridge, the dip steepens, and many joint faces are seen to be mineralized. High in the south wall is a large slump structure, and low down at the end of this face the Hob's House Coral Bed appears, though much obscured by mineralization. The top of the Coral Bed is cut into by a channel at one point. A few yards further is an opening (care!) into the Putwell Hill vein (sometimes known as Putty Hill Vein). Some 6 feet (2 m) of radiating crystals of dirty white calcite remain in place.

Monsal Dale Station cutting (SK 176721). Immediately behind the site of the station is a small exposure of Pleistocene till, apparently resting on a terrace of the River Wye. To the west of the station a low crag extends for some hundred yards alongside the old track on the south side. This shows the Upperdale Coral Bed about a foot thick in the upper part, consisting of abundant silicified *Lithostrotion junceum*, and a turbidite bed of disoriented Gigantoproductids in the lower part. These beds gradually rise westwards and reappear in the Cressbrook tunnel east cutting.

Cressbrook Tunnel West cutting (SK 168726) shows a section also containing a bed with many silicified *L. junceum*, but this is within the top of the massive Millers Dale Beds, and the base of the thin-bedded Monsal Dale Beds is a few feet higher up. The junction is sharp but not obviously discordant.

A few paces west of Cressbrook tunnel, there is a fine viewpoint looking down into the narrow part of Millers Dale known as Water-cum-Jully. Cliffs of massive Millers Dale Beds form the walls below railway track level. Away to the left is a mound-like structure in the top of the massive beds. To the right they dip beneath the Cressbrook volcanics at the foot of Cressbrook Dale.

The Litton Tunnel East cutting (SK 166727) shows the "wash-out" or channel, described by Cope (1933), in the south face. Here the basal Monsal Dale Beds, probably the Station Quarry division, (if *Saccaminopsis* beds are present they are inaccessible) rest on a greenish clay with limestone pebbles in the channel bottom. The channel is cut into the top of the Millers Dale Beds. Above the channel, thin-bedded cherty limestones are also discordant on the Millers Dale Beds. Some 20 feet (6 m) above the track are two thin Gigantoproductid turbidite beds, and two thin clay way-boards representing tuffs.

The Litton Tunnel West cutting (SK 162729) was described as Section I by Cope (1937). It shows an erosion surface on the top of the Millers Dale Beds, with a tuff over two feet thick above the tunnel mouth, which was not recorded by Cope as it was then walled up. This tuff is believed to be at the horizon of the Upper Millers Dale Lava and the Cressbrook volcanics. Above it are some 15 feet (5 m) of Station Quarry Beds with *Saccaminopsis* bands, a Gigantoproductid turbidite and another thin tuff.

Some 500 metres west of Litton tunnel is the Litton cutting described by Cope (1937), which shows the flow-front of the Upper Millers Dale Lava, here very much brecciated. The excursion may be continued into the Millers Dale Limeworks quarries above the track to the south and into Millers Dale Station Quarry, using the sections provided by Cope (1937).

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