A STRATIGRAPHIC REVISION OF THE LATE PRECAMBRIAN ROCKS OF CHARNWOOD FOREST, LEICESTERSHIRE

by

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Summary

It is proposed in keeping with modern stratigraphical procedure that the Late Precambrian rocks of Charnwood Forest should be redefined as the Charnian Supergroup and a division into the Blackbrook, Maplewell and Brand Groups and two volcanic complexes is recommended.

The slump breccias, conglomerates and volcanic breccias previously used as long range stratigraphic marker horizons are shown to be inadequate for this purpose and only of limited local value for correlation. The remnants of a volcanic centre, composed largely of volcanic breccias and quartz-feldspar porphyries, are represented by the Whitwick and Bardon Hill complexes and these may be contemporaneous with part of the completely clastic Maplewell Group.

Introduction

Precambrian rocks crop out in Charnwood Forest, Leicestershire, a triangular area of 110 km^2 rising above the general level of the Midland Plain to 280 m above ordnance datum at Bardon Hill. The Charnian Supergroup is not well exposed, being overlain unconformably by Triassic and Pleistocene sediments.

Modern stratigraphic practice and international rules of nomenclature require that a tightening and some re-definition of Watts' (1947) rock units is necessary. Where the degree of exposure permits, formations must now have strictly defined type sections with the bases of units clearly indicated so that other sections may be compared and correlated. This new nomenclature is introduced herein: it supercedes and revises the simplified version already published in the key to the revised edition of the Coalville Sheet (No. 155) of the Geological Survey (Old & Worssam, 1982).

Although Cribb (1975), Evans (1963), Ford (1958, 1968, 1979, 1980, 1981 & 1983), Thorpe (1972, 1979, 1982), Le Bas (1981, 1982), Boynton (1978) and Boynton & Ford (1979) have recently added to our knowledge of the age, structure, palaeontology and geochemistry respectively of the ancient rocks of Charnwood Forest, little has been written on the stratigraphy since the work of W. W. Watts. He published many papers from 1895 onwards and the culmination of these studies was the posthumous publication of "Geology of the Ancient Rocks of Charnwood Forest" (1947). The bulk of Watts' work was compiled for the Geological Survey beginning in 1896 and there has long been a need for his stratigraphic classification to be revised (table 1), modern terms for the rocks and rock units to be introduced and, particularly, a reinterpretation of certain distinctive lithologies and their reliability as stratigraphic marker horizons. To define these predominantly volcaniclastic rocks accurately, an integration of the classifications for pyroclastic (Fisher, 1960, 1961 and 1966; Le Bas & Sabine, 1980) and epiclastic rocks (Pettijohn, Potter & Siever, 1972, p. 71) became necessary (table 2).

Of other earlier works, Howell and Hull, working for the Geological Survey, mapped the Charnwood area (c. 1857-1860) without erecting a stratigraphic succession; Hill and Bonney published papers (1877-1891) describing the petrography of the Charnian. Bennett (1928) published a geological map of Charnwood that suggests he may have recognised, without appreciating the full significance, the discontinuous nature of certain slump breccias, conglomerates and volcanic breccias. The history of research into the Charnian was comprehensively summarized by Ford (1979).

Mercian Geologist, vol. 10, no. 1, 1985, pp. 1-18, 3 figs., 1 folded map (Plate 1)

Table 1 The main stratigraphic divisions of the Charnian supergroup

Earlier stratigraphic divisions by W.W. Watts (1947) in parentheses

Groups	Formations	Members
The Brand Group (The Brand Series)	*Swithland Formation* (Swithland Slates) Purple pelites and very fine-grained greywackes.	None
	Brand Hills Formation Quartz-arenites, greywackes, conglomerates. A tuff at or near the base of the Brand Group.	Stable Pit Quartz-arenite Member. (Trachose Grit and Quartzite) Hanging Rocks Conglomerate (Hanging Rocks Conglomerate)
The Maplewell Group (The Maplewell Series)	*Bradgate Formation* Pelites, dust tuffs, greywackes. Slump breccias at base of the Formation.	Hallgate Member (Woodhouse and Bradgate Beds) Sliding Stone Slump Breccia Member (Slate Agglomerate)
	Beacon Hill Formation Pelites and coarse-grained tuffs, with some lapilli tuffs and volcanic breccias. Subordinate slump breccias, pull-apart breccias, conglomerates and breccias.	Old John Member (Beacon Hill Beds) Sandhills Lodge Member Beacon Tuff Member (Beacon Hill Beds) Benscliffe Member (Felsitic Agglomerate)
The Blackbrook Group (The Blackbrook Series)	*Blackbrook Reservoir Formation* (Blackbrook Beds) Tuffaceous pelites, dust tuffs and subordinate coarse-grained tuffs.	None
	Ives Head Formation (Blackbrook Beds) Greywackes, tuffs, pelites and a slump breccia.	South Quarry Slump Breccia Member Lubcloud Greywackes Member Morley Lane Tuffs Member

Table 2 The classification of the main types of epiclastic and pyroclastic rocks

(after Pettijohn, Potter and Siever, 1972, p. 71; Fisher, 1960, 1961 and 1966; Le Bas and Sabine 1980).

	Epiclastic		Pyroclastic	
	Rock	*Fragment*	*Rock*	*Fragment*
	Conglomerate	boulder	Coarse volcanic breccia	blocks
			Coarse agglomerate	bombs
256 mm				
	Conglomerate	Cobble	Fine volcanic breccia	blocks
			Fine agglomerate	bombs
64 mm				
	Conglomerate	pebble	Lapilli tuff	lapilli
4 mm				
	Conglomerate	granule		
2 mm				
	Very coarse-grained arenite/greywacke	grains		
1 mm				
	Coarse-grained arenite/greywacke	grains	Coarse-grained tuff	lithic grains
1/2 mm				
	Medium-grained arenite/greywacke	grains		crystals
1/4 mm				
	Fine-grained arenite/greywacke	grains		shards
1/8 mm				
	Very fine-grained arenite/greywacke	grains		
1/16 mm				
	Pelite	grains	Dust tuff or fine-grained tuff	

In the north-east and south, pre-Triassic dioritic rocks, referred to here as the Northern and Southern Diorites, intrude and are faulted against the sedimentary rocks of the Charnian Supergroup. The main mass of the Southern Diorites obliquely cuts the contact of the Brand and Maplewell Groups and may not form a laccolith as previously suggested (Watts, 1947, p. 72). The Northern Diorites form intrusive bodies, some with faulted contacts, at Longcliffe and Newhurst Quarries, Bawdon Hill, on the Buck Hills and the Ulverscroft Nature Reserve (fig. 1).

In 1975, Cribb determined the Rb and Sr isotopic compositions of these diorites, but the ages calculated from these data are geologically difficult to accept as the date of emplacement given by Cribb (1975) but revised for new decay contents by Pankhurst (1982) for the Northern Diorite is 304 ± 90 Ma, and is probably a re-set age dating the Hercynian mineralization (King 1968) of that area. The Southern Diorite yielded an isochron corresponding to an age of 540 ± 57 Ma (Cribb 1975 revised by Pankhurst, 1982) which, if one sets aside the error margins, is rather young for a Precambrian intrusion, the Precambrian-Cambrian boundary being placed usually at about 570 Ma (Sepkoski 1983) but ranging from 550-570 Ma (Glaessner 1984) to 610 ± 10 Ma (Xiaofeng 1984).

The Charnian Supergroup

The assemblage of ancient, Precambrian sedimentary and igneous rocks outcropping in Charnwood Forest, Leicestershire, is here designated the Charnian Supergroup. The assemblage indicates an active zone with intermittent vulcanicity and earthquake activity. Calc-alkaline porphyry masses, thick local accumulations of volcanic breccias and waterlaid tuffs indicate an explosive, volcanic focus that became dormant or extinct after the deposition of the conglomerates at the base of the Brand Group. Earthquakes, possibly triggered by vulcanicity, are thought to have been responsible for the development of slump breccias that are confined to the Blackbrook and Maplewell Groups. The interbedding of coarse-grained tuffs, volcanic breccias and slump breccias with sparsely fossiliferous, finely laminated dust tuffs and pelites suggests sporadic volcanic and seismic activity with longer periods of quiescence. Directional sedimentary structures show that the Charnian sediments accumulated in a N.N.E.-S.S.W. trending basin sited to the immediate south-east of the volcanic centre.

The Charnian Supergroup has been folded into an open asymmetric anticline that plunges gently to the south-east. Minor folds are superimposed and there has been considerable faulting. Very low grade metamorphism has been imposed and cleavage affects fine-grained rocks along a trend nearly parallel to but not identical with the main fold axis (Evans, 1963).

The Division of the Charnian Supergroup into Groups

The division of the Charnian Supergroup into the Blackbrook, Maplewell and Brand Groups is based on major lithological differences (see table 1). The Brand Group, being almost entirely devoid of pyroclastic detritus, is distinct from the Blackbrook and Maplewell Groups that are comparatively rich in this material. The Blackbrook and Maplewell Groups both contain thick sequences of dust tuffs, pelites and tuffaceous pelites. The main differences are that the Maplewell Group contains well-developed horizons of volcanic and sedimentary breccias, slump breccias and lapilli tuffs which are absent or only poorly represented in the Blackbrook Group.

The Blackbrook Group

The division of Blackbrook Group into the Ives Head and Blackbrook Reservoir Formations (table 3) was determined on the south-west limb of the anticline (fig. 1). On the north-east limb there are lithological variations, structural complications and an eastward thinning of the Group. This pattern of coarsening and thinning is not easily resolved, but the general increase in greywackes over dust tuffs eastwards may be related to increasing distance from a volcanic centre lying to the north-west. Type sections are located around Blackbrook Reservoir and on Ives Head Hill (kilometre squares SK 45.17, 46.17 and 47.17) and together show an overall upward increase in the proportion of dust tuffs and pelites as the spasmodic explosive vulcanicity responsible for the development of local coarse-grained tuffs waned. The base of this Group is not seen but the lowest section exposes dust tuffs and coarse-grained tuffs in the disused quarries at Morley Lane, Shepshed (SK 47531796 and 47651790). The highest strata of the Blackbrook Group are the tuffaceous pelites and coarse-grained tuffs in Benscliffe Wood (51481250) and on the M1 Motorway section (49041705) and underlie the lowest volcanic breccia, the base of which is taken as the bottom of the Maplewell Group.

Table 3 The stratigraphic divisions of the Blackbrook Group

	Members	Lithologies
Blackbrook Reservoir c. 610 m	None	c. 370 m of tuffaceous pelites dust tuffs and subordinate coarse-grained tuffs c. 30 m of very weathered coarse-grained tuffs with subordinate tuffaceous pelites c. 210 m of tuffaceous pelites, dust tuffs, pelites and subordinate coarse-grained tuffs
Ives Head Formation at least 820 m	South Quarry Slump Breccia Member c. 32 m	Slump breccia, coarse-grained tuffs and dust tuffs
	Lubcloud Greywackes Member c. 550 m	Medium- to very fine-grained greywackes are dominant. Some greywackes are tuffaceous. Subordinate coarse-grained greywackes and tuffaceous pelites
	Morley Lane Tuffs Member at least 238 m	Coarse-grained tuffs with subordinate dust tuffs and tuffaceous pelites

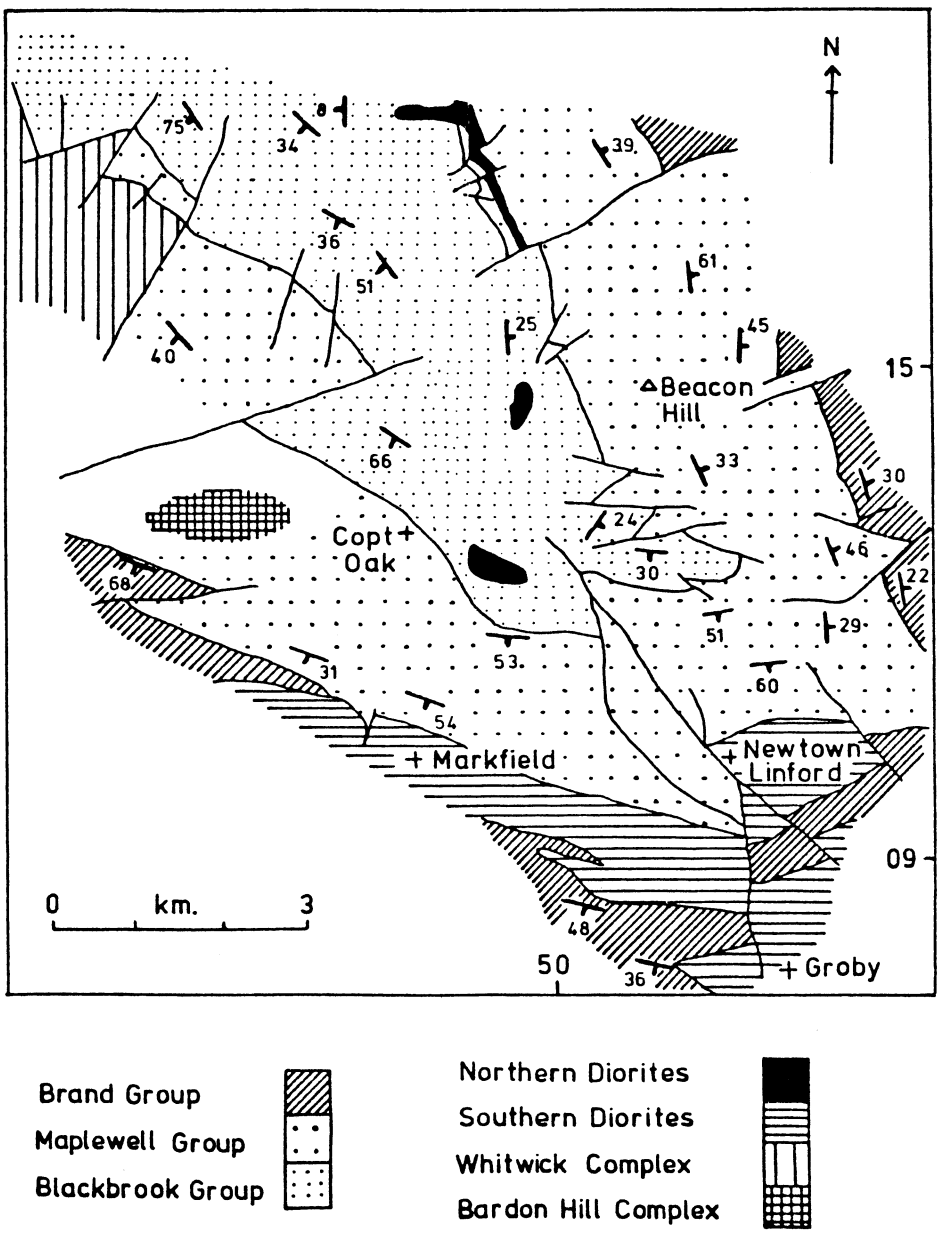


Fig. 1. The outcrop pattern of the Blackbrook, Maplewell and Brand Groups.

(*a*) *Ives Head Formation*

This formation is divided into the following Members:-

(i) *Morley Lane Tuffs Member*

The only localities for this Member, the lowest of the Blackbrook Group, are the disused quarries at Morley Lane, Shepshed (47531796 and 47651790). The base of the Member and the contact with the overlying Lubcloud Greywackes Member is not exposed. Coarse-grained rhyolitic crystal tuffs and dust tuffs are predominant (table 3) in the 14.7 m of strata in the type section (47651790).

(ii) *Lubcloud Greywackes Member*

The base of this Member is not exposed but the contact with the overlying South Quarry Slump Breccia Member is at the eastern end of Blackbrook Reservoir (46431712) and Lubcloud Farm (47871627). The type section is represented by the following 39 m of strata that crop out on Ives Head Hill (47731701):

Fine-grained greywackes and tuffaceous pelites	11.0 m
Medium-grained lithic greywackes	5.5 m
Very fine-grained tuffaceous greywackes	5.5 m
Medium-grained lithic greywackes	11.0 m
Very fine-grained tuffaceous greywackes and pelites	6.0 m

Lithic grains in the greywackes from the type section are of acid igneous origin, and in the coarser-grained greywackes exceed the pyroclastic (fraction of broken, euhedral quartz and feldspars).

The Lubcloud Greywackes Member can be tentatively traced around the nose of the anticline to Short Cliff (48621715) where medium- to coarse-grained tuffaceous greywackes are the dominant lithology and may represent an eastwards thickening of the coarser beds exposed on Ives Head Hill.

(iii) *South Quarry Slump Breccia Member*

Both top and base of this Member are exposed at the south-east end of Blackbrook Reservoir (46401712) in the following type section:-

Interbedded coarse-grained rhyodacitic tuffs and rhyolitic dust-tuffs	29.0 m
Coarse-grained rhyodacitic tuff	0.5 m
Slump breccia	2.0 m

This breccia consists of randomly orientated, contorted and undeformed clasts of rhyolitic dust-tuffs in a structureless matrix of weathered coarse-grained rhyodacitic tuffs. The bed of slump breccia which is a useful, but limited stratigraphic marker horizon is underlain by the Lubcloud Greywackes Member and the interbedded tuffs are succeeded by the lowest tuffs and tuffaceous pelites of the Blackbrook Reservoir Formation. The Member can be traced to Moult Hill (46501701) and Lubcloud Farm (17871627) beyond which it is not exposed and may die out laterally.

(*b*) *The Blackbrook Reservoir Formation*

Tuffaceous pelites and rhyolitic dust-tuffs are the main lithologies of the Blackbrook Reservoir Formation but thin horizons of coarse-grained rhyolitic and rhyodacitic tuffs occur 210 m above the base, and in Benscliffe Wood (51271277, 51371281 and 5138126) near the top of the Formation. Basal dust-tuffs and tuffaceous pelites are exposed at 46401708 (see above) and the dust tuffs at 45681774 are succeeded by 30 m of very weathered, coarse-grained tuffs. These tuffs and pelites comprise the type section which is intermittently exposed in the north-east corner of kilometre square 45.17. The coarse-grained tuffs are tentatively correlated with those near Rock Farm (48051543 and 48321526) Hall Farm (47861428) and the band of coarse grit (Watts, 1947, p. 27) at Ringing Hill (45211838) which is no longer exposed. The top of this Formation is exposed on the M1 Motorway section (49041705) where 12.5 m of tuffaceous pelites and dust tuffs are overlain by the lapilli tuff of the Benscliffe Member (Plate 1).

The Maplewell Group

The rocks of the Maplewell Group are exposed in a horseshoe-shaped area reflecting the gently plunging structure of the Charnian anticline (fig. 1). Type sections occur in kilometre squares 51.12 (Benscliffe Wood), 52.11 and 53.11 (Bradgate Park), and 50.14 (Beacon Hill). The base of the Group is defined in the preceding section while the top is represented by the highest pelites of the Hallgate Member. The Group is divided into the Beacon Hill and Bradgate Formations (tables 1, 4 & 5). In the north-east the coarse tuffs and slump breccias of the Outwoods and Buck Hills Members, which cannot be traced south of northing 15, represent a coarsening within the Old John Member (page 9), presumably due to a localized phase of explosive vulcanicity with

Table 4 The stratigraphic divisions of the Maplewell Group

	Members	*Lithologies*
Bradgate Formation 649 m	Hallgate Member 640 m	Tuffaceous pelites, pelites and dust tuffs are the dominant lithologies. Thin horizons of coarse-grained tuffs and medium-grained greywackes are developed.
	Sliding Stone Slump Breccia Member 9 m	5 m of coarse-grained andesitic tuffs that grade into medium-grained tuffaceous lithic greywackes. 4 m of slump breccias composed of clasts, sometimes distorted, of dust tuffs and tuffaceous pelites in a matrix of coarse-grained tuffs and medium-grained greywackes.
Beacon Hill Formation 1119 m	Old John Member 430 m	Tuffaceous pelites are the dominant lithology with dust tuffs and subordinate coarse-grained tuffs and greywackes, slump breccias and pull-apart breccias.
	Sandhills Lodge Member 27 m	6.4 m of coarse-grained tuffs with some lapilli tuff. 12.8 m of coarse-grained tuffs. 4.7 m of pelites with some very fine-grained greywackes. 0–0.1 m of deeply weathered breccia. 2.4 m of pelites.
	Beacon Tuffs Member 740 m	Coarse-grained tuffs dominant. Some dust tuffs, tuffaceous pelites and pelites.
	Benscliffe Member 22 m	Main development is of lapilli tuffs, coarse-grained tuffs with some volcanic breccias. There is a finer grained development of the Member at Rocky Plantation with dust tuffs containing rotten, limonitic lapilli.

Table 5 The division of the Beacon Hill Formation into members

W. Charnwood	S.W., S and S.E. Charnwood	N.E. Charnwood
Charnwood Lodge	Chitterman Hills— Benscliffe Wood— Bradgate Park— Beacon Hill	Buck Hills—Outwoods
Base of Bradgate Formation →		
Charnwood Lodge Member 1300 m	Old John Member 330 m	Old John Member 860 m Outwoods Member 71 m Buck Hills Member 176 m
	← Sandhills Lodge Member → 9 m	11 m
	← Beacon Tuffs Member → 560 m	350 m
← Benscliffe Member → 47 m	22 m	28 m
← Blackbrook Group →		

associated seismicity and instability (table 5). In parallel with the thinning of the Blackbrook Group is the decrease in thickness to the north-east of the Beacon Tuffs and Hallgate Members although the Old John Member thickens in this direction. Volcanic breccias and lapilli tuffs developed in the west from the Charnwood Lodge Member.

(*a*) *The Beacon Hill Formation*

In the type area this Formation is divided into four Members (table 4) and their description precedes that of the Buck Hills, Outwoods and Charnwood Lodge Members (table 5).

(i) *The Benscliffe Member*

Previously called the Felsitic Agglomerate (Watts, 1947) this Member consists of volcanic breccias, lapilli tuffs, rhyolitic to andesitic tuffs and subordinate dust tuffs. The distinctive coarser lithologies contain pale pink blocks, lapilli and grains usually composed of devitrified rhyolite that due to a patchy secondary silicification often appear to blend into a dark chlorite matrix. The type section in Benscliffe Wood (51451247) is overlain by the lowest beds of the Beacon Tuffs Member:-

Coarse-grained tuffs	5.4 m
Volcanic breccias, rhyolitic lapilli tuffs and coarse-grained tuffs	16.2 m

The base of the Member is not exposed here although Blackbrook beds (51481250) lie 5.4 m below the crags of volcanic breccia and lapilli tuff. In the vicinity of Benscliffe Wood the Member can be traced to Brockers Cliff (50491239) and, tentatively, due to structural complications, to Green Hill (51021306) and Black Hill (50521351).

On the north-east limb of the anticline the Benscliffe Member is exposed at Whittle Hill (49841580), in Roe's Plantation (49811623), on the M1 (Longcliffe) cutting (49051708 and 49021700) and Ingleberry Rock (48971731). On the south-west limb the Member is exposed at Stoneywell Cottage (49771172), in Rocky Plantation (49831183), on the M1 (Birch Hill) cutting (48181339 and 48231387), at Abbot's Oak (46411424), in Cat Hill Wood (47531521) and on Collier Hill (46841583), at Charnwood Towers (46291625) and in Strawberry Hill Plantation (45601710) (Plate 1).

The lithology and thickness of the Benscliffe Member varies as it is traced westwards from the type section, particularly in Rocky Plantation where the massive coarse-grained lithology is not exposed and in Strawberry Hill Plantation where the coarse-grained rhyodacitic to andesitic tuffs and lapilli tuffs are only tentatively correlated with the Benscliffe Member. The Benscliffe Member represents a zone of varying stratigraphic thickness of interdigitating coarse-grained tuffs, lapilli tuffs and volcanic breccia that can be used as a stratigraphic marker horizon only over small areas. The variations in the lithology and thickness prevent its use as an accurate marker horizon throughout Charnwood Forest.

(ii) *The Beacon Tuffs Member*

Previously referred to as the Beacon Hill Beds (Watts, 1947), the base of the Beacon Tuffs Member is exposed in Benscliffe Wood (51441244), at Ingleberry Rock (49001730) and on the M1 (Birch Hill) cutting (48211345). The top of the Member is not exposed. The type section is at Beacon Hill (50941481) where there is the following succession:

Interbedded coarse-grained tuffs with subordinate tuffaceous pelites and dust tuffs	55.1 m
c. 14m of strata not exposed. Thickly bedded coarse-grained tuffs with some thin tuffaceous pelites and dust tuffs	27 m
Dust-tuffs	0.8 m
Coarse-grained tuffs	2.8 m
Dust-tuffs	0.8 m
Dust-tuffs with subordinate coarse-grained tuffs	2.8 m
Very thickly bedded coarse-grained epidotic tuffs	2.8 m

The Beacon tuffs Member consists of coarse-grained tuffs, pelites with subordinate grewackes. It is exposed on the north-east limb of the main anticline in Longcliffe Quarry (49331700), on Nanpantan Hill (49951686 and 50021694), at Whittle Hill (49911577), on Beacon Hill, Broombriggs Hill (51471422 and 51821428) and Ling Hill (52151257 and 51291229). West of Benscliffe Wood and the Member is very poorly exposed and estimates of the stratigraphic thickness vary because of this and structural complications, particularly folding in the Beacon Hill—Broombriggs area.

Of the wide range of rock types in this Member the coarse-grained tuffs range from rhyodacitic to trachyandesitic; the dust tuffs are rhyolitic. Subordinates vitric tuffs, which are restricted to the type section, contain acicular and Y-shaped moulds of shards orthogonal to bedding in a dust-tuff matrix. The shard moulds indicate the former presence of glass shards that fell 'end-on' into unconsolidated dust.

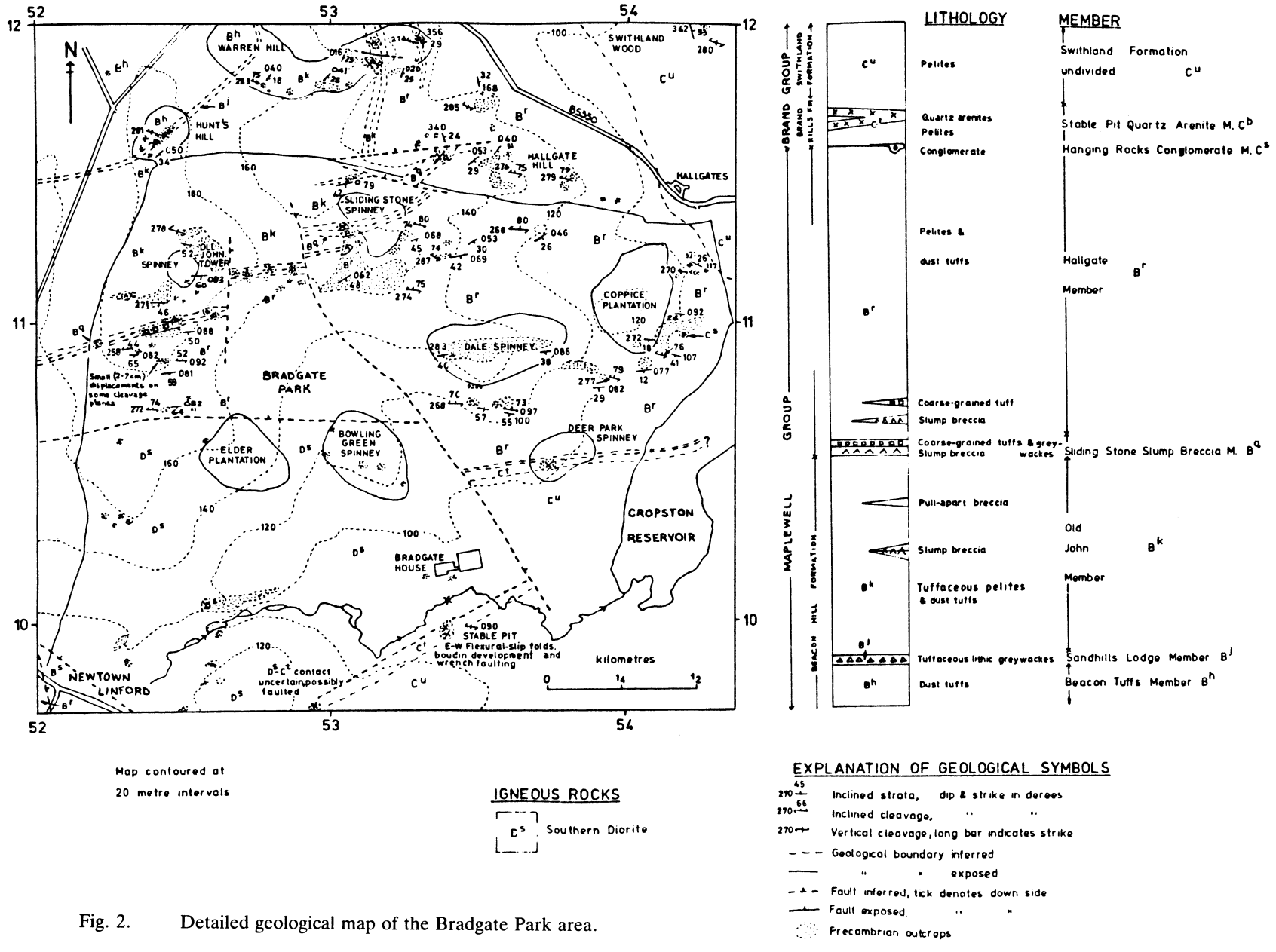


Fig. 2. Detailed geological map of the Bradgate Park area.

(iii) *The Sandhills Lodge Member*

The top and base of this Member are not seen and although exposed at only eight localities it has some value as a stratigraphic marker consisting mainly of coarse-grained lithologies that separate the dominantly fine-grained overlying and underlying Members. The type section for the Member is near Sandhills Lodge (50251100, table 4) and it can be traced to Stinking Wood and new Plantation (49921089) where breccias are interbedded with coarse-grained tuffs. Tracing the Member eastwards 9.4 m of coarse-to fine-grained tuffaceous lithic greywackes are exposed on Hunt's Hill (52441161) and weathered breccias at Maplewell School (52201323). The breccias contain pelitic clasts and, like the greywackes, grains of trachyte and devitrified rhyolite. To the north, near the Buck Hills, 10.7 m of coarse-grained tuffs (50291639 and 50471569) and lapilli tuffs (50361621 and 50411603) are petrographically similar to and tentatively correlated with those seen in the type section (table 4).

(iv) *Old John Member*

The base of this Member is not seen but the top is exposed on the Charnwood Forest Golf Course (52201550), Warren Hill (55131188) and the M1 (Hollies) cutting (47871172). At each of these localities tuffaceous pelites, dust tuffs and subordinate coarser-grained tuffs are overlain by the Sliding Stone Slump Breccia Member. The type section is in the north-west part of Bradgate Park where there is the following semi-continuous exposure around the War Memorial (52441109) and Old John Tower (52561125): (fig. 2)

Sliding Stone Slump Breccia Member	9.1 m
Interbedded tuffaceous pelites, dust tuffs, and coarse-grained tuffs c. 57 m of strata not exposed	72.5 m
Tuffaceous pelites, dust tuffs and subordinate coarse-grained tuffs	12.6 m
Coarse-grained tuffs with thin dust tuffs c. 18 m of strata not exposed	5.7 m
Dust tuffs and tuffaceous pelites	18.5 m
Sandhills Lodge Member	9.4 m

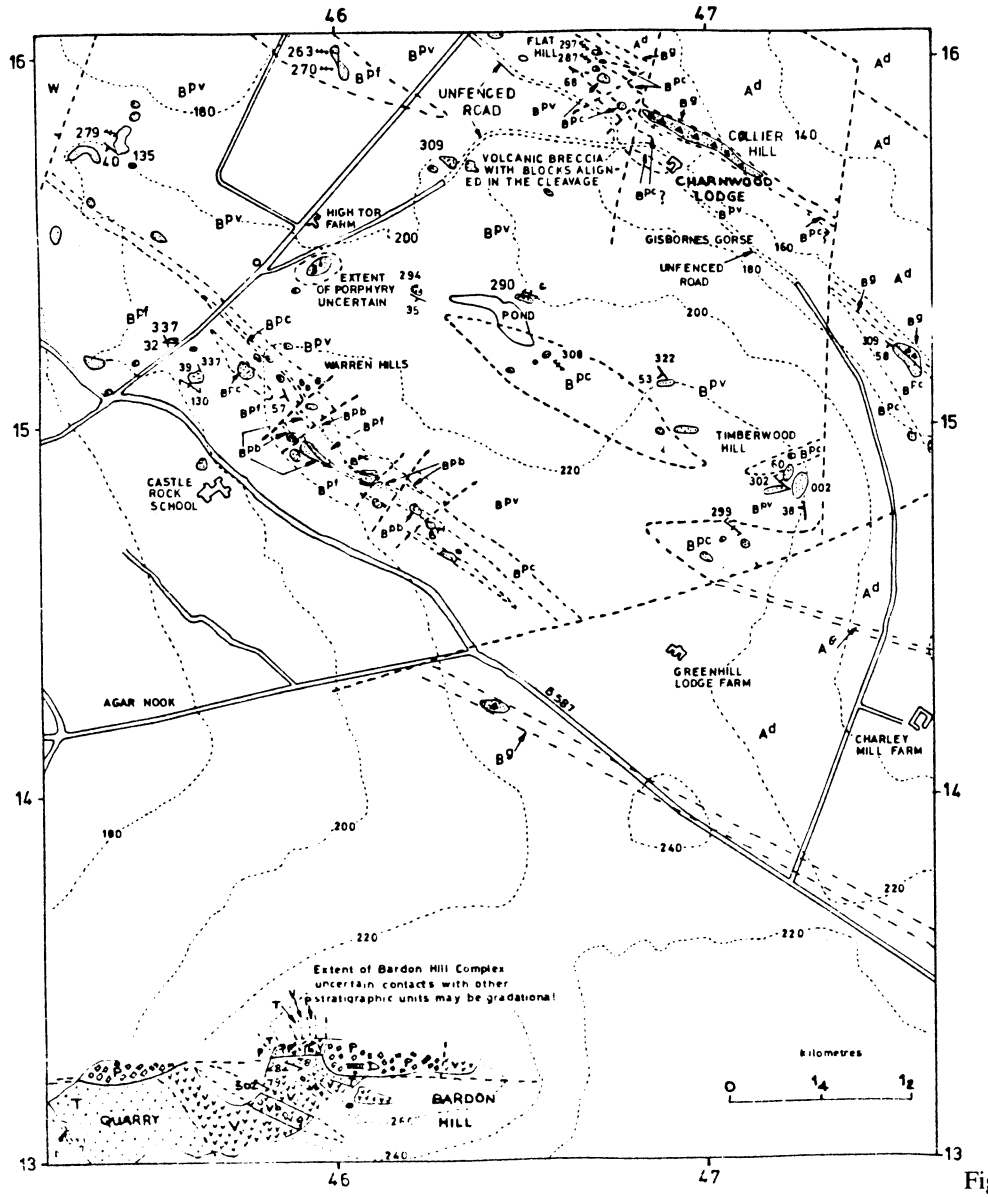
A pull-apart breccia 67.6 m below the top of the Member (53091148) is not exposed again in the southeast of Charnwood Forest, but one does crop out 98.3 m below the top of the Member in the A50 cutting (48611095):

Coarse-grained tuffs	2.8 m
Tuffaceous pelites, dust tuffs and subordinate coarse-grained tuffs	0.2 m
Coarse-grained tuffs	0.2 m
Coarse-grained tuffaceous lithic greywacke grading upwards into tuffaceous pelite	0.1 m
Coarse-grained tuffaceous lithic greywacke with pull-apart breccia at base	1.4 m
Coarse-grained tuffaceous lithic greywacke with large and small clasts of pelite and tuffaceous pelite	0.8 m
Coarse-grained tuffs	0.1 m
Coarse-grained lithic greywackes with pull-apart breccias	2.0 m

The Member can be traced north-eastwards from the type area to Warren Hill (53001180), Spring Hill Wood (52801270), Windmill Hill (52621430), Longhill Plantation (51521535) and the Charnwood Forest Golf Course (52201550). North of grid northing 15 it interdigitates with the Outwoods and Buck Hills Members (table 5) and shows a slight coarsening. Westwards the Member can be traced to Ulverscroft Mill (51441080), where there are pelites and coarse-grained tuffs, and to the A50 and M1 cuttings. Tuffaceous pelites predominant in this Member over rhyolitic to andesitic tuffs, greywackes and pull-apart breccias. The latter contain elongate pelite clasts lying approximately parallel to bedding in coarse-grained andesitic tuffs.

(v) *The Buck Hills Member*

The development of this Member is confined to the north-east of the Forest (Table 5), where it cannot be traced south of Blackbird's Nest Farm (51351557) or to the north of the Home Farm (50481672). Exposures are in the Buck Hills where the following type section occurs between 50901624 and 50971633:



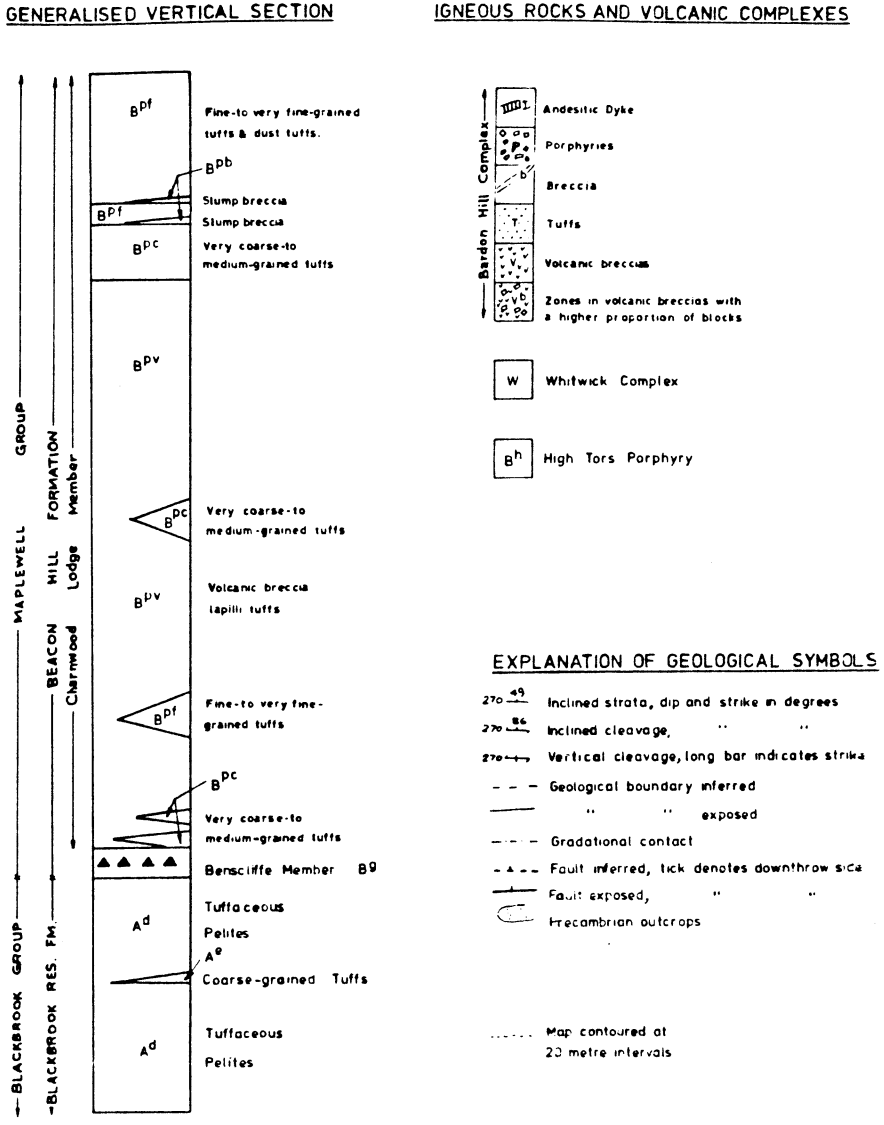


Fig. 3. Detailed geological map of the Charnwood Lodge and Bardon Hill area.

Coarse-grained tuff	10. m
Coarse-grained rhyodacitic to andesitic tuffs with some rhyolitic dust tuffs	149.2 m
Coarse-grained tuffaceous greywackes	12.2 m
Breccias	3.5 m

The breccias and 10.8 m of coarse-grained tuffs which mark the base and top of the Member respectively wedge out to the north and south away from the type section. When traced southwards all the coarser-grained lithologies thin and become finer-grained, until the very thin coarse-grained tuffs at 51291576 are thought to represent the most southerly development and feather-edge of the Member.

(vi) *The Outwoods Member*

The following type section is in the Outwoods (51371662):

Coarse-grained tuffs with channelling and an associated breccia	38.0 m
Coarse-grained tuffs	16.9 m
Lapilli tuff	6.3 m
Slump breccia	9.5 m

South of this also in the Outwoods (51451638) is a partially exposed, thinner succession

Conglomerate, conglomeratic coarse-grained tuff with a subordinate slump breccia	6.2 m
Coarse-grained tuffs	9.2 m
Dust tuffs and coarse-grained tuffs	0.5 m
Lapilli tuff	6.2 m

The Old John Member, which interdigitates with the Outwoods Member (table 5), can be seen to underlie the slump breccia at 51371662 and to overlap the conglomerate at 5141638; otherwise the base and top of the Member are not exposed. On the Charnwood Forest Golf Course a very thin band of conglomeratic tuff (52091539) may represent the feather-edge of the Outwoods Member which thins southwards from the type section.

Tuffs are of rhyodacitic to andesitic composition; pebbles and lithic grains from the conglomerate include of quartz, quartzite, trachyte and a quartz-feldspar rock.

This Member also occurs in the north-east but is not developed south of northing 15 nor exposed north of northing 17.

(vii) *The Charnwood Lodge Member*

The development of the Charnwood Lodge Member is confined to the area around Charnwood Lodge and Mount St. Bernard Abbey and, as it overlies the Benscliffe Member, it is thought to be contemporaneous at least with the lower part of the Beacon Tuffs Member and may be correlated with the Bardon Hill Complex (section 8b). The following type section is in the Nature Reserve between Flat Hill (4651606) and Warren Hills (46051481): (fig 3)

Coarse-grained andesitic tuffs with thin dust tuffs and tuffaceous pelites	214.0 m
Slump breccia	0-1 m
Coarse-grained andesitic tuffs	92.0 m
Volanic breccias, lapilli tuffs and subordinate coarse-grained tuffs	980.0 m
Benscliffe Member	

The top and the base of the Charnwood Lodge Member are not exposed. West and east of the type section there is a thinning and fining respectively of the volcanic breccias, lapilli tuffs and coarse-grained tuffs with the resultant development of finer grained tuffs. The thick accumulation of nearly 1000 m of volcanic breccias and lapilli tuffs suggests the existence of an adjacent volcanic centre (section 8). From the stratigraphical and petrographical evidence it is impossible to tell if the slump breccias exposed on Warren Hills should be correlated with those of the Sliding Stone Slump Breccia Member (section 5b(i)) as originally suggested by Watts (1947). The Charnwood Lodge Member is not exposed east of Little Hill (47621493) or west of Mount St. Bernard Abbey (45781621) where it is faulted against the Blackbrook Group and Whitwick Complex respectively.

(*b*) *The Bradgate Formation*

The Bradgate Formation is divided into the Hallgate and Sliding Stone Slump Breccia Members: the type section for both Members is in the Bradgate Park-Warren Hill-Hallgate Hill area.

(i) *The Sliding Stone Slump Breccia Member*

This Member was previously known as the Slate Agglomerate (Watts, 1947). It can be used as a stratigraphic marker horizon with some confidence around the southern half of Charnwood Forest (fig. 3). Thinner, discontinuous slumped horizons within the Old John and Hallgate Members suggest an intermittent zone of slumping in which the Sliding Stone Slump Breccia Member is the main component. The base of the Slump Breccia Member and of the Bradgate Formation is exposed on Warren Hill (53131188), at the Altar Stones (48431094) and on the M1 (Hollies) cutting (47861169). On Hangingstone Hills (52221559) the Member has thinned to a minimum and here the top and base are exposed. The top of the Sliding Stone Slump Breccia Member is seen in Bradgate Park (52401097 and 53061130) and on Warren Hill (53231187).

The Sliding Stone Slump Breccia Member is traced easily across Bradgate Park into Hallgate Filter Station grounds (53391156) and on to Warren Hill. North of this area, at Roeclife (53231276) a slump breccia is intercalated with coarse-grained tuffs (18.4 m). At Windmill Hill a very small outcrop (52631440) of slump breccia is tentatively correlated with the Sliding Stone Slump Breccia Member. On the Hangingstone Hills the Member thins northward to its minimum development beyond which it is not exposed and presumably has wedged out. West and north-west of Bradgate Park the Member is recognised at Field Head (47951026), the Altar Stones (4843-092), an M1 cutting (47861169) and possibly near Hobby Hall (47191213). The stratigraphic horizon of the zone of thin, discontinuous slump breccias found on the Warren Hills (46051481) is uncertain (section 5a (vii)).

(ii) *The Hallgate Member*

The base of the Hallgate Member, formerly the Woodhouse and Bradgate Beds (Watts, 1947), is exposed in Bradgate Park (52401097 and 53061130) and on Warren Hill (53231187) where dust tuffs and tuffaceous pelites are underlain by the Sliding Stone Slump Breccia Member, and on the Hangingstone Hills (52221559) where the Breccia has almost completely wedged-out (see above). The top of the Member is exposed at Billa Barra Hill (46581142) and on the Hangingstone Hills (52451496) where tuffaceous pelites are overlain conformably by coarse-grained crystal lithic tuffs of the Brand Hills Group and conglomerates of the Hanging Rocks Conglomerate Member respectively. In the north-east of Bradgate Park, an area complicated by minor folding, no contact is exposed but pelites of the Hallgate Member (54081087, 54141094 and 54221120) appear to be succeeded by coarse-grained sedimentary rocks of the Brand Hills Group. The predominantly fine-grained strata of the Hallgate Member (dust tuffs, tuffaceous pelites, pelites and medium-grained greywackes) are best exposed in Bradgate Park (53851085, 53491074 and 53151115), on Hallgate Hill (53531174 and 53541151), at Broombriggs (52701450) and on the Hangingstone Hills (52221554). In the north-east the Member is terminated by faulting. The most westerly exposure of the Hallgate Member is at Bardon Lodge (45771188).

In the type area the Member is 640 m thick and thins towards the north-east where there is the complication of faulting in the Brand-Roecliffe area. To the west poorly exposed folding and a faulted contact with the Southern Diorites precludes an accurate estimate of the thickness.

The Hallgate Member contains the fossiliferous beds noted by Ford (1958, 1963, 1968, 1980), Boynton (1978), and Boynton & Ford (1979). The impressions of *Charnia masoni, Charniodiscus concentricus, Pseudovendia charnwoodensis* and various medusoids have all been found a few metres above the base of the Member.

The Brand Group

This Group is intermittently exposed around the eastern, southern and south-western margins of the Forest (fig. 1) and is divided into the Brand Hills and Swithland Formations (table 6). Type sections for the Group are in Bradgate Park (53400999), on the Charnwood Forest Golf Course (52461497) and the Brand Estate, including part of Swithland Wood.

Table 6 The stratigraphic divisions of the Brand Group

Swithland Formation 260 m	No division is made into Members and Beds	Purple pelites and fine to very fine-grained greywackes. Thin discontinuous shale-pebble conglomerates are developed at and near the base of the Formation
Brand Hills Formation 0–95 m	*Hanging Rocks Conglomerate Members* Interbedded very coarse to very fine-grained tuffaceous greywacke with subordinate trachyandesitic crystal lithic tuffs — 40 m Tuffaceous conglomerates with conglomeratic greywackes — 7 m Similar lithologies at about the same horizon are developed at small outcrops in Bradgate Park and at Bardon. Coarse-grained trachyandesitic crystal lithic tuffs on Billa Barra Hill are at the same horizon as in the type section	*Stable Pit Quartz Arenite Members* Pelites — 2.2 m (cut by clastic dykes of quartz arenite) Quartz arenites and greywackes — 0.9 m Breccia — 1.8 m (pelite clasts in a quartz-arenite matrix; equivalent greywackes also have pelite clasts) Quartz arenites and greywackes — 4.3 m (greywackes from The Brand may represent facies equivalents of the quartz arenite lithology — 94.7 m)

(*a*) *The Brand Hills Formation*

This Formation is divided into the Hanging Rocks Conglomerate and Stable Pit Quartz-arenite Members which are discontinuous and show lithological variations and consequently are of little value as stratigraphic markers.

(i) *Hanging Rocks Conglomerate Member*

The type section, in which the base and top of the Hanging Rocks Conglomerate Member are exposed, is at the Charnwood Forest Golf Course on the Hangingstone Hills (52461497, table 6) and at this locality the base of the Member represents the base of the Brand Group. The tuffaceous conglomerate in the type section consists of a mature fraction of pebbles and lithic and quartz grains, an immature fraction of elongate pelite clasts and euhedral and broken feldspar and quartz phenocrysts. The 40 m of fine-grained greywackes overlying the conglomerate are petrologically comparable to the coarser-grained rocks in the Hanging Rocks Conglomerate Member, and not to the succeeding greywackes of the Swithland Formation (table 6). Pebbles and lithic grains found in this Member consist mainly of quartz, quartzite, trachyte or rhyolite; less common are grains of granite and schist. To the north of the type section the Member is not exposed and to the south its outcrop is terminated by a small fault. In Bradgate Park (54211097) the Hanging Rock Conglomerate Member crops out at a lower topographic level than the adjacent crags of pelite of the underlying Hallgate Member. An excavation around this outcrop revealed an irregular base to the conglomerate which was underlain by very fine- to very coarse-grained tuffaceous lithic greywackes.

The conglomerate contains a block of pelite ($43 \times 21\text{cm} \times 30\text{cm}$) and is thought to represent deposition in a channel that locally scoured and eroded the top beds of the Hallgate Member.

Tuffaceous lithic greywackes at Bardon (44711267) and crystal lithic tuffs on Billa Barra Hill (46601134) are tentatively correlated with the Hanging Rocks Conglomerate Member. As the Member is exposed at only four localities it is a poor stratigraphic marker. It is thought to consist of discrete lenses developed at approximately the same stratigraphic level.

(ii) *Stable Pit Quartz-arenite Member*

The type section for the Stable Pit Quartz-arenite Member, previously called Trachose Grit and Quartzite (Watts, 1947), is the Stable Pit in Bradgate Park (53400999, table 6). From here the Member can be traced to Deer Park Spinney (53761052), Lady Hay Wood (51700832) and New Plantation (50230900). On the Brand Hills where the top of the Stable Pit Quartz Arenite Member is exposed (53481322 and 53641315) there is the following facies equivalent to the typical quartz-arenite lithology:

Swithland Formation

Very coarse-grained greywackes with clasts of pelite and interbedded thin pelites	15.2 m
Pelites, with some fine- to coarse-grained lithic greywackes	79.5 m

Base of Member not exposed

This correlation is based on the petrological comparison between and the gradation from quartz-arenites and quartzwackes at the Stable Pit and Deer Park Spinney to comparatively mature greywackes on the Brand Hills. This Member is of limited value as a stratigraphic marker as it can only be traced around the south of Charnwood Forest.

Secondary enlargement of the rounded quartz grains by quartz overgrowths is common in the quartz-arenites: the contact between overgrowth and detrital grain is sometimes marked by a thin film of chlorite. Lithic grains in the greywackes are mainly of quartzite, and there is also a minor feldspar fraction.

(*b*) *The Swithland Formation*

The type section for the Swithland Formation, which is not subdivided into Members, is on the Brand Estate and in the northern part of Swithland Wood:

Pelites with very fine- to fine-grained lithic greywackes	250.0 m
Interbedded shale-pebble conglomerates, pelites and greywackes	7.0 m

Stable Pit Quartz-arenite Member

The occurrence of shale-pebble conglomerates near the base of the Formation in the type section is not recognised as a reliable indicator of stratigraphic position. Although similar conglomerates near Nanpantan (51051737) and Swithland Camp (53731200) are close to the base of the Swithland Formation they are absent from this stratigraphic level on the Charnwood Forest Golf Course (52531508) and in the Groby Parks area (50170877). The base of the Swithland Formation is also exposed on the Charnwood Forest Golf Course (52481509) where 54 m of pelites and very fine-grained greywackes succeed the Hanging Rocks Conglomerate Member. The highest strata of the Swithland Formation and of the Charnian Supergroup are pelites and very fine-grained lithic greywackes on the margin of Swithland Wood (54131285 and 54221220). There are excellent sections in the old flooded quarries in the Brand and Swithland Woods from which Swithland Slate was once obtained (53841336, 53851312, 53761310, 53721322, 53901314, 53871300 and 53901218). In the south-west of Charnwood Forest there are c. 160 m of folded pelites and greywackes in the area of Little John (50120830), Bradgate Home Farm (51050830 and 50810824), Groby Upper Park (49680915), Burchnall Spinney (49730900) and Groby Lodge (50390782).

Sedimentary rocks of uncertain stratigraphic position

In the Grace Dieu area in the extreme north-west of the Forest there are tuffs and shale-pebble conglomerates whose stratigraphic position is unresolved (fig. 1). The most northerly outcrop (43951878) of the Charnian Supergroup consists of weathered, hematite-stained dust tuffs and coarse-grained tuffs that are tentatively placed in the Blackbrook Group. At three localities near Grace Dieu Warren, which are all close to the fault zone that delimits the Whitwick Complex, there are tuffaceous shale-pebble conglomerates (44361768 and 44191780) and coarse-grained tuffs (44051759). From the same area Watts (1947, p. 59) described a 'fine-grained slate breccia' (presumably a shale-pebble conglomerate) exposed in a small quarry 366 m south-west of Spring Barrow Lodge (44901792), now filled in.

Igneous Complexes

In the north-west of Charnwood there are the remnants of one or more volcanic centres here called the Whitwick and Bardon Hill Complexes (fig. 4). On stratigraphic and petrographic evidence the latter may be correlated with the Charnwood Lodge Member. It is thought that these calc-alkaline complexes originated as an explosive volcanic arc on the north-west margin of a basin in which the Charnian sediments accumulated. Vulcanicity became dormant or extinct during Brand times.

(*a*) *The Whitwick Complex*

This is composed mainly of fine- to coarse-grained volcanic breccias and extrusive acid to intermediate dacitic quartz-feldspar-porphyries, with subordinate breccias, lapilli tuffs, very coarse- to medium-grained tuffs and dust tuffs (fig. 4). The type section occupies kilometre squares SK 44.16 and 44.17 and consists of the porphyries at High Sharpley (44771705) and High Cademan (44181690), and volcanic breccias (44031680 and 44501724). Contacts with the tuffaceous shale-pebble conglomerates at Grace Dieu Warren (section 7) and the Bardon Hill Complex are faulted. Bedding or layering is rarely preserved so it is difficult to estimate the thickness of the porphyries and volcanic breccias. The distinctive colouration of the purple groundmass and red, corroded, embayed quartz phenocrysts in the porphyries are due to secondary hematite impregnation. Broken, euhedral and twinned feldspar phenocrysts are of orthoclase, albite, oligoclase and andesine. The plagioclases are sometimes zoned with reverse zoning suggesting mixing. Contacts between volcanic breccias and porphyries are gradational, unless faulted, partly because the matrix and groundmass of breccias and porphyries are recrystallized and partly due to the development of friction breccias by autobrecciation at porphyry margins. Some rounding of the blocks in the volcanic breccias has occurred and may be due to fluidization prior to expulsion and/or downslope movement after explosive ejection in the manner of 'Cannonball bombs' (Francis, 1973).

(*b*) *Bardon Hill Complex*

The quarried area of Bardon Hill represents the type section where the Bardon Hill Complex is composed of acid to intermediate dacitic quartz-feldspar porphyries (petrologically similar to those of the Whitwick Complex), and of the lithologies previously referred to as Bardon Rock (Watts, 1947) which are volcanic breccias, tuffs and brecciated porphyries. Distinguishing between igneous and clastic rocks in the Bardon Hill Complex is often difficult because groundmasses and matrices have been recrystallized obliterating any diagnostic fine textures, and the framework constituents (euhedral and broken quartz and feldspar phenocrysts) of tuffs and porphyries are similar. Evidence for clastic origin is found in some grains which consist of an embayed, cracked quartz phenocryst partly surrounded by original igneous groundmass and abraded feldspar and trachytic grains. These volcanic breccias and tuffs may be correlated with the Charnwood Lodge Member of the Maplewell Group (see Table 5), for both are underlain by the Benscliffe Member at Abbots Oak (46411425) and Collier Hill (4901580) respectively. Also thin slump breccias occur near the top of both stratigraphic units. In Bardon Hill Quarry recent quarrying activities (1983) show the porphyry is intrusive as a small dome some 50 m across into dominantly clastic rocks, some of the clasts being identical with the dacite of the dome, suggesting the dome and its clastic envelope probably belong to a single volcanic episode. Later, sheared dykes, striking 088°, cut the porphyries and may be the same age as a similar dyke in Whitwick Quarry.

Discussion and Conclusions

The Charnian Supergroup is composed of some 3500 metres of thickly-bedded tuffs, pelites and greywackes with comparatively thinly-bedded slump breccias, volcanic breccias, conglomerates and quartz-arenites that have been used previously as long range stratigraphic markers. These special lithologies used by Watts characterize submarine volcanic piles and cannot be regarded as once-only unique events. For example, the discovery of a slump breccia within the Blackbrook Group approximately 1400 m below the Sliding Stone Slump Breccia Member,. and lapilli tuffs within the Sandhills Lodge Member 350 m above the Benscliffe Member indicate that long range correlation of the same lithology is not feasible. Stratigraphic markers such as the Sliding Stone Slump Breccia, Outwoods and Buck Hills Members thin to a feather-edge and these are only of local use for correlation purposes, although still extremely valuable as the only practical means of establishing a stratigraphy. Stratigraphic marker units are rarely composed of one continuous bed, but usually consist of discrete lenses, as in the Hanging Rocks Conglomerate Member, or more than one bed of the same rock type that may or may not be interbedded with finer-grained rocks as in the Sliding Stone Slump Breccia Member. Slump breccias, volcanic breccias, conglomerates and quartz-arenite are inconsistent in thickness and extent and the compilation of the stratigraphy of the predominantly volcaniclastic Charnian succession has been based on dovetailing these short range stratigraphic markers within a pelitic sequence in the absence of reliable regional ones.

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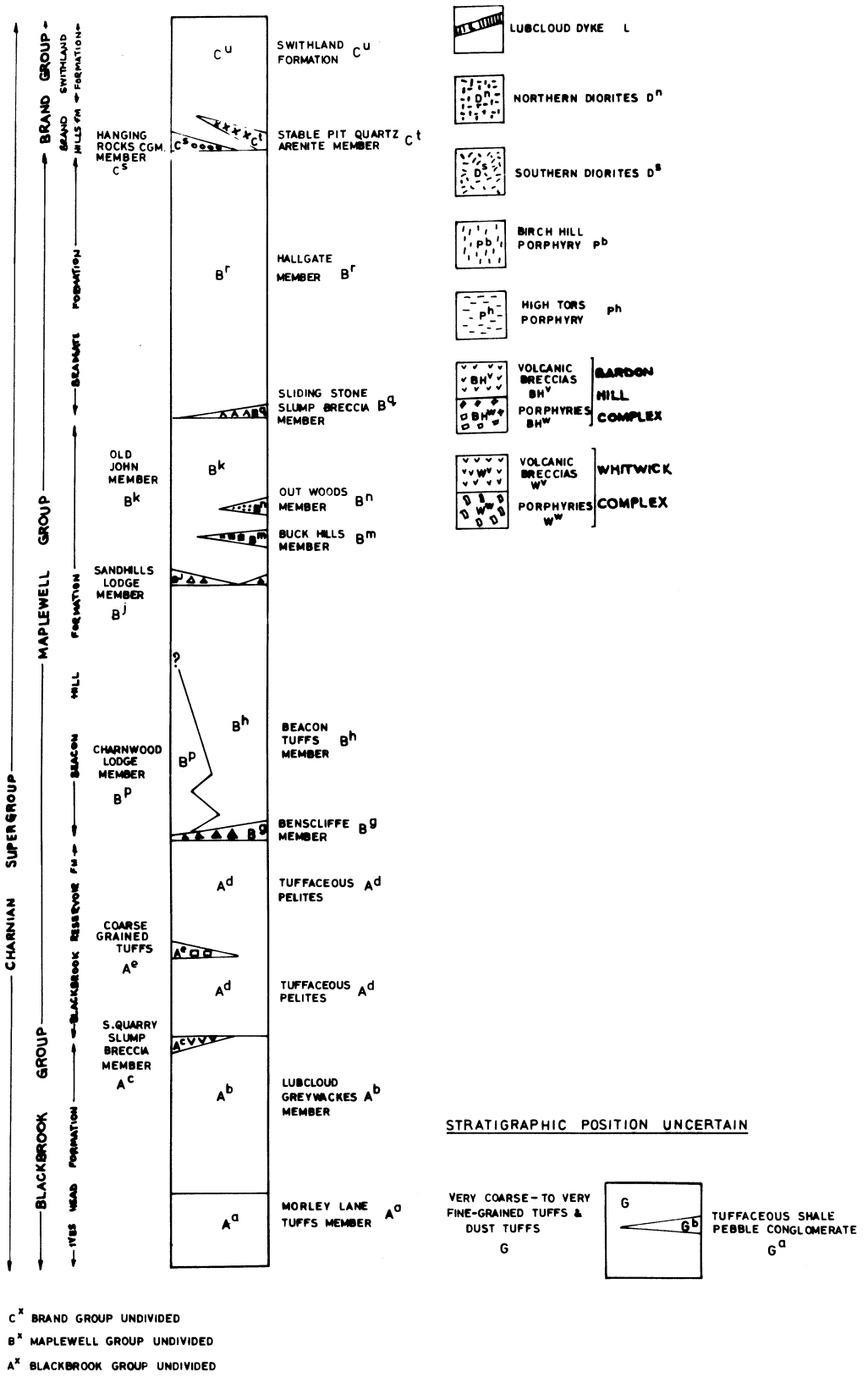
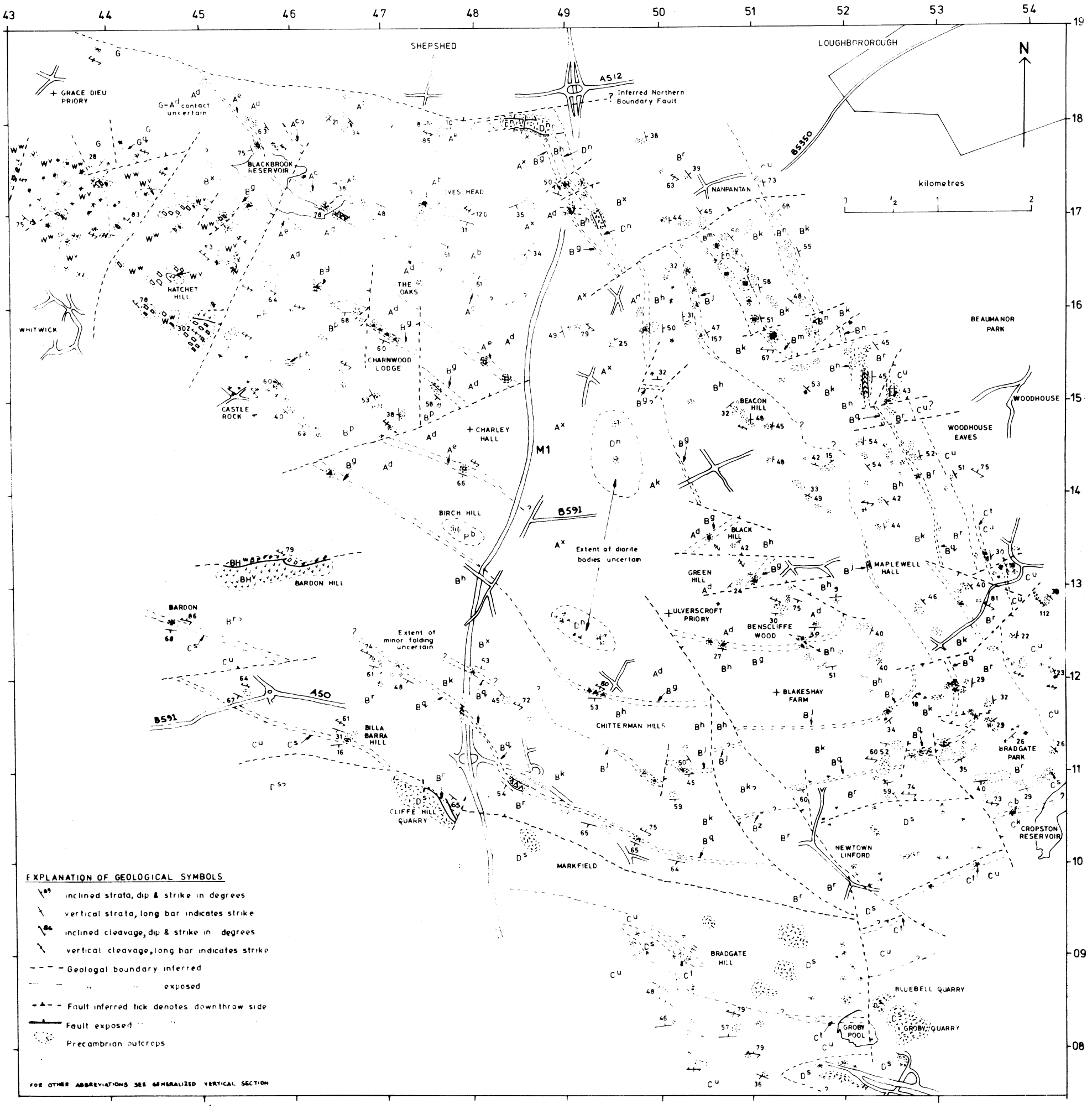


Plate 1 Detailed geological map of the Late Precambrian rocks of Charnwood Forest. (Key above and folded map on facing page)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kilometres
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½
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+ GRACE DIEU PRIORY
G-Ad contact uncertain
BLACKBROOK RESERVOIR
NANPANTAN
BEAUMANOR PARK
HATCHET HILL
THE OAKS
WHITWICK
CHARNWOOD LODGE
CASTLE ROCK
+ CHARLEY HALL
M1
BEACON HILL
WOODHOUSE
WOODHOUSE EAVES
BIRCH HILL
B591
BLACK HILL
Extent of diorite bodies uncertain
GREEN HILL
MAPLEWELL HALL
BARDON HILL
BARDON
+ULVERSCROFT PRIORY
BENSCLIFFE WOOD
Extent of minor folding uncertain
+ BLAKESHAY FARM
A50
BILLA BARRA HILL
CHITTERMAN HILLS
BRADGATE PARK
CLIFFE HILL QUARRY
CROPSTON RESERVOIR
NEWTOWN LINFORD
MARKFIELD
BRADGATE HILL
BLUEBELL QUARRY
GROBY POOL
GROBY QUARRY
EXPLANATION OF GEOLOGICAL SYMBOLS
inclined strata, dip & strike in degrees
vertical strata, long bar indicates strike
inclined cleavage, dip & strike in degrees
vertical cleavage, long bar indicates strike
Geological boundary inferred
" " exposed
Fault inferred tick denotes downthrow side
Fault exposed " "
Precambrian outcrops
FOR OTHER ABBREVIATIONS SEE GENERALIZED VERTICAL SECTION