THE LOWER CARBONIFEROUS VOLCANIC ROCKS OF THE ASHOVER AREA, DERBYSHIRE

by

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Summary

This paper describes the varied succession of basalts, basaltic breccias and tuffs revealed in boreholes and at outcrop around Ashover, Derbyshire. These rocks represent the thickest Lower Carboniferous volcanic sequence recorded in the English Midlands and indicate the presence of a large volcanic centre to the east of those previously described on the Derbyshire limestone platform.

Introduction

The village of Ashover (SK 3463) is situated 5 km east-north-east of Matlock in east Derbyshire. It lies on the axis of the Ashover-Crich anticline which is aligned NW-SE (text-fig. 1). The anticline exposes Dinantian limestones (Brigantian stage), in the form of an inlier within shales and sandstones of the Millstone Grit Series (text-fig. 2). The inlier lies to the east of the main Dinantian limestone outcrops of the Derbyshire Dome. The lowest stratigraphical unit exposed at the surface in the centre of the inlier is the Ashover Tuff which has an outcrop area of approximately 0.4 km^2 and represents the uppermost volcanic unit of the Dinantian succession. However, boreholes sunk for the Clay Cross Company, and for the Institute of Geological Sciences (IGS) in 1955 and 1956 revealed a thick succession of basalts, basaltic breccias and tuffs at depth (text-figs. 3 and 4). Whilst the presence of volcanic rocks in the Matlock and Castleton areas of the Derbyshire Dome is fairly well known (e.g. Arnold-Bemrose, 1894, 1907; Wilkinson, 1967), the sequence at Ashover has not been fully described. This paper links information derived from the Ashover boreholes to data collected during a recent examination of surface outcrops and temporary exposures. It attempts to provide a complete and interpretative account of the Ashover Volcanics in the context of the Lower Carboniferous palaeogeographical setting, even though the base of the volcanic rocks has not yet been reached by bore-holes.

Previous work

Previous descriptions of the Ashover Volcanics have been limited to general accounts on the geology of the area based on surface exposures (Sweeting, 1946; Sweeting & Himus, 1946; Neves & Downie, 1967; and Smith *et al.*, 1967). Early short contributions in regional studies of

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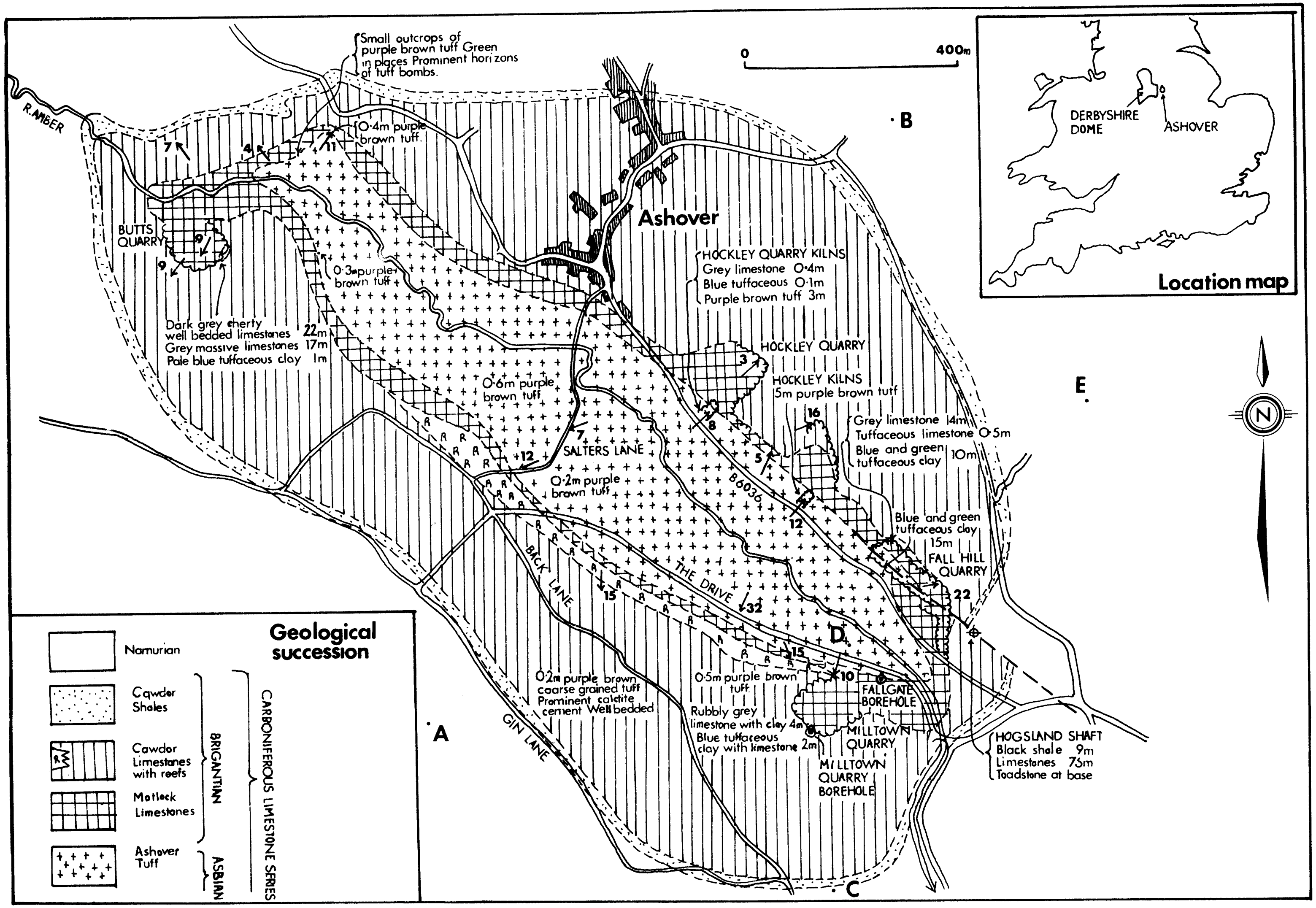
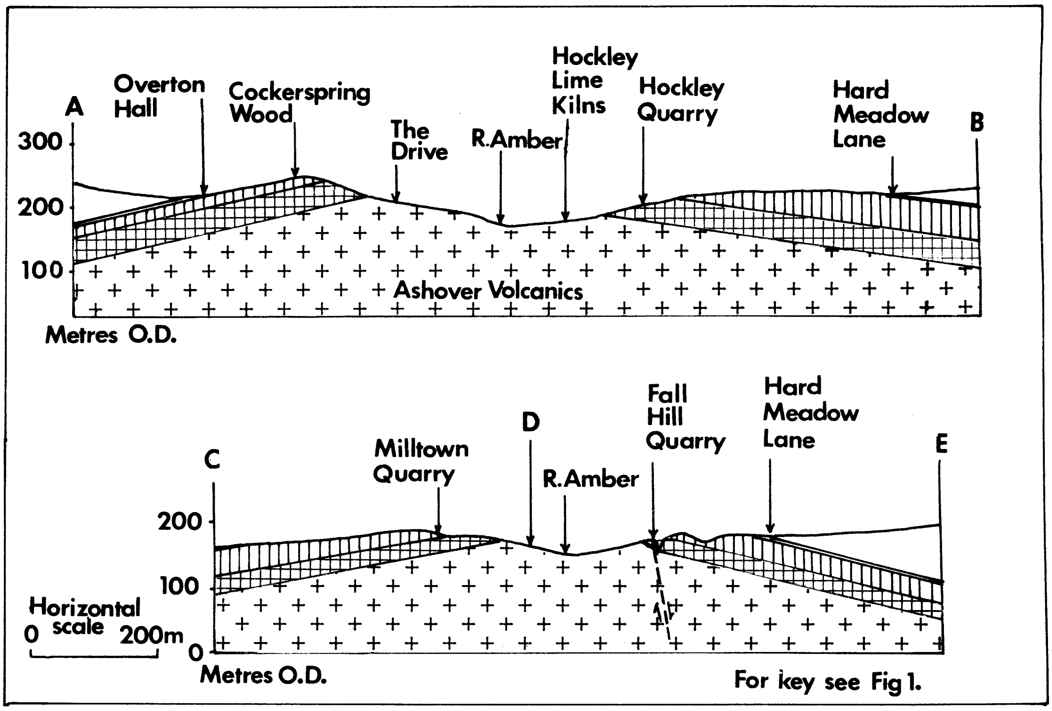
1980, pp.11-28, 9 text-figs.



Text-fig.1. Geological map of Ashover, Derbyshire



Text-fig. 2: Geological sections across the Ashover inlier. (Points A-E shown on text-fig. 1).

Lower Carboniferous volcanics were made by Arnold-Bemrose (1894 & 1907). In addition, a fairly detailed description of the borehole material drilled in the IGS programme of 1955 was published by Ramsbottom *et al.* (1962) in a work emphasising the petrographical and geochemical aspects of the succession.

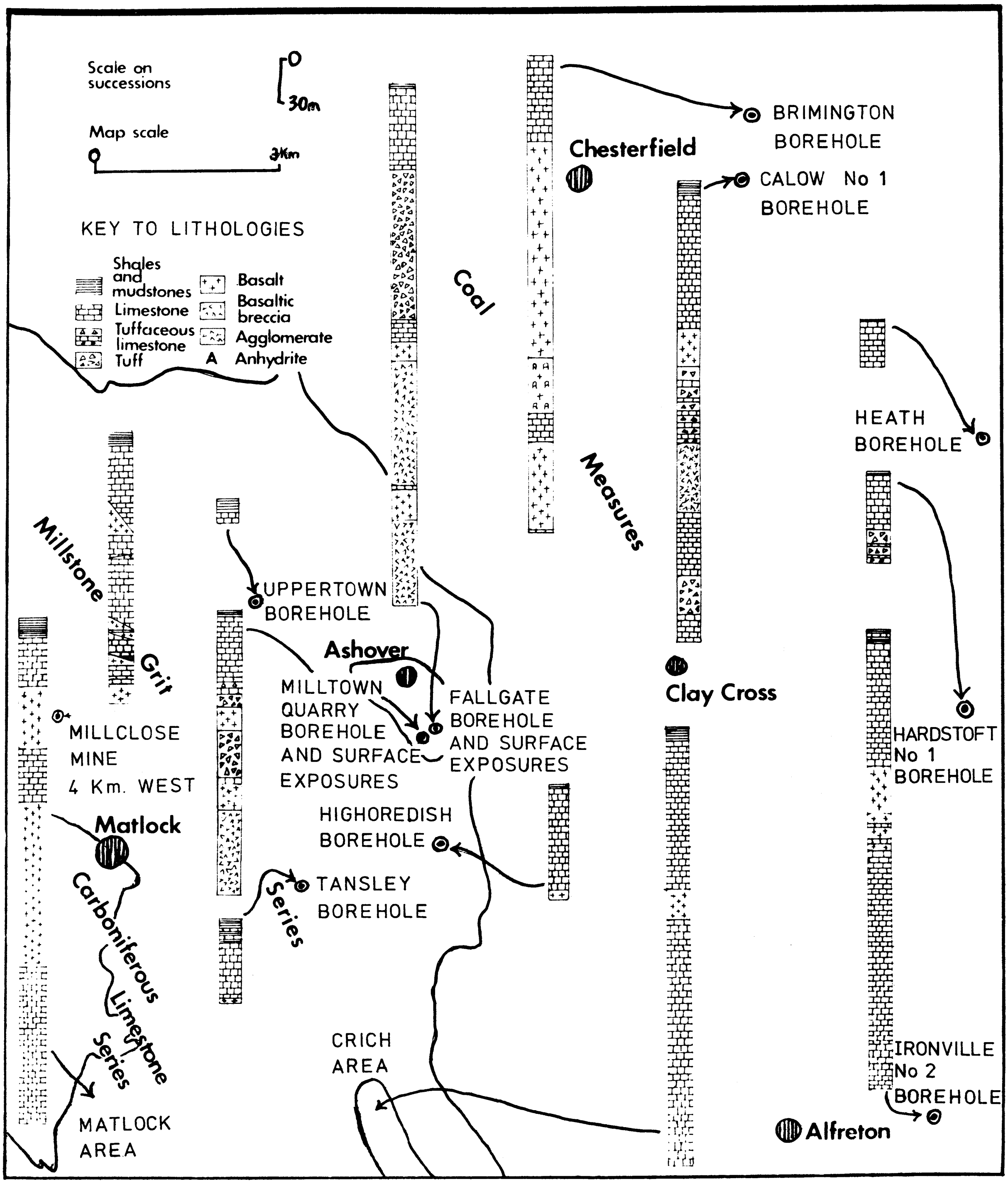
Palaeoenvironmental context

The Ashover Volcanics were deposited on a platform of shallow marine carbonate deposition as indicated by the nature of adjacent limestones. The platform covered much of the area of the Derbyshire Peak District and was flanked by deeper basinal areas of thick mud deposition (text-fig. 5). To the south of the platform this is represented by the Widmerpool Gulf formation of siltstones, to the north by the Edale Gulf shale deposits, and to the west by shales and sandstones exposed around Mixon. A transitional shelf margin characterised by reefs was present in the Wirksworth and Longnor areas (Wolfenden, 1958; Walkden, 1970).

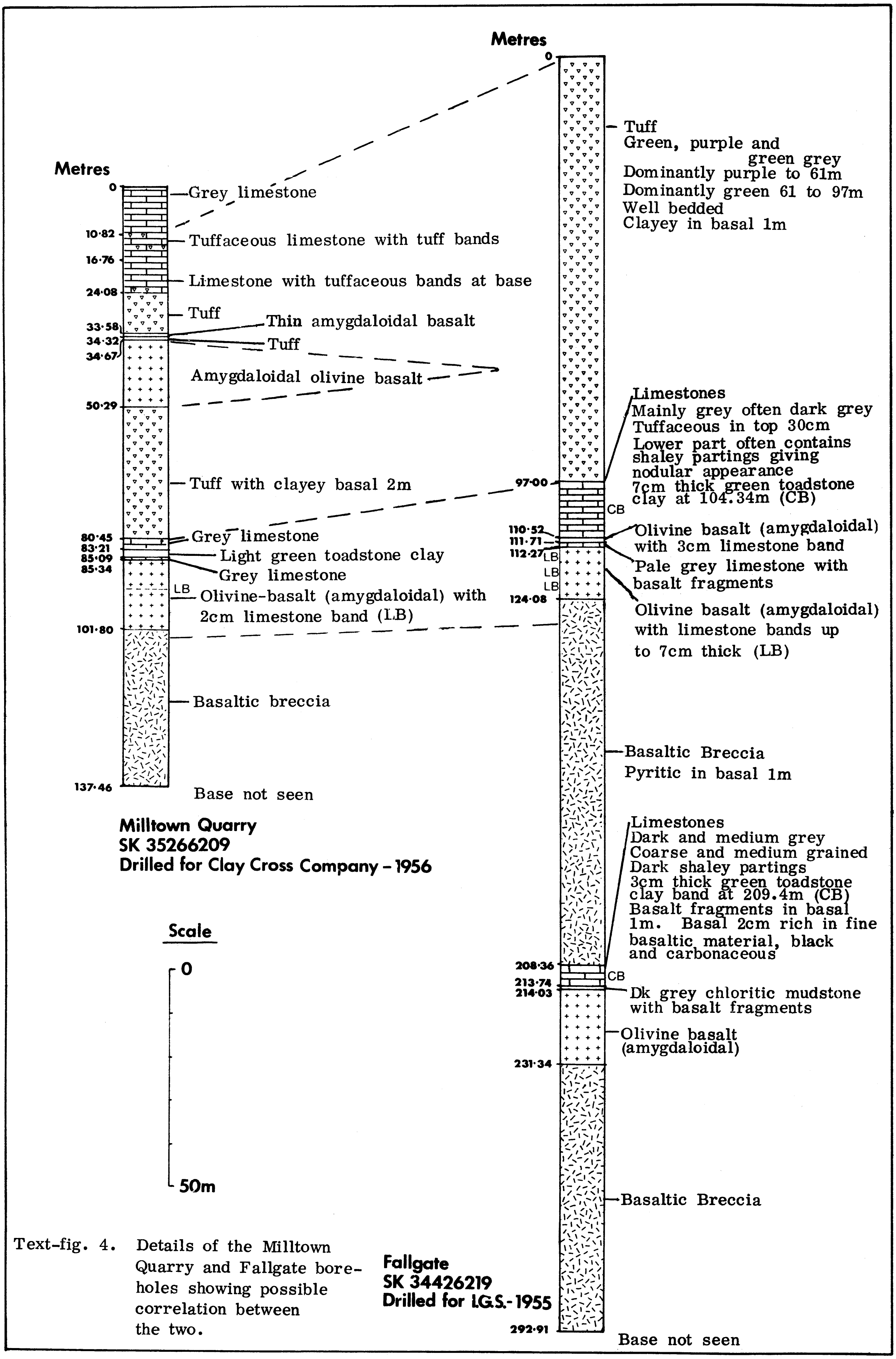
The shallow marine deposition on the platform was at several times interrupted by volcanic episodes throughout the Matlock and Ashover areas, especially in Asbian and Brigantian times. These are represented by the extensive lava flows making up the Upper and Lower Matlock Lavas in the Matlock area (table 1 and text-fig. 3). The basic volcanic events show that the area was one of crustal instability. This instability is also indicated by the presence of penecontemporaneous folding and numerous non-sequences in the limestone.

Description of the volcanic rocks

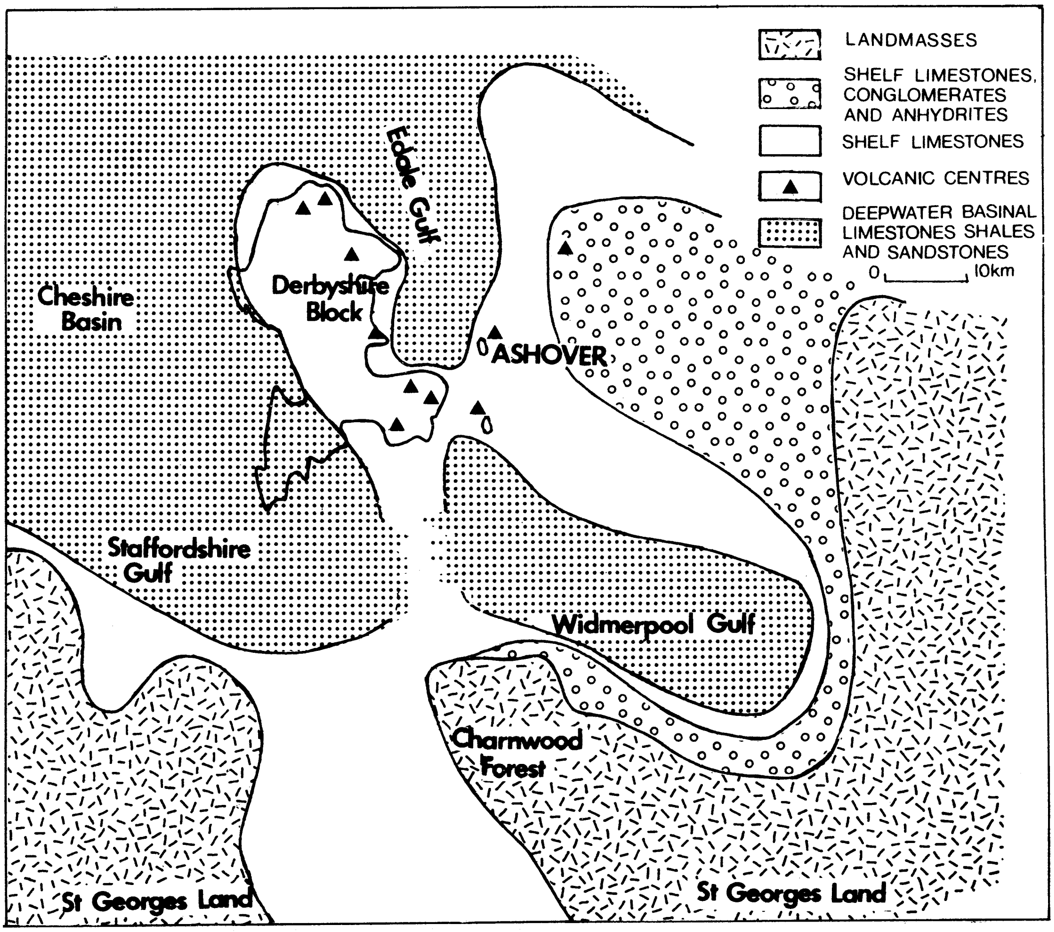
The volcanic rocks comprise three lithological types: tuffs, olivine basalts and basaltic breccias. The tuffs are well represented at the top of the sequence in a formation called the Ashover Tuff. The upper section of the Tuff is the only part of the volcanic sequence exposed



Text-fig. 3. Summary of lower Carboniferous successions in the Ashover region.



Text-fig. 4. Details of the Milltown Quarry and Fallgate bore-holes showing possible correlation between the two.



Text-fig. 5: Lower Carboniferous palaeogeography of the Midlands.

Table 1: Dinantian stratigraphical table

Local succession: Matlock		Ashover	Classical faunal zonation in the area	Regional stages (George *et al.*, 1976)
NAMURIAN				
Cawdor Group			P_2 Upper Posidonia	
Shale on limestone 20-60m				Brigantian
Matlock Group Up to 80 m excluding lava	Upper Matlock Lmst	Limestones	D_2 Upper Dibunophyllum	
	Matlock 0-40m Upper Lava			
	Lower Matlock Lmst	Ashover volcanics		
	Matlock 0-120m Lower Lava			
Hoptonwood Group Approx. 80m		--?--?--	D_1 Lower Dibunophyllum	Asbian
Griffe Grange beds 35m+			S_2 Seminula	Holkerian
			C_2S_1	Arundian
			C_1	Chadian
			K	Courceyan

at the surface. The remainder is revealed in the boreholes sunk by the IGS at Fallgate (SK 3442 6219) to 293 m and by the Clay Cross Company in Milltown Quarry (SK 3526 6209) to 137 m (text-figs. 1, 3 and 4). The Fallgate borehole was cored mainly at 6 inch diameter and logged in detail, portions of the core being stored by IGS at their Leeds offices. The Milltown Quarry borehole was logged but the core was not retained. The lithologies of the units seen are described below. The base of the volcanic sequence has not yet been proved.

1. The Ashover Tuff

Four major outcrops are present at Fall Hill Quarry (SK 355624), Hockley Kiln cutting (SK 352625), Butts Quarry (SK 340630) and Hockley Quarry Kiln cuttings (SK 350627), (text-figs. 1 and 6). Several smaller exposures show rock types very similar to those of the major outcrops. At depth tuff was encountered between 0 - 97 m in the Fallgate borehole and between 24.1 - 34.7 m and 50.3 - 80.5 m in the Milltown Quarry borehole (text-fig. 4). The tuff is variable in colour, composition and texture. Several lithological types can be distinguished.

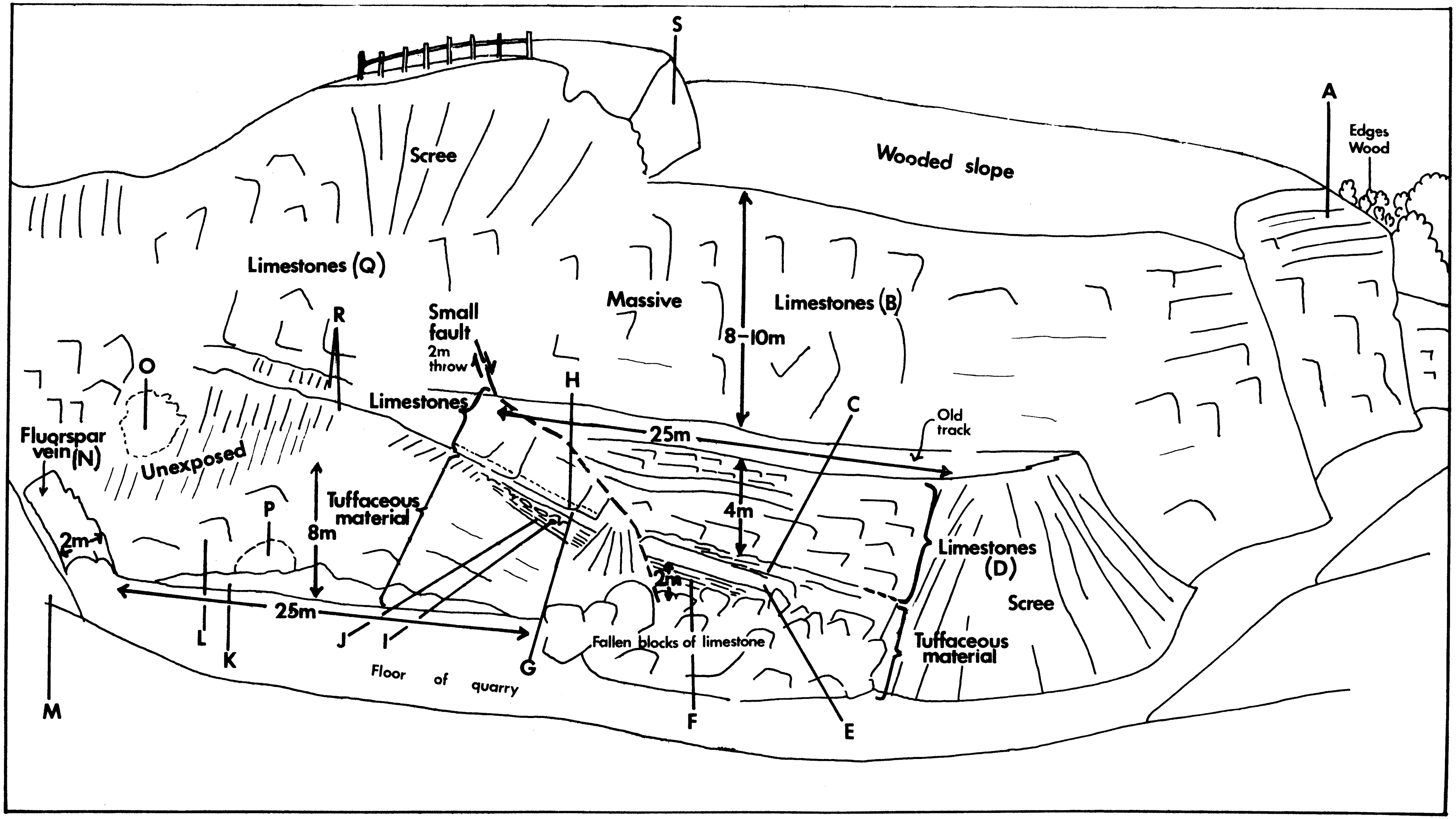
(a) Purple-brown tuff. Most of the surface exposures are composed of purple-brown tuff including those at Hockley Quarry, Hockley Lime Kilns and exposures along The Drive (351623). This rock also occurs between 0-60m in the Fallgate borehole where it appears to pass gradationally downwards into a dominantly green tuff (type b).

Alternating bands of fine and coarse material ranging from a few mm to several m in thickness are characteristic of the purple-brown tuff. The average grain size of these bands varies from 0.1 mm to 100 mm. The grains are generally subangular but occasional rounded particles are seen. The tuff usually shows a high degree of sorting and bedding is often pronounced. The rock is composed of clasts of pumice, basalt and dolerite set in a fine matrix and cemented by calcite (text-fig. 7).

Pumice forms about 90% of the clasts in the purple-brown tuff. The clasts are pale green under plane polarised light and appear pale green or brown in polished section. They are usually angular and can be cuspate being generally highly altered and vary in size from that of the matrix material (i.e. 0.1 mm to several cm in diameter). Commonly the clasts are vesicular with abundant calcite amygdales which average 0.05 to 0.1 mm in diameter and show a circular to irregular outline in thin section. Traces of chlorite and quartz are occasionally associated with the calcite fills. Elongate vesicles often form trains within the pumice fragments. In thin section they are seen to be composed of a fine mass of clay, opaque iron minerals and chlorite, the latter often with a strong concentration of opaques round the edges of the clasts. Patches of clearer material with a very pale green colour in plane polarised light are often present. These patches have subquadrate outlines and may represent crystal pseudomorphs.

Basalt fragments make up a further 10% of the clasts in the purple-brown tuff. These display a medium brown colour in polished sections. They are angular to subrounded in shape and generally have a size range of 0.1 mm - 5 cm. One block of basalt seen in Hockley Lime Kilns has a diameter of 40 cm. The clasts are strongly altered. This is probably a result of weathering during their formation and deposition. They contain a groundmass of clay, chlorite and fine opaque minerals representing an altered glassy material with occasional pseudomorphed phenocrysts, probably of olivine, now replaced by chlorite and other alteration products. Occasional felspar laths less than 0.01 mm in length are visible but are largely altered to sericite. Vesicles are often present being near circular to irregular in outline and varying in diameter from 0.03 to 0.3 mm. The vesicles are usually filled by calcite but traces of chlorite, chalcedony and quartz are often present.

Dolerite fragments make up about 2% of the clasts in the purple-brown tuff. These fragments appear dark brown in polished section. They are usually subangular and reach several centimetres in diameter. Alteration of the fragments is advanced. Phenocrysts of olivine and occasional feldspar are present. The feldspars are subhedral and lath shaped and the olivines subhedral being pseudomorphed by chlorite and serpentines with occasional traces of



Text-fig. 6: Sketch of the east face of Fall Hill Quarry (SK 355624) as seen in May 1978.
(This section of the quarry has since been filled).

Key to Text-fig. 6

A. Fairly well bedded coarse grained grey limestone with productids and crinoid debris. Very little chert is present. - CAWDOR GROUP.

B. Grey fine and coarse grained limestone. Some chert nodules. Irregular and impersistent joints give a shattered appearance. Occasional productids.

C. Thin poorly defined horizon of blue fine grained tuffaceous clay. Average thickness 0.5 m.

D. Pale grey limestone. Coarse crinoidal biosparite with occasional productids. Some bedding. - MATLOCK GROUP.

E. 1 m thick bed of grey limestone tuffaceous in part. Sharp basal contact.

F. Thinly laminated, fine grained pale blue tuff. Thin fibrous calcite veinlets 1-15 mm wide lying generally parallel to the laminations.

G. 0.45 m thick horizon of blue homogeneous fine grained tuff. Sharp lower contact. Gradational upper contact. Well defined unit.

H. Tuffaceous limestone grading into 'clean' limestones above and becoming increasingly tuffaceous at the base. 0.5 m thick.

I. Unit of variable thickness, 0.1-0.7 m. Limestone lenses and tuffaceous blocks in mineralised blue tuffaceous clay. Often discoloured grey or orange. Sharp contact with unit above. Single large agglomerate block.

J. Laminated fine grained blue tuff with calcite veinlets mostly parallel to the laminations. A green colouration is present in places.

K. Blue tuffaceous clay. Occasional pale grey patches.

L. Green tuffaceous clay with blue streaks and patches. Indistinct bedding. Some small scale shearing is present.

M. West face of quarry. Mostly green tuffaceous clay with orange discolouration in places. Some mineralisation and shearing. Bedding indistinct. The visible thickness of this unit is approximately 20 m.

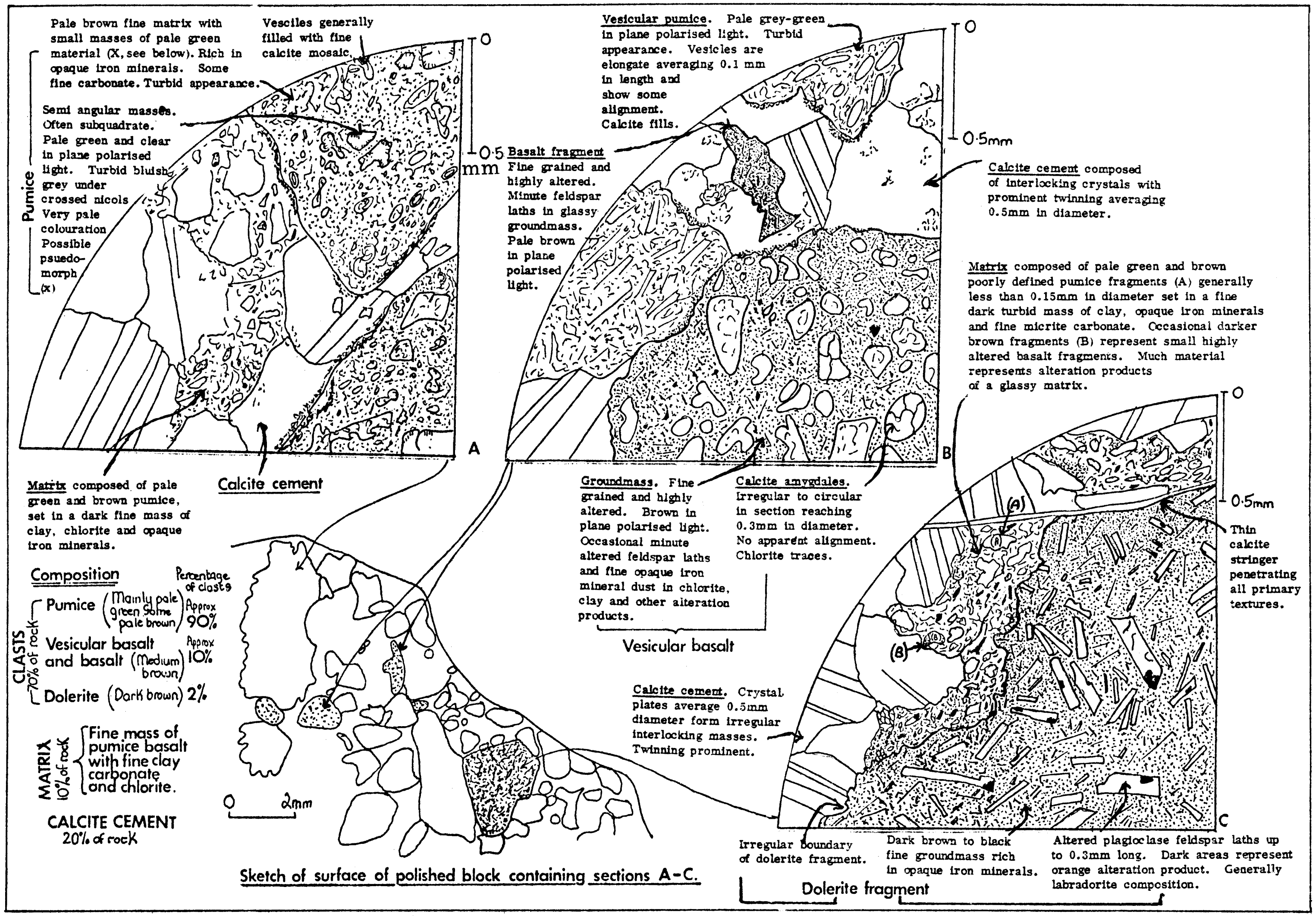
N. Fluorspar vein. Orange mineral and replaced limestone containing tuffaceous material. The vein represents a fault zone the tuffaceous clay being downthrown 10 m on the east side of the vein.

O,P. Pale grey clay patches.

Q. Massive coarse to fine grained limestone. Some richly crinoidal areas. Occasional productids are present. Pale grey in colour. - MATLOCK GROUP.

R. Pale blue tuffaceous clay.

S. Dark grey fine grained limestone with gigantoproductids. Irregular bedding and jointing. Fluorspar veinlets.



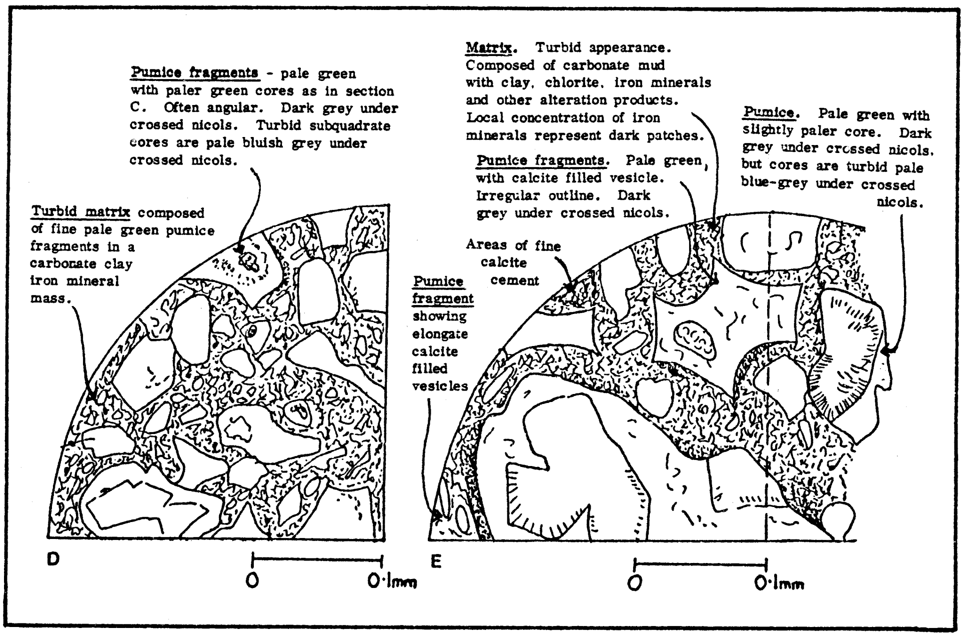
Text-fig. 7: Thin sections of the Ashover Tuff viewed in plane polarised light. A, B and C are from a single section of the purple brown tuff collected at the Drive (SK 351623).

reddish-brown iddingsite. The phenocrysts are enclosed by a fine groundmass of dark clays, chlorite and opaque iron minerals with twinned labradorite laths reaching 0.5 mm in length.

The matrix of the purple-brown tuff which encloses the pumice, basalt and dolerite clasts is composed of fine grained carbonate, very fine pumice and basalt dust, with chlorite, clay and opaque minerals. It is presumably the result of alteration of a matrix originally consisting of a fine mass similar in composition to the clasts, set in a glassy material. The matrix has a turbid appearance in thin section and usually represents about 10% of the rock.

Patches of coarse calcite cement replace the matrix in some areas. The cement normally forms 10 - 20% of the rock but in coarser-grained areas it is more prominent and occasionally it forms 50% of the rock. The calcite is in the form of a network of irregular interlocking crystals showing typical rhombohedral cleavage. Standard tests (Lindholm & Finkelmann, 1972) show the calcite is essentially free of FeO and MgO.

Occasional fragments of limestone are present in the tuff. These are generally 1 - 10 cm in diameter and concentrated in poorly defined bands which are seen most clearly in Hockley Lime Kilns. Many fragments of the purple-brown tuff are included within rock of the same type. A sandstone fragment has been identified in this unit of the Fallgate borehole.



Text-fig. 8: Thin sections of the Ashover Tuff viewed in plane polarised light. D and E are sections of the green tuff taken from a depth of 72 m in the Fallgate borehole (see text-fig. 4).

(b) Green Tuff: This forms the lower part of the Ashover Tuff in the Fallgate borehole at a depth of 60 - 97 m. It is largely composed of pumice fragments in a fine matrix having an overall pale green colour in hand specimen. The pumice is similar to that seen in the purple-brown tuff (text-fig. 8, D.E). The fragments vary in size from 0.1 mm to several centimetres and are subrounded to angular and are occasionally cuspate in form. Vesicles are sometimes present and are usually calcite filled. The matrix is composed of chlorite, fine carbonate, clay and opaque iron materials which represent decomposed glass and fine pumice dust. Iron mineral grains are locally concentrated around the clasts. Rare basalt fragments occur in this lithology.

Table 2: Bulk Chemical analyses of Samples from the Ashover Volcanic Sequence

	1	2	3	4	5	6	7	8	9	
SiO_2	35.89	19.92	36.90	19.48	30.44	35.31	44.60	40.13	34.57	SiO_2
Al_2O_3	10.23	10.83	17.29	10.43	12.96	11.36	12.43	11.41	10.72	Al_2O_3
							3.89	2.62	2.22	Fe_2O_3
Total Iron as Fe_2O_3	9.52	8.75	13.68	8.02	7.83	9.00	7.38	7.86	5.11	Fe
MgO	5.14	0.58	4.38	0.81	1.43	2.23	14.31	15.76	6.78	MgO
CaO	14.70	28.44	7.46	29.34	21.30	19.09	1.46	4.09	15.12	CaO
Na_2O	0.43	Not	1.56	Not	Not	0.62	1.60	0.33	1.02	Na_2O
K_2O	0.60	estab.	3.25	estab.	estab.	1.10	1.37	0.71	4.20	K_2O
H_2O (+ 105°C)	6.97	8.02	5.21	8.13	7.74	2.08	6.54	8.09	4.14	H_2O (+ 105°C)
H_2O (- 105°C)	4.00	2.70	2.90	4.56	4.46	3.00	3.85	3.99	1.45	H_2O (- 105°C)
TiO_2	1.81	0.50	1.51	0.84	1.33	1.01	1.74	1.93	1.51	TiO_2
CO_2	10.73	8.03	5.26	8.10	4.00	14.40	0.30	2.40	11.47	CO_2
Total S as FeS_2	Nil	12.03	0.04	6.09	4.80	Nil	Nil	Nil	0.95	Total S as FeS_2
	100.02	99.80*	99.43	95.79*	96.29*	99.27	0.09	0.16	0.16	MnO
							0.20	0.31	0.24	P_2O_5
							0.21	0.16	0.12	Allow for minor constituents
							99.95	99.95	99.78	Totals

Details of analysed rocks:

1. Purple Tuff. Hockley Lime Kilns. (SK 352625)
2. Blue tuffaceous clay. Butts Quarry. (SK 340630)
3. Large basalt block. Hockley Lime Kilns.
4. Blue tuffaceous clay. Fall Hill Quarry.
5. Green tuffaceous clay. Fall Hill Quarry. (SK 355624)
6. Purple tuff. The Drive (see text-fig. 8). (SK 351623)
7. Basaltic breccia, chloritised. Fallgate borehole 163-165 m.
8. Tuff. Fallgate borehole 56-58 m.
9. Altered amygdaloidal olivine basalt. Fallgate borehole 113-115 m.

Analyses 1-6 by the author 1977; analyses 7-9 by A.D. Wilson & J.F. Palframan, in Ramsbottom, *et al.*, 1962.
Using classical wet and spectrophotometer analysis.
*Analyses totals do not contain alkali.

(c) Tuff Clays: These are seen in Butts, Milltown and Fall Hill Quarries. They form the uppermost units of the Tuff. However, occasional thin bands of tuffaceous clay occur within the main body of the Tuff in both the Fallgate and Milltown quarry boreholes and even within the underlying limestones and basalts. In surface exposures they are generally pale blue in colour representing fine grained highly altered tuff. They are too altered to yield useful thin section data but chemical analyses (table 2) show high carbonate and sulphide contents, the latter indicating the amount of pyrite present. Much pyrite occurs as disseminated grains in the clays. In deeper levels of the Fall Hill Quarry, green and occasionally purple-grey clays are seen. In the boreholes green clays within the Tuff may represent short periods of erosion during which the tuff surface was exposed to weathering, while clays in the limestone represent short periods of deposition of volcanic material probably as single ashfalls. The clays are often referred to as Wayboards.

(d) Tuffaceous Limestone Conglomerate: This lithological type has not been reported previously in the area. It has been seen only in a single block measuring 30 x 20 cm enclosed in blue tuffaceous clay in Fall Hill Quarry some 1.5 m below the base of the limestones (text-fig. 5). The block is slickensided intensely on one surface and may have been tectonically emplaced in the clay. The rock has an overall bluish grey colouration and comprises two lithologies. The bulk of the rock is composed of a coarse conglomerate. The clasts are rounded and subrounded generally averaging 1 - 5 cm diameter. They are composed of pale blue and buff tuffaceous clay and make up some 40% of this rock. One large clast some 15 cm in diameter is composed of grey and grey-green fine grained highly weathered volcanic material having a concentric structure and is penetrated by a network of very fine dark grey veinlets. The matrix makes up some 60% of this lithology be volume, and is composed of tuffaceous coarsely crystalline grey limestone. Pale bluish-grey clay fragments up to 4 mm diameter make up a third of the matrix. Pyrite grains are scattered throughout and are locally concentrated into mineral patches.

The basal 3 cm of the block is composed of finer pale grey-blue pyritic tuffaceous limestone with an average grain size of under 2 mm. Tuffaceous clay makes up some 50% of this lithology. It is separated from the conglomeratic mass by a clear sharp cut boundary. Small rounded fragments of the fine lithology are included and protrude into the conglomeratic lithology which forms the bulk of the block.

2. The Olivine Basalts

Basalts occur in both the Milltown Quarry borehole and the Fallgate borehole but are not exposed at the surface. In the Milltown Quarry borehole basalts occur between 34.7 and 50.3 m and between 85.3 and 101.8 m, representing a combined thickness of approximately 32 m. A further basalt (0.74 m thick) occurs at 33.6 m. In the Fallgate borehole basalt occurs between 110.5 and 124.1 m and between 213.7 and 231.3 m, giving a combined thickness of 31.1 m.

The basalts are fine grained and vary in colour from green to dark grey-green and brown. They are altered to varying degrees. Small phenocrysts of olivine are pseudomorphed by chlorite and enclosed in the groundmass. Occasionally small plagioclase phenocrysts occur and orthoclase is sometimes present. The diameter of phenocrysts does not exceed 2 mm. Rarely chlorite and calcite pseudomorphs after pyroxene are visible. Grains of pyrite, magnetite and haematite occur as opaque phases in the chlorite and calcite groundmass, which contains small felspar laths averaging 1 mm in length. These are usually altered and have a turbid appearance. Compositionally they appear to be albite to oligoclase and often show albite twinning. Amygdales are often abundant being composed of calcite with occasional areas of chlorite and quartz being present. The amygdales are generally irregular or near spherical in shape and may reach 1 cm in length. The phenocrysts usually form less than 10% of the rock by volume, the amygdales making up between 0% and 20% of the rock, the remainder being groundmass.

3. The Basalt Breccias

Basaltic breccias are found in both the Milltown Quarry and the Fallgate boreholes. In the former they make up the lowermost 35.6 m seen and in the latter they occur as two masses between 124.1 and 208.4 m and between 231.3 m and the borehole base at 292.9 m, a combined thickness of 145.9 m.

The breccias are remarkably similar in composition in both boreholes. They consist of angular and subangular pale green fragments of altered olivine basalt set in fine grained dark green interstitial chlorite rich basalt. The fragments range in size from less than 1 mm to about 200 mm in diameter, and represent about 70% of the rock generally. Scattered fragments of this basalt have brown cores of less altered basalt. Occasional fragments of brown vesicular basalt with calcite amygdales are seen.

The basalt fragments are composed of highly altered phenocrysts of albite and pseudomorphed olivine in a matrix of chlorite, carbonate, clay, iron minerals and other alteration products. The breccias are similar in chemical composition to the basalts (table 2) but tend to be slightly richer in magnesium (possibly due to an originally greater concentration of olivine in the breccias), and poorer in potassium. Carbonate is less important in the breccias due to the lower density of amygdales.

The breccias are sandwiched between olivine basalts except for the lower contact of the upper breccia unit in the Fallgate borehole at 208.36 m where a gradational contact with the underlying limestone is seen. The uppermost few millimetres of the limestone contains highly altered basalt fragments which become quickly dominant over carbonate, upwards, grading into the overlying breccias. At the contact the breccia is fine grained, the fragments being generally less than 1 cm in diameter.

Relationships and Origins of the Lithologies

The basaltic breccias make up the basal 35.6 m of the Milltown Quarry borehole and the basal 168 m of the Fallgate borehole where an olivine basalt some 17 m thick overlain by thin limestones is included in the succession. Their considerable thickness clearly indicates that the volcanic vent was close to the present site of the Fallgate/Milltown Quarry boreholes. These breccias seem to represent either:

(a) Thick lavas extruded on the flanks of a volcano which were brecciated due to rapid cooling as they flowed into shallow marine waters.

(b) Pyroclastic material ejected from the vent and deposited nearby in shallow water.

Fine cuspate fragments in the matrix similar to those seen in the Ashover Tuff suggest they are of similar pyroclastic origin. The contact between the upper basaltic breccia and underlying limestone is gradational with fragments of basalt in the limestone increasing in number upward. This indicates that basalt fragments fell into carbonate mud, quickly covering the sea and possibly forming the whole of the breccia. The underlying limestone is at 208.4 m in the Fallgate borehole.

The included basalt seen in the breccia of the Fallgate borehole represents a thin lava flow and is overlain by a 15 cm thick chloritic mudstone containing many basalt fragments, which appears to represent marine reworking of the lava flow surface. The limestone represents a period of sediment deposition in shallow marine waters as indicated by the fauna of brachiopods corals and crinoids.

The olivine basalts which overlie the breccias in both the Fallgate and Milltown boreholes are 12.37 and 15.46 m thick respectively. The basalts are amygdaloidal and have uneven upper surfaces suggesting that they formed as lava flows. A 0.2 m band of limestone lies 8 m below the upper surface of the basalt in the Milltown Quarry borehole, a further 0.56 m thick band lies some 1.19 m below the upper surface and several thin 0.2 m bands occur at various levels in the basalt. These probably represent periods during which carbonate mud was swept on to the submarine flows and was deposited in depressions on its surface. The thin limestone bands in the Fallgate succession may thus define up to ten individual flows the spacing of the bands indicating flow thickness of between 0.3 m to 3.5 m. Small euhedral quartz and albite crystals occasionally seen sparsely scattered in the limestones may be the result of recrystallisation due to residual heat in the lava flows at the time of their deposition.

Angular limestone fragments at the base of the basalt in the Fallgate borehole may represent block plucked up by flow as it passed over a partially consolidated carbonate surface.

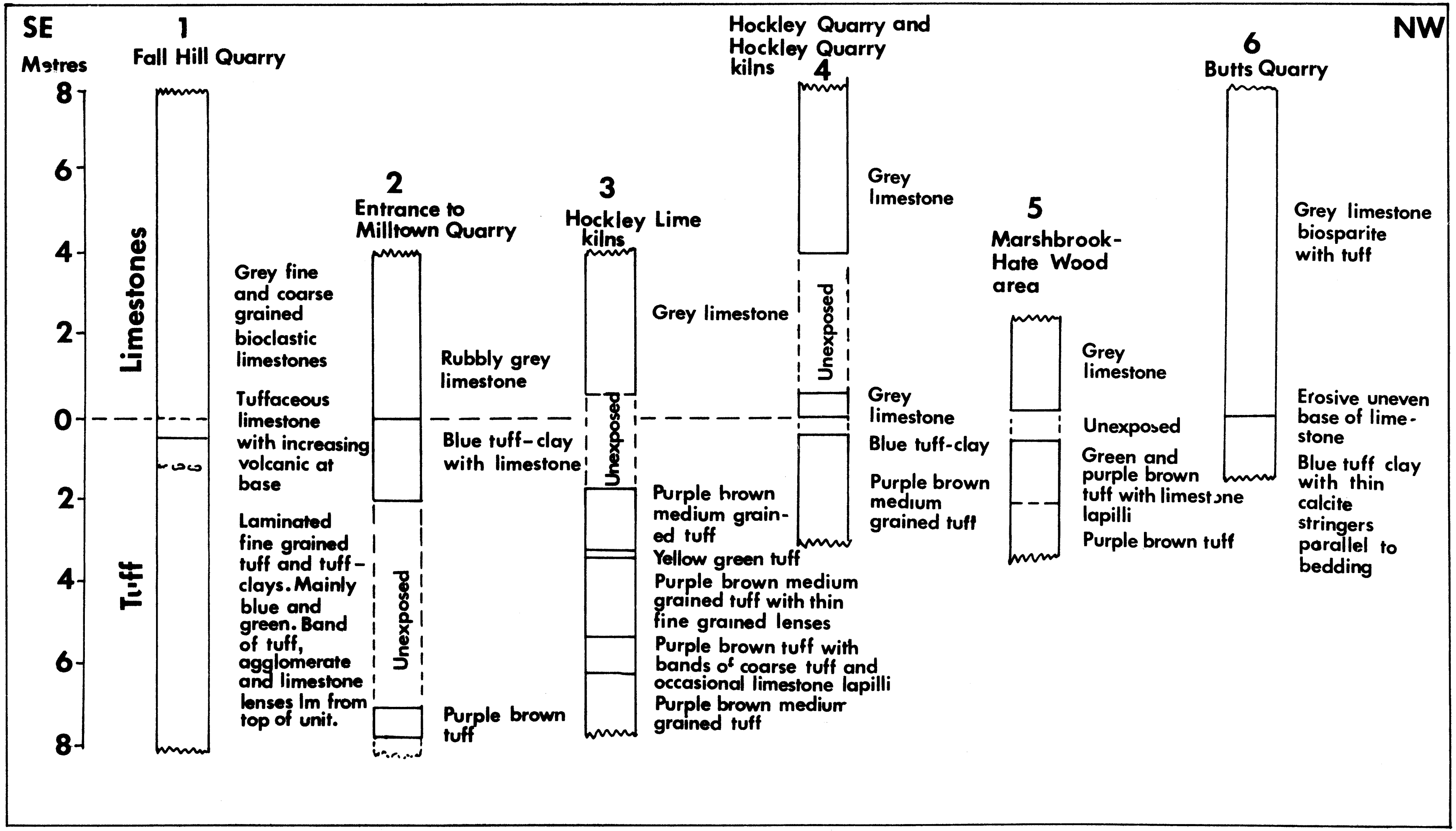
Limestones overlie the basalts in both boreholes. Usually they are grey, fine and medium grained bioclastic limestones with fossils suggesting a low D_2/high D_1 zone including crinoid ossicles, brachiopods (notably productids) and corals including *Lithostrotion martini*. In the Milltown Quarry borehole the limestone is 3.05 m thick with an additional 2 m thick pale green clay near the base representing a period of explosive volcanic activity and ashfall. In the Fallgate borehole the limestone is almost 14 m thick. The limestones contain 'nodular' horizons with shale partings and occasional thin green volcanic clays. The limestone directly above the basalt has laminations parallel to irregularities in the basalt surface. This suggests that the deposition of carbonate mud was in hollows on the top of an eroded lava flow.

The Ashover Tuff overlies these limestones in both boreholes. In the Fallgate borehole the Tuff has a sharp and angular lower boundary. Angular limestone fragments containing crinoid ossicles and enclosed in the lower few centimetres of the Tuff where calcite has replaced much of the volcanic material. These basal few centimetres of the Tuff are rich in disseminated pyrite. In the Milltown Quarry borehole the Tuff grades downward through 2 m of clayey tuffaceous material into the underlying limestone.

This shows that in the area of the Fallgate borehole erosion of the limestone occurred following its deposition and consolidation, before the deposition of volcanic material commenced. In the area of the Milltown Quarry borehole however carbonate and volcanic material was deposited simultaneously. The sites of these boreholes are only 200 m apart indicating that at the beginning of volcanic activity local basins of deposition and scoured limestone platforms existed. The Tuff is a fragmental rock composed of angular basaltic fragments and shows graded bedding and a high degree of sorting. This combination of features suggests that the Tuff is a result of explosive volcanic activity which ejected basalt and pumice fragments into the atmosphere from a nearby vent. These fragments then fell into shallow water and settled under gravity. The absence of active currents to rework this sediment is indicated by the angular nature of the grains and lack of current bedding. The Tuff is thus interpreted as an ashfall deposit.

The Fallgate borehole shows that the purple-brown tuff overlies the dominantly green tuff, the boundary being transitional at about 60 m. The change in colour is partly a result of the decrease in pumice content in the upper unit indicating a change in the volcanic material being deposited. The tuff is divided into two units by some 15.62 m of amygdaloidal olivine basalt between 34.67 m and 50.29 m in the Milltown Quarry borehole. This basalt is absent in the Fallgate borehole. The basalt has an uneven upper boundary and probably represents lava flows which flowed down the flanks of the volcano into shallow water. A similar basalt at 33.58 m, some 0.74 m thick may represent a large block which has blown out of the vent or a thin lava flow. The overall thickness of the two tuff layers in the Milltown Quarry borehole is approximately 40 m while some 97 m of tuff is present in the Fallgate borehole representing a rapid thickening eastward in the area. The increased thickness of the tuff and the relatively small proportion of the succession occupied by basalt in the Fallgate borehole suggest that this succession was deposited further away from the vent then the Milltown Quarry borehole succession.

The tuffaceous clays lie at the top of the tuff. The thickness of these clays is shown in text-fig. 9. They appear to be absent in places. The contact of the tuff and tuffaceous clays with



Text-fig. 9: The nature of the contact between the Ashover Tuff and the overlying limestones.

the limestone is rarely seen but its approximate position may be deduced by field mapping. Tuffaceous clay is seen to be interbedded with and pass into tuffaceous limestone and finally limestone in Fall Hill Quarry while in Hockley Quarry some 300 m away a sharp contact between purple-brown tuff and limestone is seen. The blue and green tuffacous clays are probably the result of weathering and decay of the purple-brown tuff when consolidated or soon after its fall as ash when on the seabed.

As ashfall ceased so the surface of the deposit was exposed to a relatively long period of reworking thus allowing the breakdown of the ash. The high CaO content of these clays suggests that calcium carbonate was being deposited during the reworking. Eventually the carbonate being deposited became dominant over the reworked ash on the seabed and gave rise to limestone deposition. This is indicated by the short transitional sequences from tuffaceous clay through tuffaceous limestone to limestone seen in Fall Hill Quarry and the interbedded tuffaceous clay and limestone seen at the entrance to Milltown Quarry.

In the Hockley Quarry Kiln sequence the tuffaceous clay is very thin indicating that a period of scouring may have cleaned the top of the tuff before carbonate sedimentation began. In Butts Quarry the contact of the limestones with the underlying tuffaceous clay is sharp and clearly erosive indicating that scouring of the reworked ash occurred in places before limestone deposition commenced.

The block of tuffaceous limestone conglomerate found in the tuffaceous clay of Fall Hill Quarry indicates that the tuffaceous clay was being reworked as limestone deposition began, rounded fragments of tuffaceous clay being swept into areas of dominantly carbonate deposition. The variation in contact sequences resulting from this complex reworking and sedimentation is shown in text-fig. 9.

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