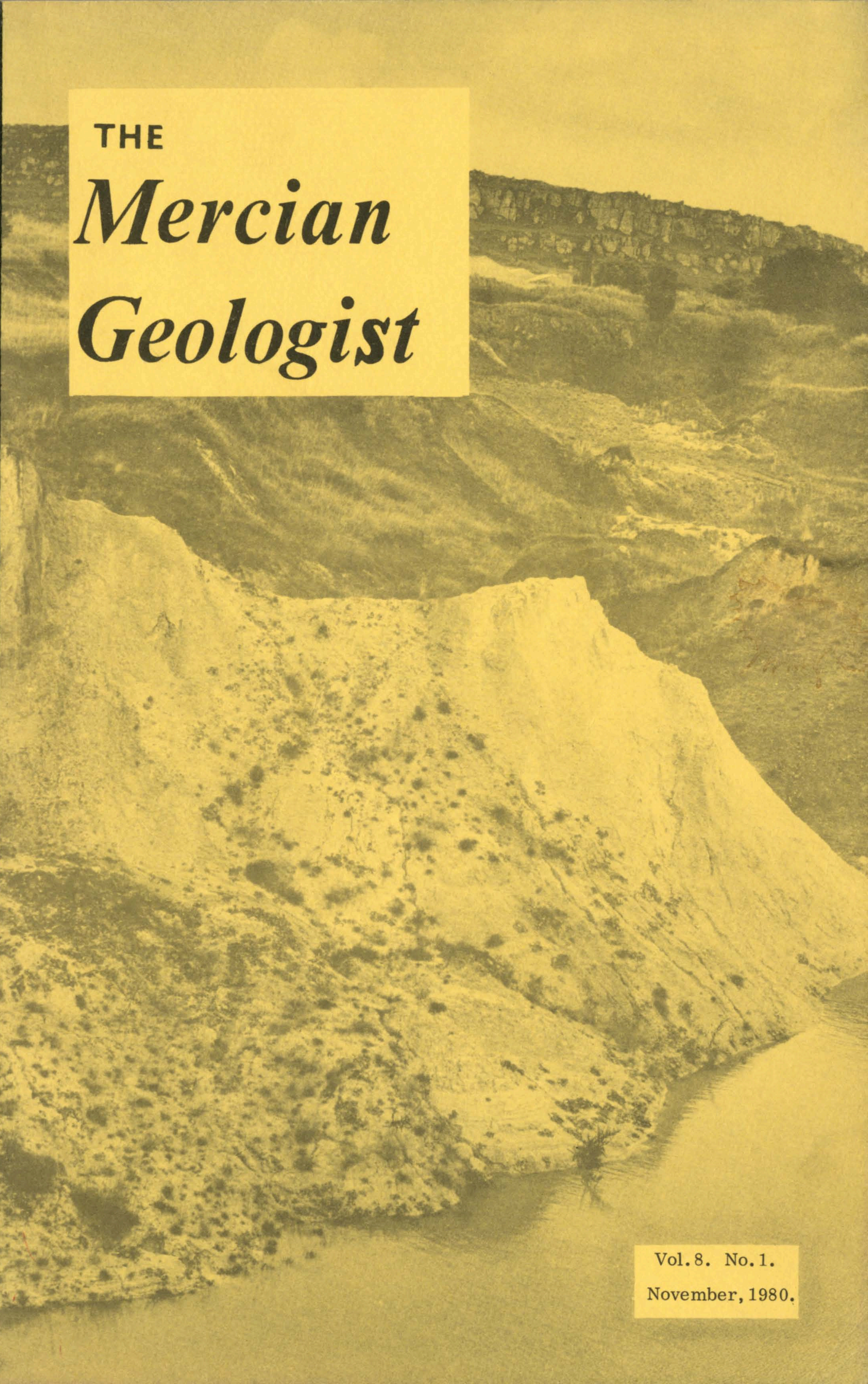
THE
Mercian Geologist



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EAST MIDLANDS GEOLOGICAL SOCIETY

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Front Cover: General view across the disused Green Clay Pit (Brassington Fm.) to the Harboro' Rocks (dolomitised Carboniferous Limestone), Carsington Pastures, Brassington, Derbyshire. (See article by Walsh *et al.*, p.49 *et seq.* this issue.)

FLAWS IN THE CONTINENTAL CRUST

Foundation Lecture, 9th February, 1980[1]

by

Janet Watson, FRS

Summary

The Precambrian portions of the continental crust commonly retain structural patterns formed in response to early global tectonic regimes which bear no relationship to the plate tectonic regime of Mesozoic and Tertiary times. Some large shear zones that were built into the European and North American continents at an early stage have persisted as deep flaws extending into the lithospheric mantle and have influenced crustal movements, magmatism and hydrothermal circulations throughout later geological events. On a larger scale, the architecture of the continents has tended to pre-determine the positions of rift systems formed during the preliminary stages of continental break-up. These relationships raise general problems concerning the functioning of the plate tectonic regime.

The antiquity of continental structures

Among the most remarkable geological findings of the past two decades has been the discovery that the crustal layer which underlies the oceanic basins differs from the continental crust not only in composition and thickness but also in age - the oceanic crust is almost everywhere less than two hundred million years in age, whereas much of the continental crust dates back to at least two thousand million years ago. The characteristic structure of the oceanic crust established by marine geophysical studies has turned out to bear a direct relationship to the process of sea-floor spreading which is responsible for the formation of new oceanic crust (Vine & Matthews, 1963, see Oxburgh, 1974, for a general synthesis). The growth of the crust is achieved by magmatic activity at the mid-oceanic ridges which are sites of abnormally high heat flow; parallel strips of igneous rock added symmetrically on either side of the ridge define a broad striping of the crust which is readily detected by magnetometer surveys. The short life-span of the oceanic crust is a consequence of the fact that the generation of new crust at the mid-oceanic ridges is balanced by the removal of the excess material at destructive plate boundaries where old oceanic crust is forced down into the mantle and largely destroyed. The integrated movements of crustal plates under the present-day tectonic regime of the Earth (the plate tectonic regime) are to a large extent controlled by the effects of sea-floor spreading and the attention of geologists and geophysicists has consequently tended to concentrate on the oceanic parts of the cycle.

The continental crust, on the other hand, is made largely of Precambrian rocks formed under tectonic regimes that have long since ceased to operate. Granitic rocks of low relative

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[1] Contribution to IGCP project 86.

density which form much of the continental crust impart a buoyancy that has rendered the continents almost unsinkable, thereby preserving them as geological entities from a very early stage of the Earth's history. Older portions of the continents may therefore preserve structural patterns which are very much older than the framework of constructive and destructive plate boundaries that control the workings of the plate tectonic system. Given this discrepancy in age, one might expect the early structural features of a continent such as North America to bear little relationship to the tectonic system controlled by sea-floor spreading in the adjacent ocean basins. A closer look at the structural evolution of the continents, however, reveals some unexpected relationships and raises interesting questions concerning the mechanisms by which place movements are initiated. I hope to explore these relationships by reference to early structures of two kinds in the continental crust. In this context, it is convenient to take up the story at about the end of the Archaean era (~2700 Ma) when, for the first times, masses of continental crust several hundred kilometres in diameter and at least 30 kms in thickness began to behave as cratons - that is, as stable and mechanically strong structural units.

Shields and platforms

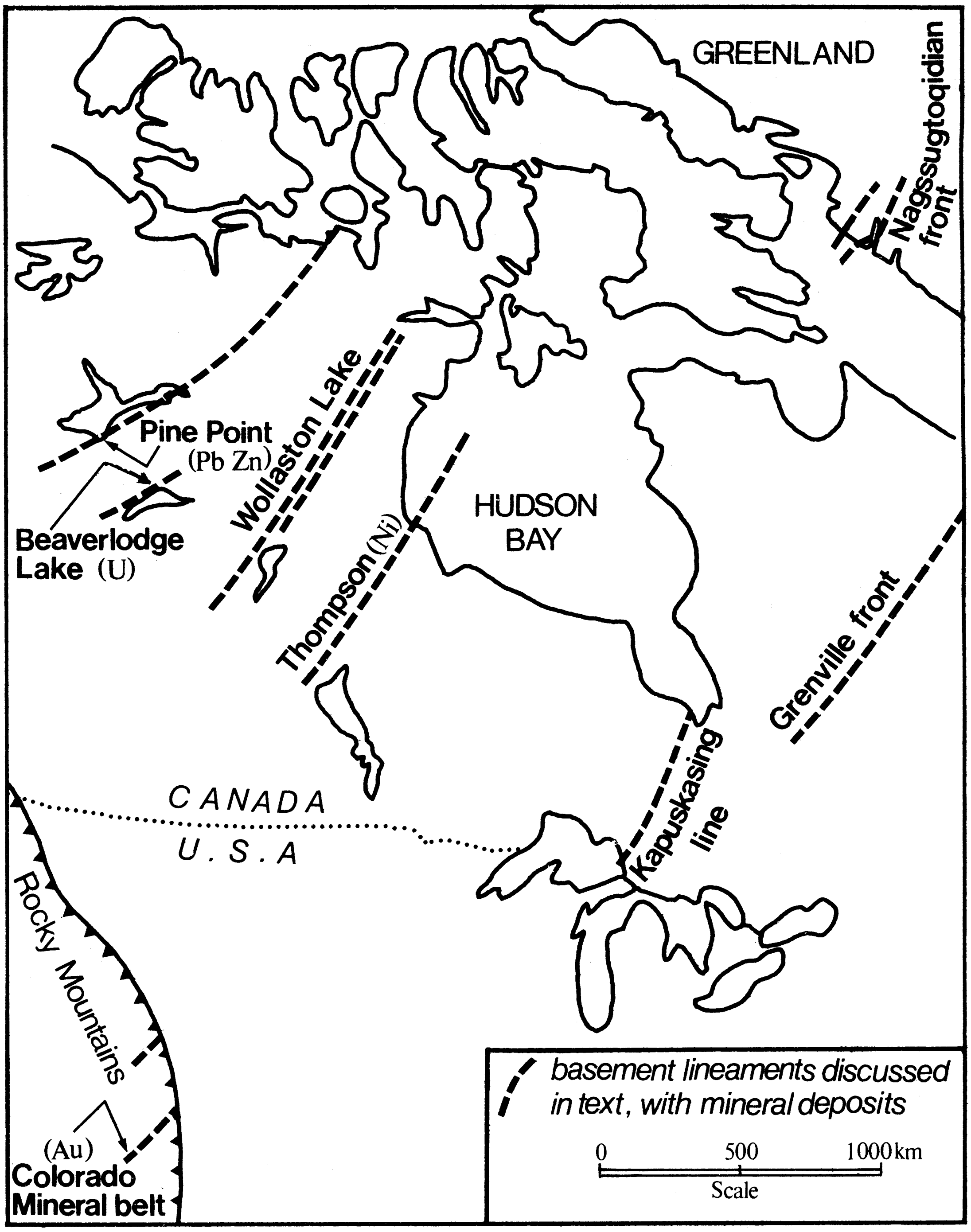
Archaean and early Proterozoic rocks in which early structural patterns remain are exposed today in most of the large Precambrian shields and in a number of smaller shield fragments such as southern Greenland and north-west Scotland. Similar rocks are also found at depth in platform regions, such as those of central USA and the plains of western USSR, where they form a basement lying unconformably beneath a cover of undisturbed younger strata. The structural patterns which were developed during Archaean or early Proterozoic periods of deformation and metamorphism can, of course, be established in the shield areas by the ordinary techniques of geological mapping. In addition, geophysical techniques which can "see through" the undisturbed sedimentary cover may enable one to trace the main structural elements through the platform areas. By these means, one can obtain structural pictures of very large areas in which the small scale complexities that take the eye of the field geologist fall into place as components of a pattern measurable in hundreds or even thousands of kilometres.

When considered on this scale, most ancient basement complexes are found to be traversed by linear zones along which regionally developed structures are distorted or truncated. Such zones evidently mark faults or dislocations on which adjacent masses of the continental crust have moved relative to one another. Examined at close quarters, they reveal a variety of signs of disturbance. Where the basement has not been deeply eroded, a mesh of clearcut faults and shatter zones may be seen, but where deeper sections are exposed, the fracture systems are replaced by steep tracts of mylonites or schists in which a strong metamorphic planar fabric is developed. These shear zones are characterised by distortion rather than disruption of pre-existing structures and are the common products of fault movements in deep crustal environments where high temperatures facilitate metamorphic recrystallisation.

From my present viewpoint, interest centres on large dislocations which were built into the continental crust in Precambrian times, long before the present-day plate tectonic regime came into existence. I shall refer firstly to examples from North America and south-west Greenland and secondly to examples from northern and north-western Europe.

Deep dislocations in North America

A look at the 1:5 million Aeromagnetic Map of Canada (Geological Survey of Canada, 1973) shows that in the area south of Hudson Bay, an irregular pattern of roughly east-west trend is interrupted and distorted by several linear zones of north-easterly trend which have the structural effects of faults. By making use of other lines of evidence, these north-easterly dislocations can be seen to be members of a set extending from south-west Greenland to the Rocky Mountains (text-fig. 1). The distortion of the east-west structures south of Hudson Bay (which are known to be of Archaean age) indicates that they were formed after the Archaean era and a number of lines of evidence suggest that they came into existence very early in the succeeding Proterozoic



Text-fig. 1: Sketch map of the basement of North America showing the shear zones discussed in the text.

era, perhaps about 2500 Ma (Escher *et al.*, 1976; Watson, 1980). Although offsets on individual dislocations seldom seem to be greater than 100-200 km, the scale of the set as a whole is so large as to suggest that they were formed in response to tectonic forces operating on a global scale (Sutton & Watson, 1974; Piper, 1976).

Two aspects of the north-easterly structures are of immediate interest - their vertical extent and their persistence through time. As regards the former, the large horizontal distances over which individual structures extend implies that they must continue down at least to the base of the crust, an implication which is supported by the available geophysical evidence (Innes *et al.*, 1967). An indirect argument based on the occurrence of suites of igneous rocks along certain lineaments suggests that they continue down through the Moho Discontinuity for distances of at least several tens of kilometres into the underlying mantle. Along the Kapuskasing line, for example (text-fig. 1), are scattered small alkaline and carbonatite plugs which are rare in the regions on either side of the line. These plugs (mostly emplaced long after the formation of the dislocation during the period 1700-1200 Ma) are derived from magmas probably originating well below the base of the crust, which appear to have used the old dislocation as a passageway in their upward migration. A more striking illustration of the connection between crustal flaws and magmas generated at depth is provided by the Nagssugtoqidian front of south-west Greenland which is penetrated by many small kimberlitic intrusion of Phanerozoic age. The parent magma of kimberlites, even those which carry no diamonds, are usually considered to have originated at depths of 100-150 km below the surface, an inference which suggests that the Nagssugtoqidian front extends deep into the mantle as an anomalous structure of some sort. Since the kimberlites are 1000-2000 million years younger than the dislocation, it follows that the lithospheric mantle has remained attached to the base of the Greenland continent for this period of time.

The presence of the igneous bodies mentioned above in association with crustal structures orginally formed in early Proterozoic times is, in itself, enough to show that the dislocations have not entirely healed up during the long period since they came into existence. Other lines of evidence point to the same conclusion - for example, a belt of Devonian reef limestones in the undisturbed platform cover of western Canada is lined up along a NE-SW Devonian topographical feature coinciding with the trace of an ancient dislocation in the basement (text-fig. 1). Watterson (1975) has concluded that deep shear zones characterised by strong parallel mineral fabrics constitute permanent flaws in the crust because there are no effective mechanisms for destroying these fabrics. The persistence of the North American dislocations is well illustrated by their relationship to mineralization. Several of Canada's principal concentrations of uranium, deposited from circulating waters of meteoric or juvenile origin, are located in north-easterly basement shear zones in Saskatchewan and Manitoba (text-fig. 1). Far to the south-west, the abundant gold deposits which drew so many nineteenth century prospectors to Colorado are strung out along a north-easterly basement shear zone. The shear zone itself is of Precambrian age (Tweto & Sims, 1963) but the deposits of the Colorado mineral belt are late Mesozoic to Tertiary. The old shear zone appears to have provided a passage for the circulation of hot mineralising solutions and, perhaps, for the uprise of magma from depth.

Deep dislocations in northern Europe

In the European continent, the exposed basement terrain of the Baltic shield is relatively small and if the crust is traversed by old dislocations like those of North America, one would expect only one or two members of the set to be exposed. There is, in fact, a major lineament of NW-SE trend which extends from the head of the Gulf of Bothnia to Lake Ladoga as a zone of structural disturbance containing a variety of mineral deposits (Kahma, 1973). This lineament played an important structural role during the early Proterozoic (Svecofennide) tectonic cycle and is therefore of much the same age as the Canadian dislocations. Although, on the principle that one swallow does not make a summer, too much cannot be read into this structure, the possibility that it originated as one of a set of parallel dislocations is enhanced by the occurrence of several anomalous NW-SE lineaments in the platform area south-west of the Baltic shield.
Chief of these structures is the Tornquist line which extends for some 1200 km from northern Denmark to southern Poland. The Tornquist line is thought to coincide with the boundary between

two tectonic provinces in the basement (e.g. Khain, 1977) and although its history cannot be carried back beyond about 1000 Ma it evidently originated in Proterozoic times. Variations of sedimentary facies and thickness in the overlying formations show that it was the site of repeated vertical movements from late Precambrian to Mesozoic times.

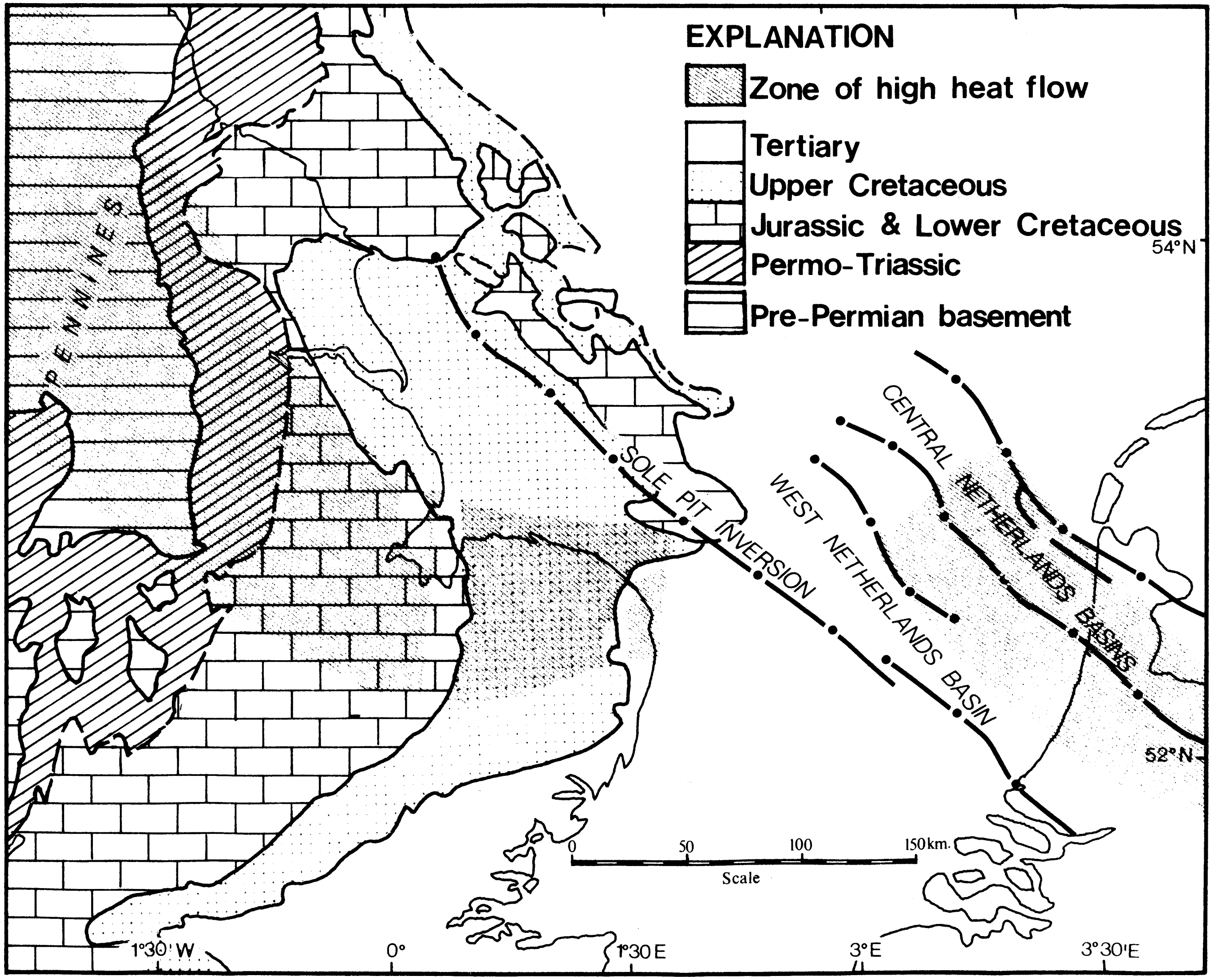
To the west of the Tornquist line, the basement of northern Europe is traversed by a system of branching rift and horst structures developed in early Mesozoic times as a result of the stretching of the continental crust immediately before the severance of Europe from North America that led to the opening of the Atlantic Ocean. Although the development of these rifts and associated structures appears to have been directly controlled by the plate tectonic regime responsible for the widening of the Atlantic and Indian Oceans by the process of sea floor spreading, it is worth enquiring whether the location and alignment of the faults themselves had any connection with the pattern of pre-existing dislocations in the basement. Evidence on this topic comes not only from Britain and the Low Countries but also from the North Sea where the principal Mesozoic rifts have attracted considerable attention on account of their influence on the distribution of oil and gas fields (e.g. Kent, 1975; Ziegler, 1978).

In eastern and northern England, where Carboniferous and Mesozoic rocks form most of the surface outcrops, an idea of the basement structure can be gained from aeromagnetic maps (Institute of Geological Sciences, 1965, 1972). Three "noisy" tracts of strong anomalies are seen on these maps running north-westward from East Anglia and the south Midlands for distances of up to 350 km (text-fig. 3). Comparison with the geological map shows that they are unrelated both to the distribution of Mesozoic strata and to the Pennine axis which controls the structure of the more disturbed Carboniferous. Hence, it seems certain that the north-westerly anomalies have their origin in pre-Carboniferous structures of some kind. It is unlikely that these anomalies relate directly to the distribution of individual pre-Carboniferous stratigraphical divisions because a single anomaly - for example, that running north-westward from the Wash - appears, from the palaeogeological map (Wills, 1978) to pass through regions underlain by basement units of several different ages.

Two alternative interpretations of these observations can be envisaged. One is to attribute the north-westerly zones of "noisy" aeromagnetic patterns to the occurrence of Caledonian (roughly end-Silurian) or pre-Caledonian igneous intrusions. The granitic plutons known to underlie the Trias near Leicester do, in fact, lie near the southern end of a lineament which continues north-westward through Derbyshire. Evans & Maroof (1976) have suggested that basement (Caledonian?) granites also underlie the Derbyshire section of the lineament and that these granites acted posthumously as a heat source which facilitated the formation of the famous lead-fluorite mineral deposits in the unconformable Carboniferous cover. A spatial connection between lead-zinc fluorite deposits in Carboniferous rocks and an underlying pre-Carboniferous granite has already been demonstrated in the north Pennine orefield where the buried Weardale granite, predicted from gravity surveys, has been encountered in the Rookhope borehole (Dunham *et al.*, 1961). The hypothetic Market Weighton granite (Bott *et. al.*, 1978) lies close to the long anomalous zone passing through the Wash; and the central Pennine orefield is also located on this zone.

An alternative possibility, which I myself favour, is that the north-westerly anomalies mark a mesh of old faults in the basement which locally acted as conduits for rising bodies of magma and which also served to focus hydrothermal convection systems in the Carboniferous and post-Carboniferous cover. Such a fault mesh would have to date back at least to Lower Palaeozoic and more probably to Precambrian times.

The picture of a heavily fractured basement underlying Carboniferous and younger strata is reinforced by recent studies of the Brabant massif which extends at depth from East Anglia south-eastward to the Netherlands (text-fig. 3). The Brabant massif has long been known to have formed a stable block during the Hercynian orogeny. Bless, Bouckaert and Paproth (1980) consider that it also escaped severe deformation during the Caledonian cycle and that it consists essentially of a mosaic of NW-SE horst blocks separated by linear basins which subsided to receive sequences of early Palaeozoic sediments. Combining the evidence from England and the



Text-fig. 2: The geology of eastern England and the south-western North Sea.

Netherlands, we arrive at the possibility that extensional fault systems with a predominant north-westerly trend had been built into the crust by late Precambrian or earliest Palaeozoic times. This possibility is in keeping with Evans' (1979) view of the principal basement structure of the Midlands as an aulacogen or fault-trough branching from the Iapetus Ocean rather than with the alternative favoured by some authors that the Midlands are underlain by a branch of the Caledonian orogen itself.

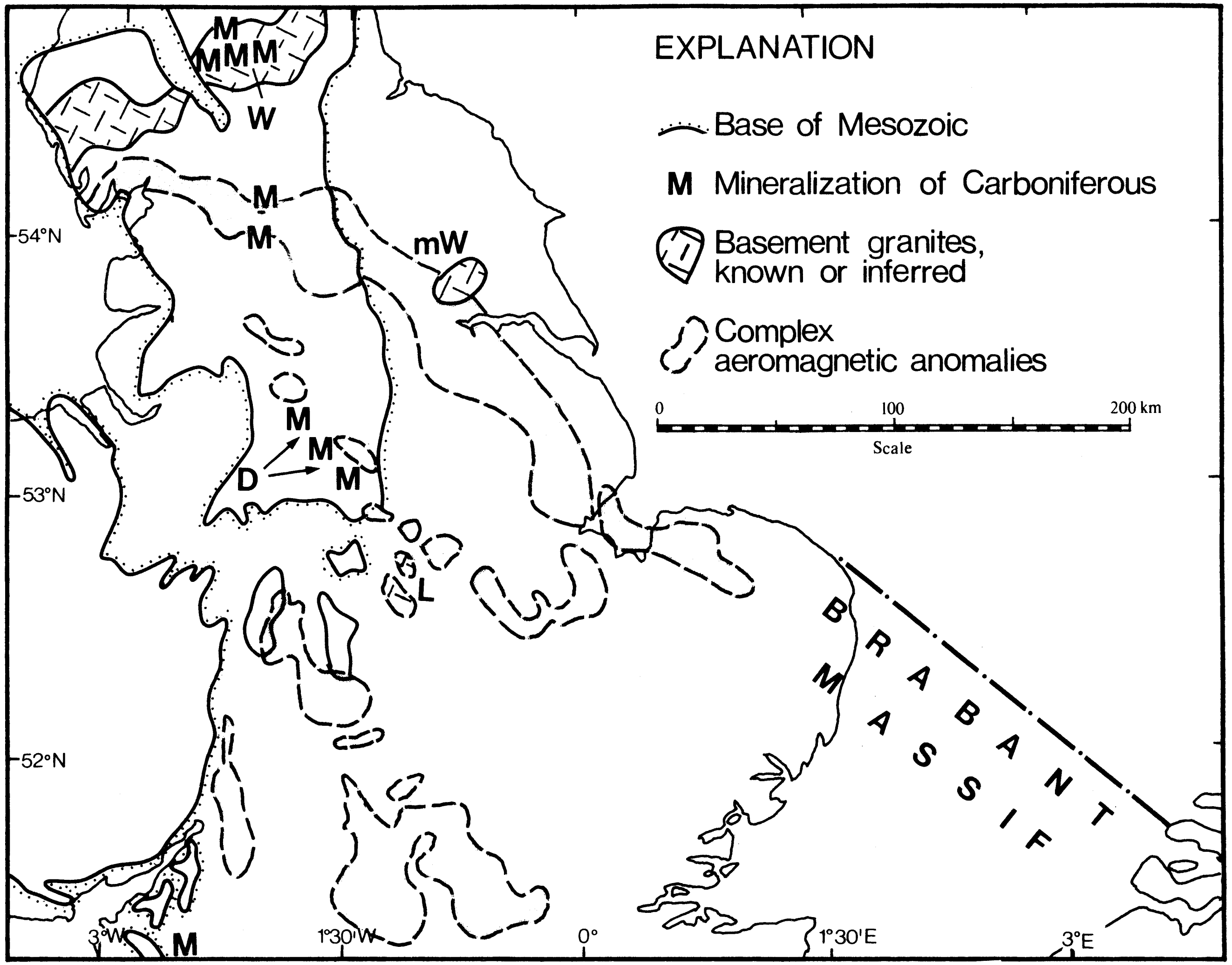
In the light of the evidence discussed above, the NW-SE orientation of the principal rifts and horsts in the southern North Sea which were formed under extensional early Mesozoic tectonic regime acquires a new significance (text-fig. 2). Bless *et al.* (1980) emphasise the parallelism between the sedimentation trends for the Carboniferous and for the Jurassic and Lower Cretaceous of the West Netherlands basin, and remark that other NW-SE fault systems in the Netherlands may also turn out to be formed by rejuvenation of Palaeozoic structures. The Sole Pit trough which skirts East Anglia and the Yorkshire coast with a SE-NW orientation developed as a subsiding trough in early Jurassic times and was subsequently uparched during a late Cretaceous phase of mild compression (Sole Pit "inversion", text-fig. 2). The Dowsing fault which marks the western boundary of the trough parallels the linear magnetic anomaly extending north-westward from the Wash and lines up closely with the eastern margin of the Brabant massif (text-fig. 3). There is thus a good case for supposing that the deformation of the north-west European crust caused by the initial stages of Atlantic opening was achieved largely by the reactivation of fractures built into the basement under a different and much earlier tectonic regime. Evidence for the persistent influence of north-westerly basement structures down to the present day is supplied by Richardson and Oxburgh's discovery (1979) of a NW-SE province of above average heat flow in northern and central England (text-fig. 2).

The disruption of continents

Although the crustal structures discussed in the last sections are not of the first order of magnitude when considered in terms of global tectonic regimes, the roles which they appear to have played in modifying the responses of the old continental cratons are of interest in several respects. In the first place, we have noted a few instances in which fractures developed under the extensional tectonic regime controlling the opening of the Atlantic Ocean are sited on older basement dislocations independent of this regime: thus, the pattern of fractures bore no direct relationship to the controlling stress system. In the second place, distinctive igneous activity originating in the mantle has been localised with respect to the siting of much older structures in the crust.

To see these relationships in context, it is helpful to look at the global pattern of structures related to the plate tectonic regime. At the present day, the arrangement of continents and oceans is the end product of a series of plate movements involving the widening of the Atlantic and Indian Oceans by sea floor spreading and the consequent dispersal of the continental masses adjacent to these oceans. At the start of this period, the continents were massed together in the supercontinents of Laurasia and Gondwanaland and the crucial event that set the Mesozoic-Tertiary cycle of continental drift in motion was the opening-up *within the super-continents* of connected fracture systems at which the continents parted company. In Europe, as we have seen, the preliminary fracturing was associated with the development of rift structures such as those which traverse the North Sea. Investigation of the borders of the Atlantic and Indian Oceans, stimulated by the search for oil, has shown that a similar phase of rifting of the continental crust preceded the opening of the oceans almost everywhere. The newly formed mid-oceanic ridges which were to be responsible for the growth of the oceans therefore made their appearance along predetermined lines in the crust of the supercontinents.

As early as 1965, Kennedy realised that the marginal rifts which define the fracture coast-lines of Africa were not haphazardly placed with respect to the structure of the continent. He showed that the sediment-filled marginal Mesozoic fault basins had been developed in regions where the basement had been strongly deformed and metamorphosed during a late Proterozoic to early Palaeozoic (Pan-African) cycle of crustal mobility. As a result of this selective placing



Text-fig. 3: Inferred basement structures in England.
D: Derbyshire L: Leicestershire
mW: Market Weighton W: Weardale

of the marginal fracture systems, the large tectonic provinces in which the basement had remained stable since Archaean or early Proterozoic times lie intact in the interior of the continent and only occasionally emerge at the coastline.

The fundamental relationship between the history of the continental crust and the siting of fractures destined to give rise to new oceans which Kennedy established in Africa (1965) has turned out to be of worldwide significance. In North America and Europe, for example, the Atlantic coasts follow the early Palaeozoic Caledonian-Appalachian orogenic belt for very long distances, only occasionally (as in north-western Scotland) trespassing into tectonic provinces where the basement has remained undisturbed since earlier Precambrian times. It seems to follow that the positions at which the new oceans began to form were determined very largely by reference to the structural history of the continental crust, together with the attached lithospheric mantle.

These inferences suggest that there may need to be a shift of emphasis, in the interpretation of plate tectonic systems, from sea floor spreading which is now rather well understood to the processes which precede the development of a new mid-oceanic ridge. The association of the ridges with magmatism originating in the mantle and the high heat flows characteristic of ridges have led many people to think in terms of a control involving mantle upwelling and/or the activity of mantle hot spots. Such mechanisms, however, leave unexplained the selectivity of the continental fracture systems whose development pre-determines the sites of the new oceans. Perhaps the time has come to look more closely at crustal and mantle processes in the continents.

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THE LOWER CARBONIFEROUS VOLCANIC ROCKS OF THE ASHOVER AREA, DERBYSHIRE

by

P. M. Kelman

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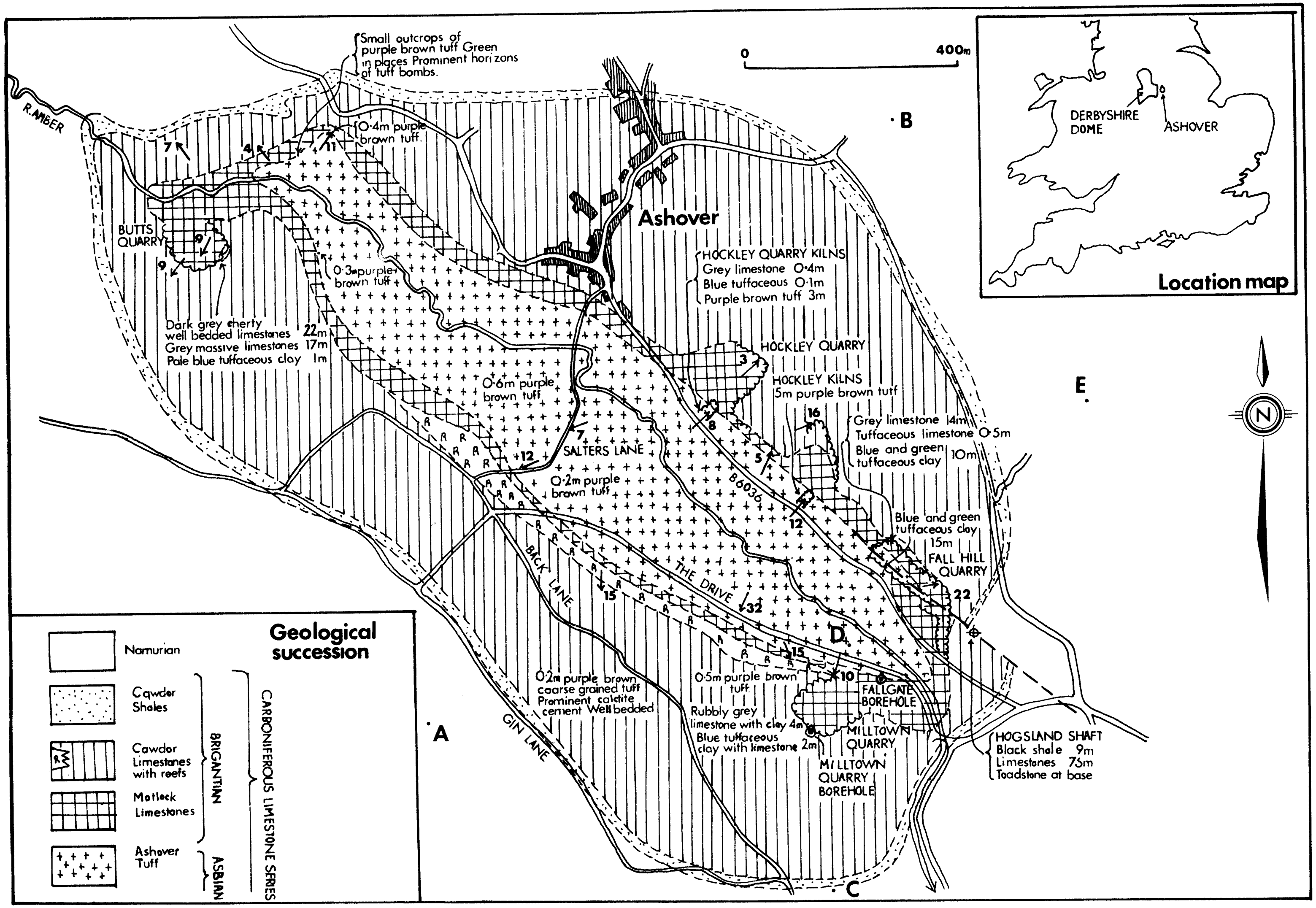
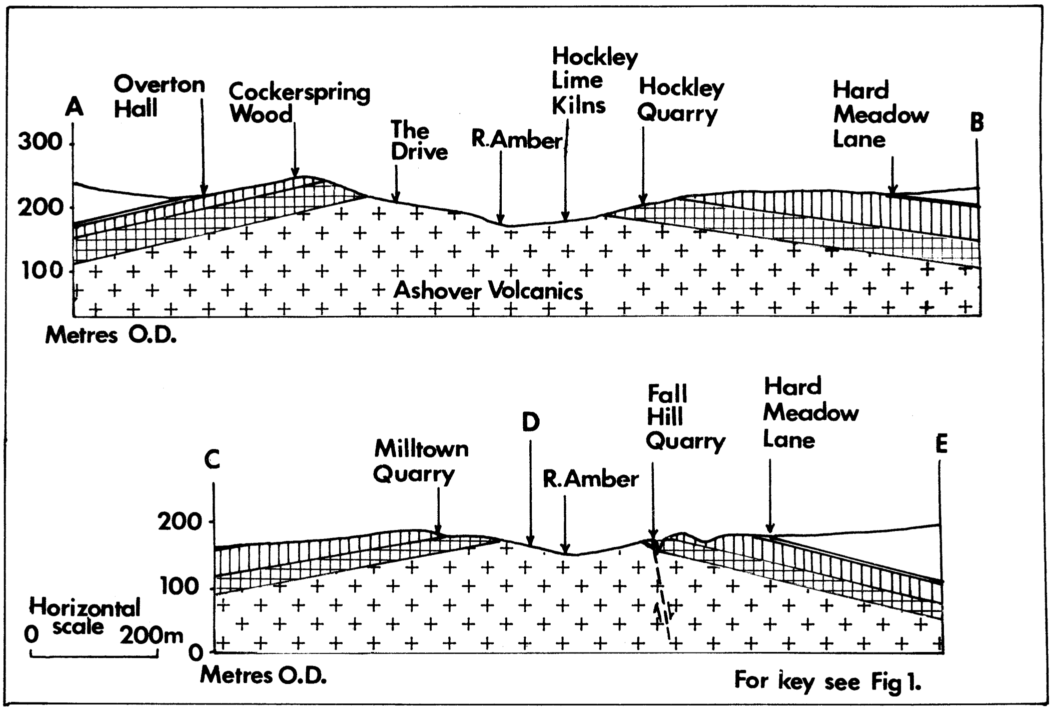
1980, pp.11-28, 9 text-figs.



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.

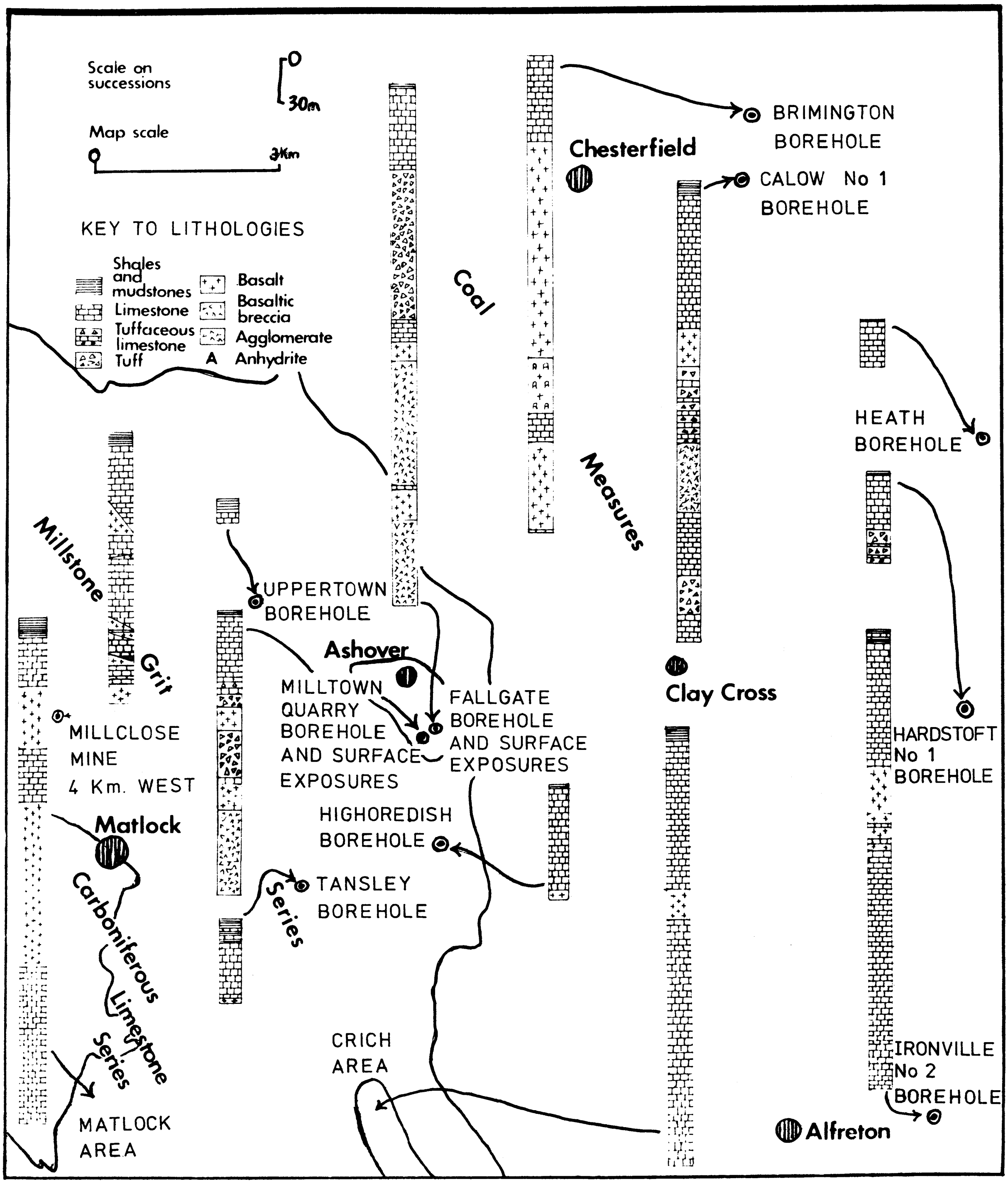
Palaeoenvironmental context

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).

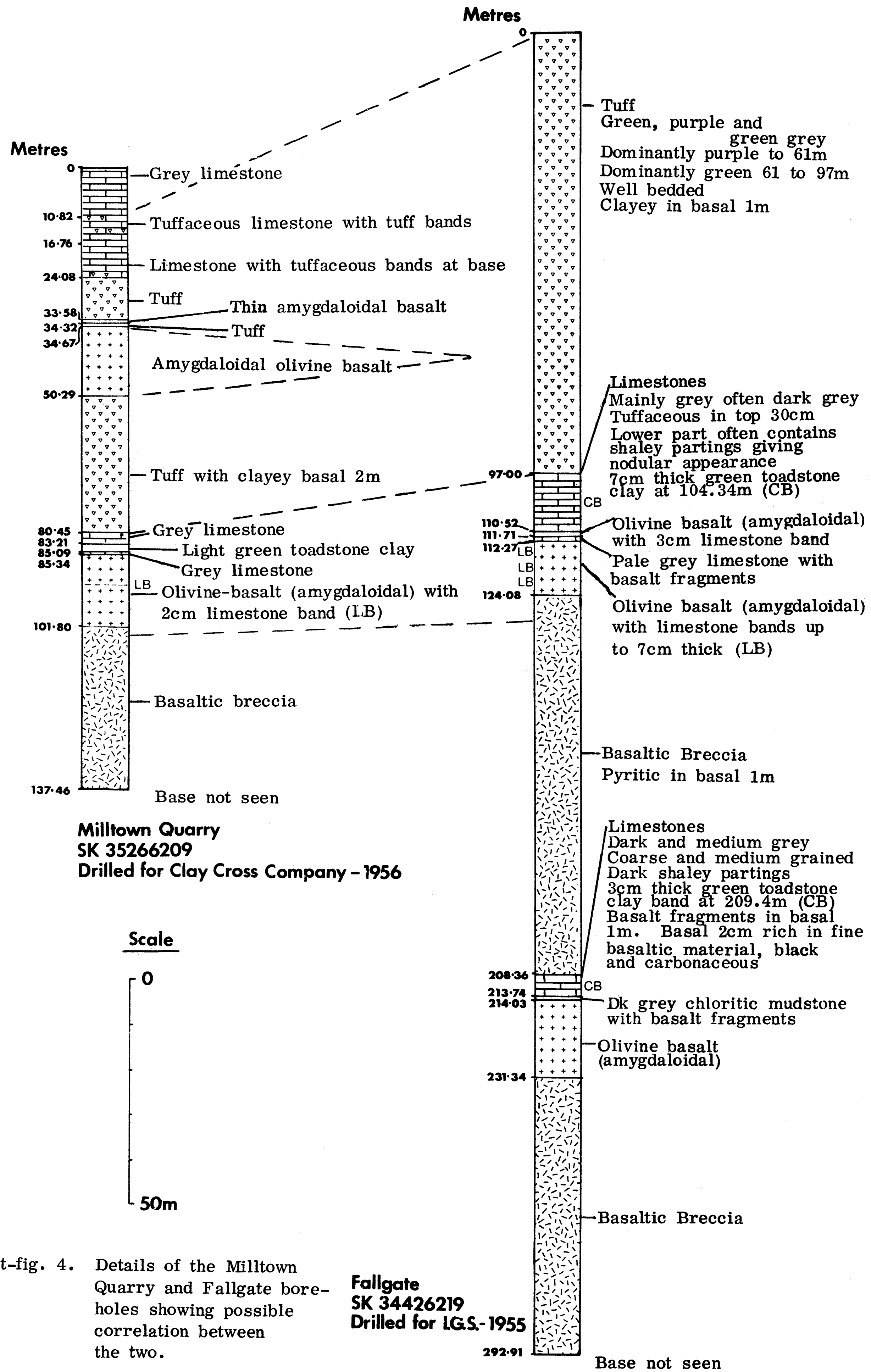
The shallow marine deposition on the platform was at several times interrupted by volcanic episodes throughout the Matlock and Ashover areas, especially in Asbian and Brigantian times. These are represented by the extensive lava flows making up the Upper and Lower Matlock Lavas in the Matlock area (table 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

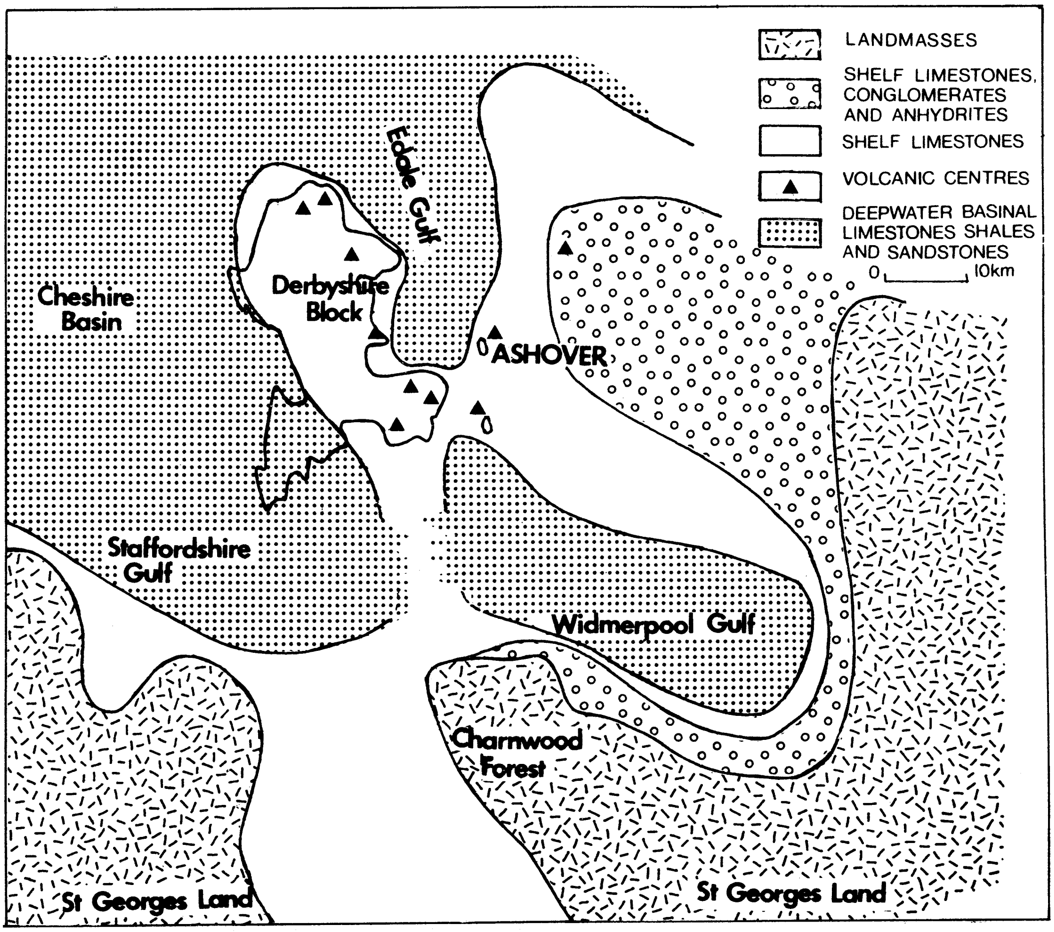
The volcanic rocks comprise three lithological types: tuffs, olivine basalts and basaltic breccias. The tuffs are well represented at the top of the sequence in a formation called the Ashover Tuff. The upper section of the Tuff is the only part of the volcanic sequence exposed



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



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



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

Table 1: Dinantian stratigraphical table

Local succession			Classical faunal zonation in the area	Regional stages (George *et al.*, 1976)
Matlock		Ashover		
NAMURIAN				
Cawdor Group			P_2 Upper Posidonia	
Shale on limestone 20-60m				Brigantian
	Upper Matlock Lmst	Limestones	D_2 Upper Dibunophyllum	
Matlock Group Up to 80 m excluding lava	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 C_2S_1 C_1 K	Holkerian Arundian Chadian 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.

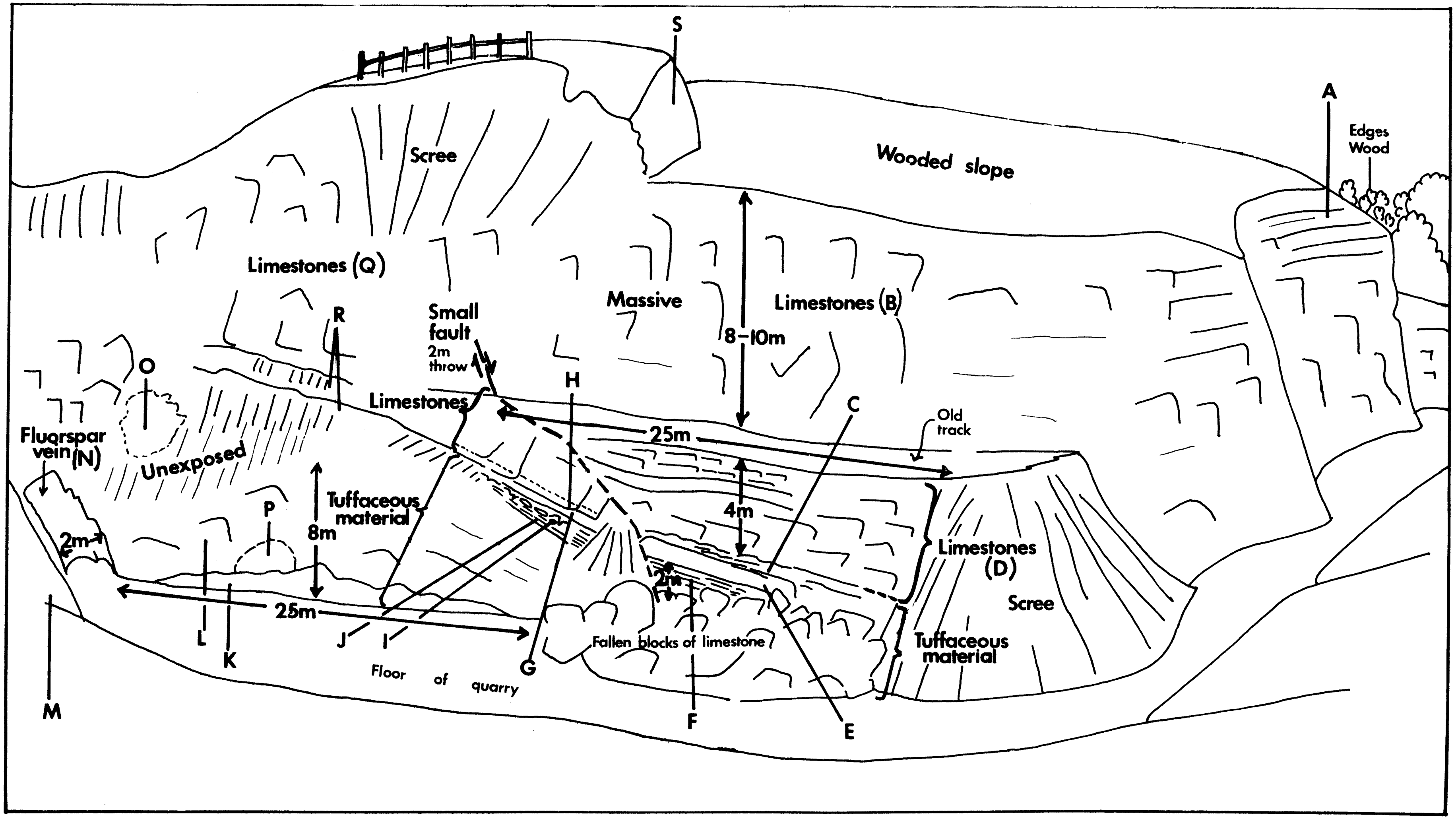
(a) Purple-brown tuff. Most of the surface exposures are composed of purple-brown tuff including those at Hockley Quarry, Hockley Lime Kilns and exposures along The Drive (351623). This rock also occurs between 0-60m in the Fallgate borehole where it appears to pass gradationally downwards into a dominantly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

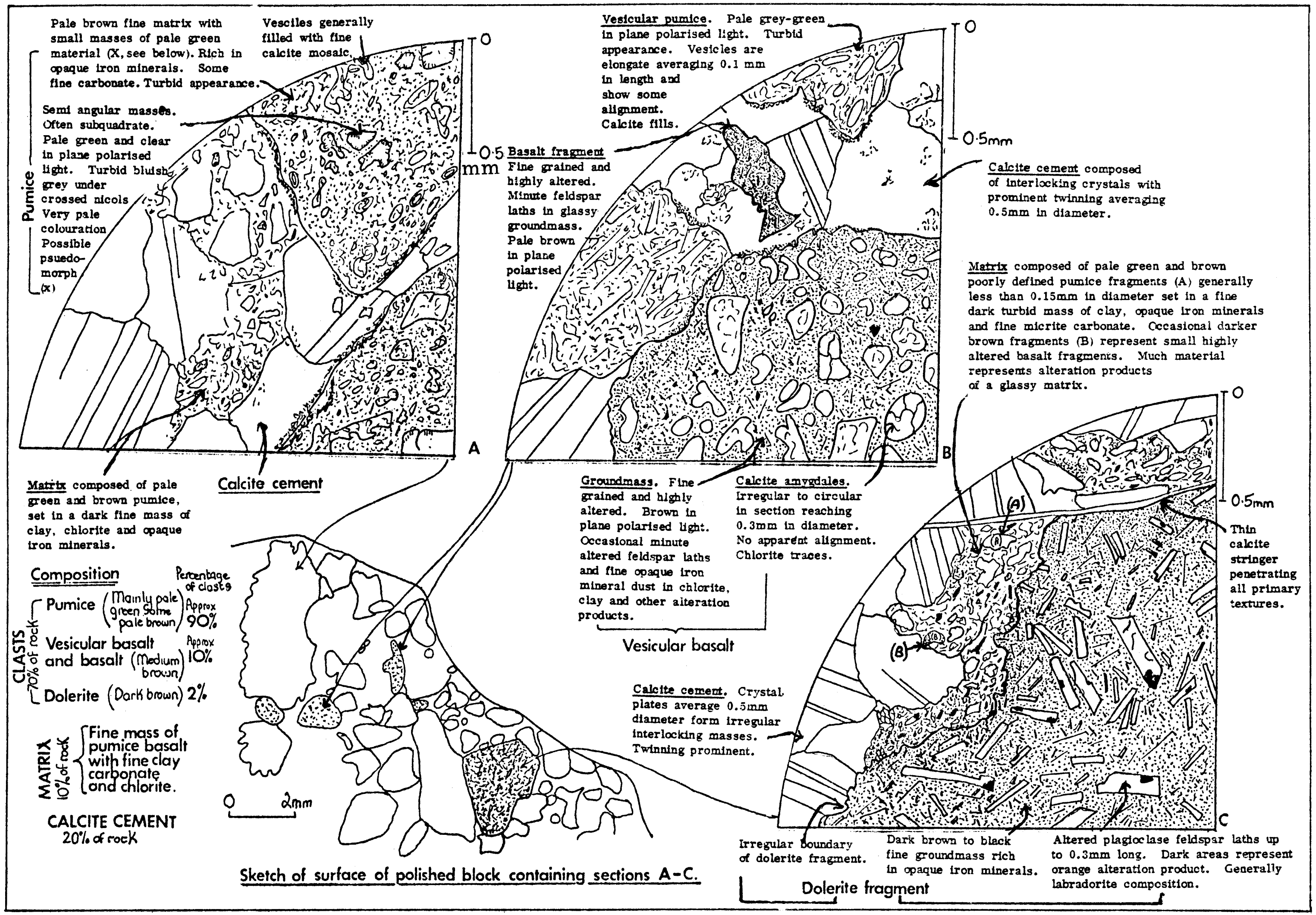
N. Fluorspar vein. Orange mineral and replaced limestone containing tuffaceous material. The vein represents a fault zone the tuffaceous clay being downthrown 10 m on the east side of the vein.

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.



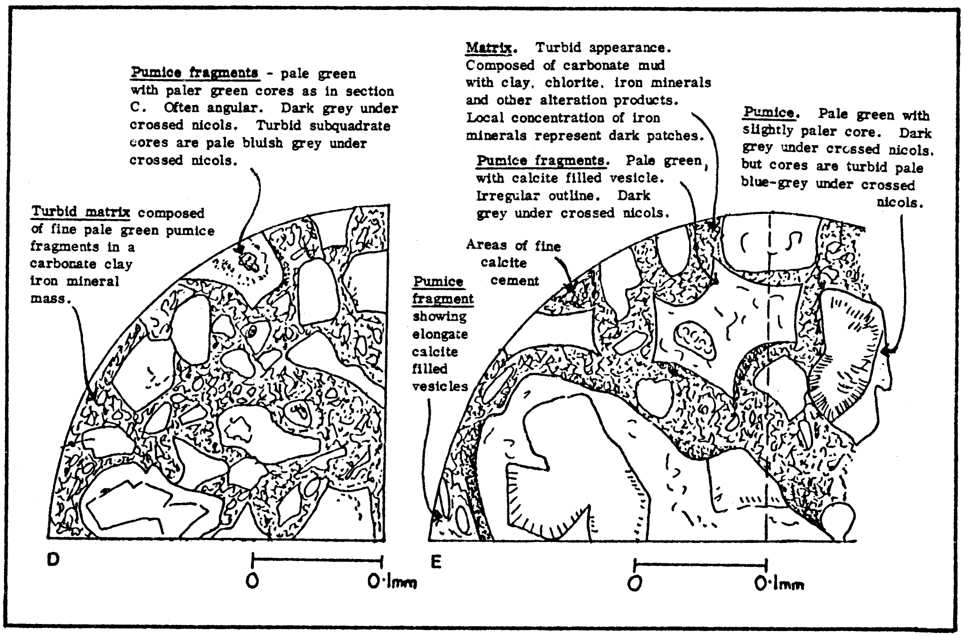
Text-fig. 7: Thin sections of the Ashover Tuff viewed in plane polarised light. A, B and C are from a single section of the purple brown tuff collected at the Drive (SK 351623).

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
Total Iron as Fe_2O_3	9.52	8.75	13.68	8.02	7.83	9.00	3.89	2.62	2.22	Fe_2O_3
							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.

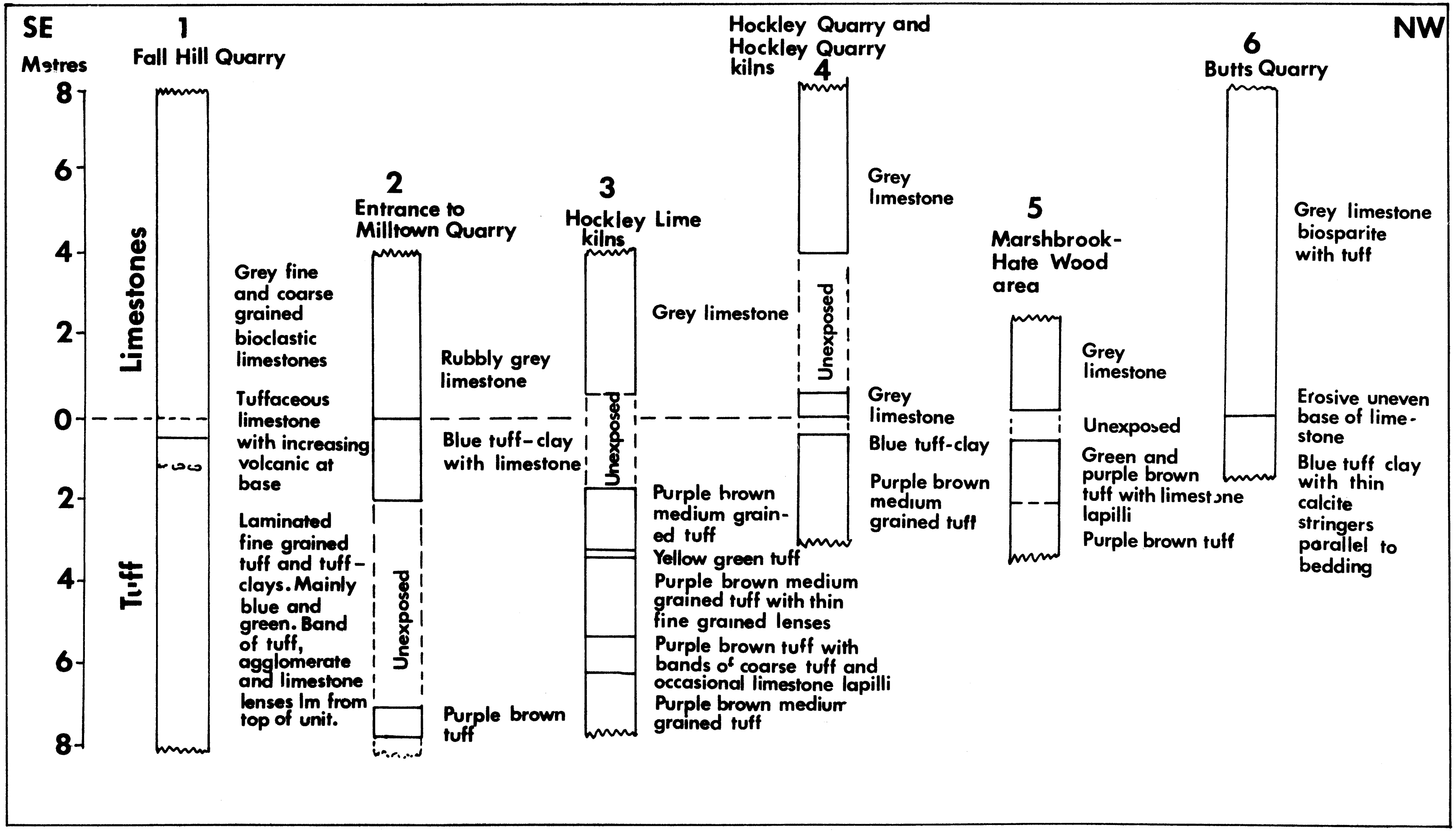
Limestones overlie the basalts in both boreholes. Usually they are grey, fine and medium grained bioclastic limestones with fossils suggesting a low D_2/high D_1 zone including crinoid ossicles, brachiopods (notably productids) and corals including *Lithostrotion martini*. In the Milltown Quarry borehole 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.

Acknowledgements

Thanks are due to staff in the Division of Geology at Derby Lonsdale College of Higher Education for advice and the provision of laboratory facilities. I am also grateful to the Institute of Geological Sciences at Leeds for the use the Institute's Petrology Laboratory and access to core samples from the Fallgate borehole. Finally, I would like to thank Mr. F. Hardy for allowing use of the facilities of the Tarmac central laboratory where many of the chemical analyses were performed.

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THE SECOND AND THIRD TERRACES OF THE RIVER NENE

by

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Summary

The distribution, composition and stratigraphy of the River Nene's Second and Third Terrace gravels are studied, following the author's earlier study of the River Nene's floodplain and First Terrace gravel sequence. The three terrace sequences are seen to be substantially similar and imply similar palaeoclimatic conditions at the time of emplacement. No absolute dates are available for the older terraces, but the circumstantial evidence for deposition within cold (periglacial) sub-stages of the Devensian is strong and the author suggests an outline chronology for the Nene valley using terrace type-areas as names for the major stadials. A map of a sample reach of the author's reconstruction of the former extent of the older terrace gravels is included; this clearly indicates that the regular form of the meandering valley has evolved during the Devensian and that the large wavelength meanders have become better defined with each successive cold sub-stage.

Introduction

The River Nene (text-fig. 1) is of medium size compared with other English rivers, being roughly half as long as the River Thames. The Nene has a channel length of some 167 km (104 miles), a mean annual discharge of 8.6 cumecs at Orton Longueville, the lowest gauging station on the river, and a catchment area of 2370 km^2 (915 $miles^2$). In each respect it is somewhat smaller than its neighbour, the Great Ouse, which once joined the Nene at Upwell in the Fens; the two waters originally flowed together for the last 10 km to a common outfall at Wisbech. The Great Ouse changed its course in the thirteenth century, making a separate outfall at King's Lynn, to which it has kept ever since. Since that time, the mouths of both rivers have advanced seaward, towards the centre of the Wash, as they have become choked with silt and sand. In this way, the rivers may eventually be re-united and receive as tributaries the lesser rivers which also drain to the Wash: the Witham, Glen and Welland. It will be apparent from discussion later in this paper that the Fenland rivers have been joined together in the remote past, as headstreams of a more extensive river system than exists in the region today.

As yet, little is known of the denudation chronology of these rivers. Worssam & Taylor (1969) discussed the four terraces of the River Cam at Cambridge and suggested a chronology for them. Straw (1958) ascribed the Martin and Southrey Terraces of the River Witham in Lincolnshire to the last (Devensian) cold stage. Horton *et al.* (1974) gave a Devensian date

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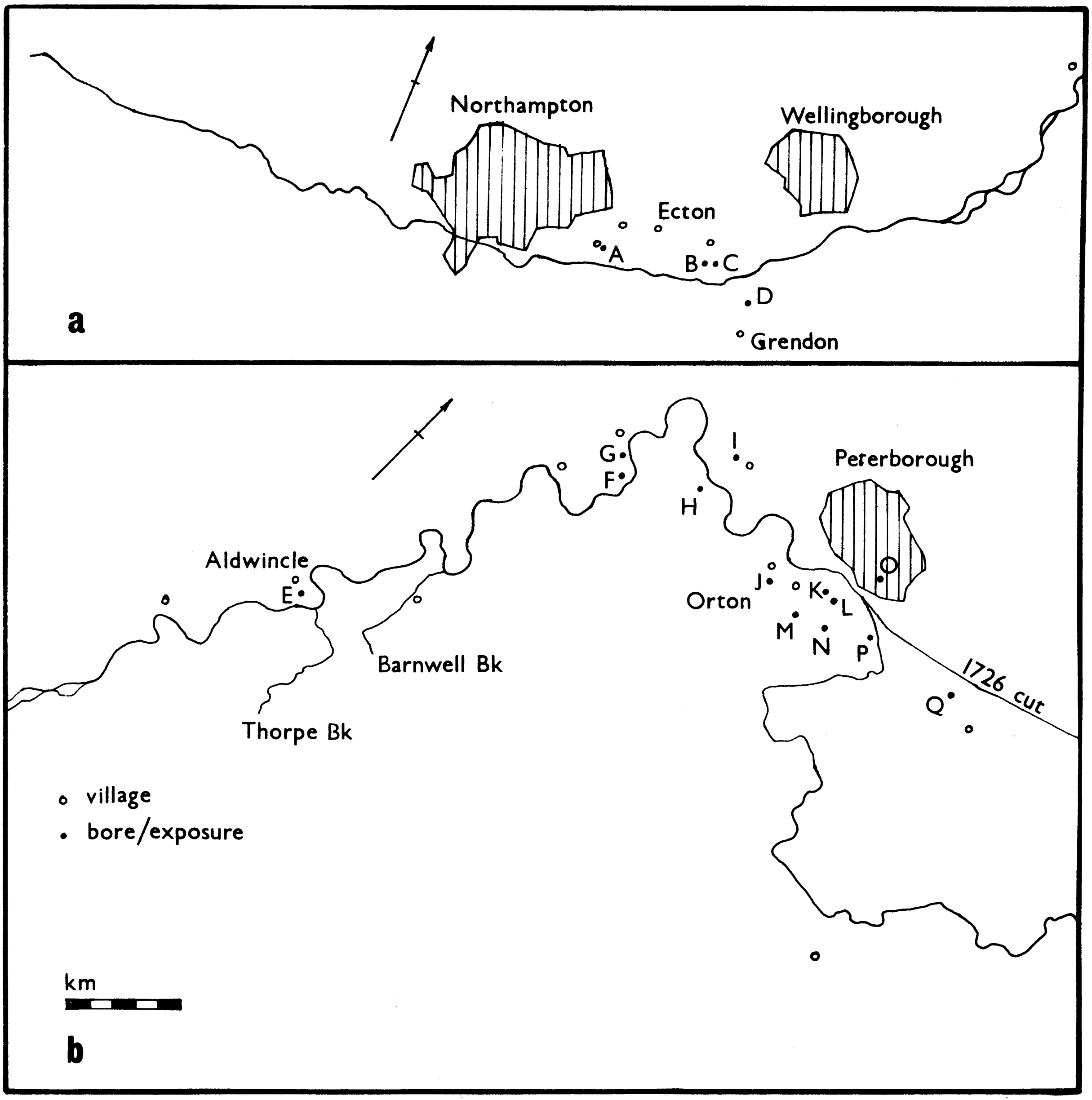
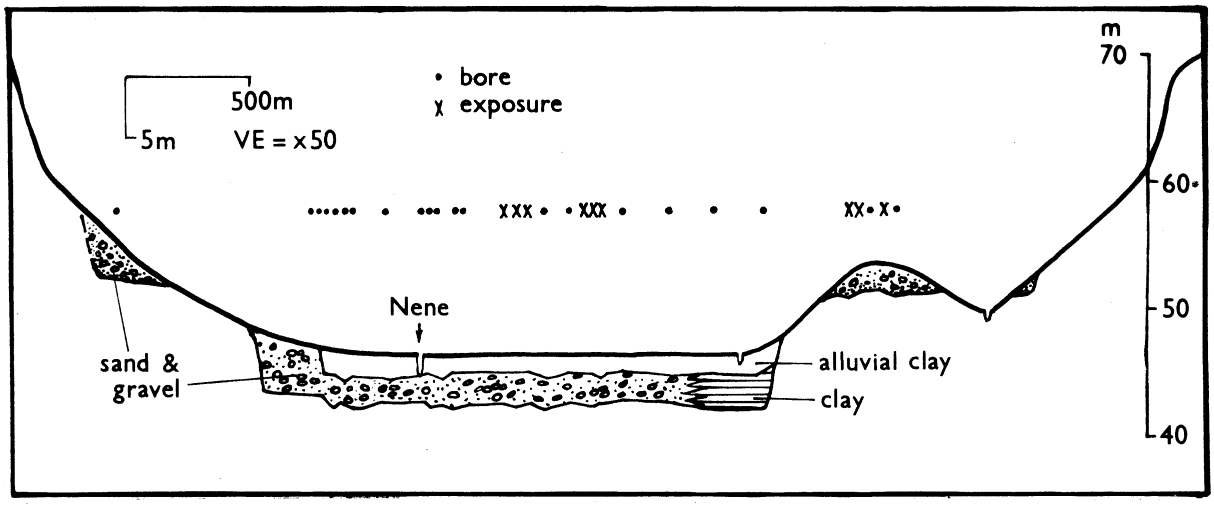
1980, pp. 29-46, 6 text-figs.



Text-fig. 1: The location of major terrace sites in the Nene valley;
a, source to Woodford; b, Woodford to March and Whittlesey.
All lettered sites are named in Table 3 except the following:
I = Ailsworth, J = Orton Waterville, M = Orton Longueville, N = Woodston



Text-fig. 2: A section across the Nene valley from Earls Barton (left) to Grendon (right).

to the First and Second Terraces of the Great Ouse, based on a single radiocarbon date for an ambiguous deposit at Earith. Taylor (1963) stated that the Nene's three terraces are 'post-glacial' (i.e. post-Wolstonian). The regional chronology is precariously tenuous, and there has been no really systematic exploration of any of the terraces mentioned: the Welland terraces do not appear to have been studied at all. Thus, the establishment of a reliable chronology for the terraces of at least one of the Fenland rivers would be regarded as a major advance.

The author's earlier paper (Castleden 1976) investigated the nature of the Nene's floodplain and First Terrace gravel deposit. It was shown that the basal gravels of that sequence were laid down from 28,000 BP onwards, and the uppermost layers were being deposited as late as 9,000 BP. The texture, stratigraphy and organic remains were used as evidence of the palaeoenvironment at the time of deposition.

This paper investigates the gravels of the Second and Third Terraces of the Nene valley. The study of the floodplain gravels revealed a subjacent pediment (i.e. a planed surface produced by lateral corrasion) instead of the expected deep fluvial channel. This discovery led to renewed discussion of the origin of valley meanders. Evidence of still earlier river behaviour may give scope for extending that discussion and possibly resolving some of the problems.

The Distribution of the Second and Third Terraces

The terraces are distinguished from one another by altitude (text-fig. 5, p. 43). Taylor (1963) defined the surface heights of the three terraces in relation to the floodplain; the First Terrace surface rising to as much as 3 m, the Second to between 5 and 9 m and the Third to between 10 and 17 m above the floodplain. It is on the basis of this convention that the Nene's terraces have been mapped by the Geological Survey. Identification in this way is not without problems. Some terrace sequences are complete, some are dissected and some have been removed altogether, so that the present altitude of the land surface may be misleading. When the interiors of the terrace remnants are known more fully, however, the altitudes of their respective bedrock floors may prove to be a surer means of identification.

The First Terrace is really an undissected extension of the floodplain gravel sequence and, as such, is always contiguous with the floodplain gravel which forms an uninterrupted lining to the valley bottom. The Second Terrace gravels rest on a valley-side bench whose floor is often only 1 m above the top of the First Terrace gravels. The Third Terrace gravels also rest on a valley-side bench. For most of the valley, the Third Terrace is situated no more than halfway up the valley side, but east of Alwalton (TL 130960) the valley walls become gradually lower and the Third Terrace fragments extend across the interfluves. On the Fenland edge itself, the gravels of the Third and Second Terraces merge with similar deposits that have debouched from the Welland and Great Ouse valleys, to form a spread of undifferentiated material known as Fen Gravel.

The floodplain gravel deposit is found along the entire length of the Nene valley to within 5 km of the river's sources. The Second Terrace, which is older and has not only its surface but its floor above the present valley bottom, has undergone considerable dissection and fragmentation. The deposit has been cleared entirely from the uppermost parts of the catchment area, and the first remnant of the Second Terrace is not encountered until Weston Favell (SP 792612). The Third Terrace, assumed from its height to be the oldest, has undergone even more dissection and is not encountered until Aldwincle (TL 003810). Downstream from these two sites, the Second and Third Terrace remnants occur intermittently as far as Peterborough, where the Nene leaves its valley to cross the Fens.

Low-angle benches cut into the Jurassic rocks outcropping on the valley sides at heights corresponding to the levels of the Second or Third Terrace bases are interpreted as terrace remnants which have been stripped of their deposits, as shown in Table 1.

Table 1

Stripped Benches in the Nene Valley

Site	Grid Reference	Terrace
Ratling Irons	TL 030830	3
White Lodge	TL 043856	3
Stoke Doyle	TL 022866	3
Oundle Lodge	TL 025875	3
Oundle	TL 043880	3
Glapthorn	TL 035898	3
Walcot Lodge	TL 045935	3
Westwood Farm	TL 168996	3
Clifford Hill	SP 810606	2
Islip	SP 989797	2
Cotterstock	TL 044912	2
Elton Park	TL 085925	2

Although these stripped benches offer no stratigraphical evidence of past river behaviour, they do indicate the former extent of the terrace gravels and so help to delineate the former margins of the floodplain.

The Composition and Stratigraphy of the Third Terrace Gravels

Realistically, the stratigraphy of the Third Terrace gravels can only be assessed from exposures, where structures such as bedding, imbrication and cryoturbation are clearly visible. Although bore-logs give useful information on sediment depth, lithology and particle size, they do not normally reveal structural features. Unfortunately, exposures in these deposits are rare. The writer was, however, able to visit an extensive exposure (100 m long) at Woodston in 1974, although this has since deteriorated.

The Woodston-Orton Longueville site (TL 178954) is 2 km south-south-east of the modern river. That is not to say that the river has changed its course: there are Third Terrace deposits 2 km to the north of the Nene as well, at the Westwood Works in Peterborough (TF 180000). The Woodston deposit occupies an interfluvial (i.e. skyline) site, with its surface 13 m above the modern floodplain, which stands at 4 m OD. The deposit consists of fine sand, coarse sand and fine and medium gravel. The largest particles are sub-rounded cobbles 10 cm in diameter, but these are rare. A sample of about 8 kg was dry-sieved and the distribution of sediment sizes was as follows:

0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	> 5.0 mm
37%	10%	11%	8%	6%	28%

This analysis shows a positively skewed distribution, with the fine sand particles predominating. Although the figures appear to show a bimodal distribution, it must be emphasised that the > 5.0 mm category includes a larger range of sediment sizes, so that 0-1.0 mm can be regarded as the mode.

The larger particles (> 4 mm in diameter) were subjected to a Powers' Roundness Analysis. This revealed that 24.5% of the stones were sub-angular, and a further 27.5% were sub-rounded.

Although these were the largest two categories, there were significant fractions of the sample in the very angular and well-rounded classes. This tends to suggest that both frost-shattering (producing angularity) and water-rolling (producing roundness) have contributed to the morphology of the deposit.

The gravel includes some local material derived from the bedrock outcrops in the Nene's catchment area and some erratic material that was presumably winnowed from the glacial drifts. The local Jurassic material includes shelly limestone, oolitic limestone, ironstone and sandstone. The erratic material includes pebbles of Bunter quartzite, gritstone, flint, chalk and pink gneissose granite.

Samples from four different sites were divided into their various lithologies and the fractions weighed. The proportions are shown, in Table 2, by percentage weight of each sample. In samples 1 to 3 the largest fraction (37-54%) is flint. Flint is important in sample 4, accounting for 29% of the sample's weight, but ranks second to limestone. The ratio of erratic to local material is 2:1 in samples 1 to 3, but 1:2 in sample 4. The results in Table 2 show sample 4 as unusual by comparison with both Third and Second Terrace samples; the amount of quartzite is unusually low and the amount of limestone unusually high, but the oddity of sample 4 is probably not significant since all floodplains, both past and present, offer a variety of sedimentary micro-environments.

Table 2

Lithological Analysis of Terrace Gravel Samples (weight %)

	1	2	3	4	5	6	7	8	9
Quartz	-	-	-	-	1.4	-	-	-	-
Felspar	-	-	-	-	-	0.4	-	-	-
Quartzite	13.4	6.8	30.0	3.3	25.7	9.2	8.9	7.5	22.5
Chalk	2.2	3.0	2.5	1.8	-	15.0	8.5	2.5	5.2
Flint	53.3	53.5	37.0	28.9	31.5	26.8	35.0	55.0	50.0
Limestone	15.0	22.0	9.0	57.8	31.4	37.6	41.8	20.0	13.0
Ironstone	13.3	13.2	20.0	5.8	2.9	9.8	5.8	12.5	7.5
Sandstone	2.8	1.5	1.5	2.4	7.1	1.2	-	2.5	1.8
Erratic	68.9	63.3	69.5	34.0	58.6	51.4	52.4	65.0	77.7
Local	31.1	36.7	30.5	66.0	41.4	48.6	47.6	35.0	22.2

Sample	Terrace	Site	Grid Reference
1	3	Aldwincle	TL 004821
2	3	Barnwell	TL 046851
3	3	Oundle	TL 045878
4	3	Orton	TL 178955
5	2	Billing	SP 808621
6	2	Grendon	SP 880618
7	2	Grendon	SP 878617
8	2	Aldwincle	TL 009815
9	2	Oundle	TL 049872

The greatest recorded thickness of Third Terrace gravels is 3 m and occurs near the centre of the Woodston-Orton Longueville remnant, at My Lady's Lodge Farm (TL 159955) and again just to the north (TL 160960). Alwalton (TL 138960) has 1.5 m, Orton Waterville and north Peterborough (TF 200010) both have up to 1.8 m. Cow Pastures Farm at Woodston (TL 181958) has 2.3 m of gravel (Horton *et al.*, 1974). The differences in thickness are explained by irregularities in the rock floor on which the gravel rests and by differential dissection of the surface layers of gravel.

The gravel at My Lady's Lodge Farm is well sorted with seams of sand and clay, but the other sites mentioned show poor sorting. This poor sorting may indicate that the entire deposit results from solifluxion. This seems unlikely, though, because so many of the particles are rounded or sub-rounded and even the unbedded gravels are interrupted by thin lenses of sand, which must have been waterlaid. An alternative interpretation is that virtually the entire sequence was waterlaid but later disturbed by frost. The repeated freezing of ground water in a gravel deposit may cause some or most of the particles to be levered into an erect position, thus disrupting the original bedding. This view is borne out by the section seen at Woodston (text-fig. 3a). In the centre of the section the original bedding survives; to the right it is disturbed by simple involutions; to the left it is disturbed by complex or amorphous involutions which almost completely obscure the original stratification.

In some places the disturbance is so severe that the base of the deposit is contorted, with the gravel folded down into pockets in underlying Oxford or Lias Clay, as at Woodston. Otherwise, the gravel rests on a nearly horizontal erosion surface.

The Composition and Stratigraphy of the Second Terrace Gravels

Exposures in the Second Terrace deposits are more numerous. The author was able to utilise temporary exposures at Grendon, Aldwincle, Fotheringhay and Ailsworth, as well as reports of exposures and bore-logs in Horton *et al.*, (1974). A sample of about 8 kg of the gravel from Grendon (SP 878617) was tested for sediment size by dry sieving. The results are similar to those from the Third Terrace:

0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	> 5.0 mm
44%	9%	9%	7%	7%	24%

The Grendon sample was also tested for roundness. As in the Third Terrace sample, there were large sub-angular and sub-rounded fractions (29% and 27.5% respectively). There was also a significantly large angular fraction, (24% as compared with only 8.5% in the Third Terrace sample). The roundness distribution for Grendon is displaced towards angularity implying that, at the Grendon site at least, extreme cold has played a major part in determining the sediment's texture. Significantly, many of the pebbles, irrespective of lithology, have been shattered *in situ* to produce very angular fragments with sharp edges. Nevertheless, enough of the particles are sub-rounded, rounded or well-rounded (34%) to suggest that the deposit as a whole was probably waterlaid.

The Second Terrace contains both erratic and local material. The local material includes shelly and oolitic limestone, siderite ironstone and sandstone. The erratic material includes Bunter quartzites, white quartz, flint, chalk and feldspar. Samples taken from Grendon, Aldwincle and Oundle were divided into lithological fractions and the results are shown in Table 2. In samples 6 and 7, from Grendon, limestone is the largest fraction (38% and 42%) while flint is the second largest (27% and 35%). In samples 8 and 9, from Aldwincle and Oundle, flint is the largest constituent (55% and 50%). In sample 5, from Little Billing, the two rock types are represented in roughly equal proportions, with 31%. The erratic content ranges from 51% to 78% and exceeds the local material in each sample.

The thickness of the Second Terrace deposit varies, largely owing to differential dissection. Table 3 shows the thickness of selected Second Terrace deposits, as reported in the literature

(Taylor, 1963; Horton *et al.*, 1974) or seen by the writer in temporary exposures. They are listed in order, with 1 as the furthest upstream.

Table 3

Thickness of Second Terrace Gravel

No.	Letter on text-fig. 1	Site	Grid Reference	Thickness (m)
1	A	Billing	SP 808621	5.0
2	B	Earls Barton	SP 850626	5.5
3	C	Earls Barton	SP 857627	3.1
4	D	Grendon	SP 878617	2.0
5	E	Aldwincle	TL 009815	5.0
6	F	Fotheringhay	TL 079947	2.0
7	G	Nassington	TL 072957	6.1
8	H	Water Newton	TL 115971	4.6
9	L	Woodston	TL 184974	4.6
10	K	Woodston	TL 180974	7.6
11	K	Woodston	TL 181975	6.4
12	O	Peterborough	TL 197990	2.7
13	P	Stanground	TL 210971	6.0

The stratigraphy of the Second Terrace deposit is also varied, as the sample sections in text-fig. 3 show. For convenience, five lithostratigraphical units may be distinguished:

(1) Sand, fine and medium gravel, coarsely bedded with occasional lenses or seams of clean sand. Often there are involutions towards the top of the sequence or amorphous involutions throughout: e.g. Ailsworth.

(2) Densely compacted masses of fine and medium gravel with little sand matrix: e.g. Nassington.

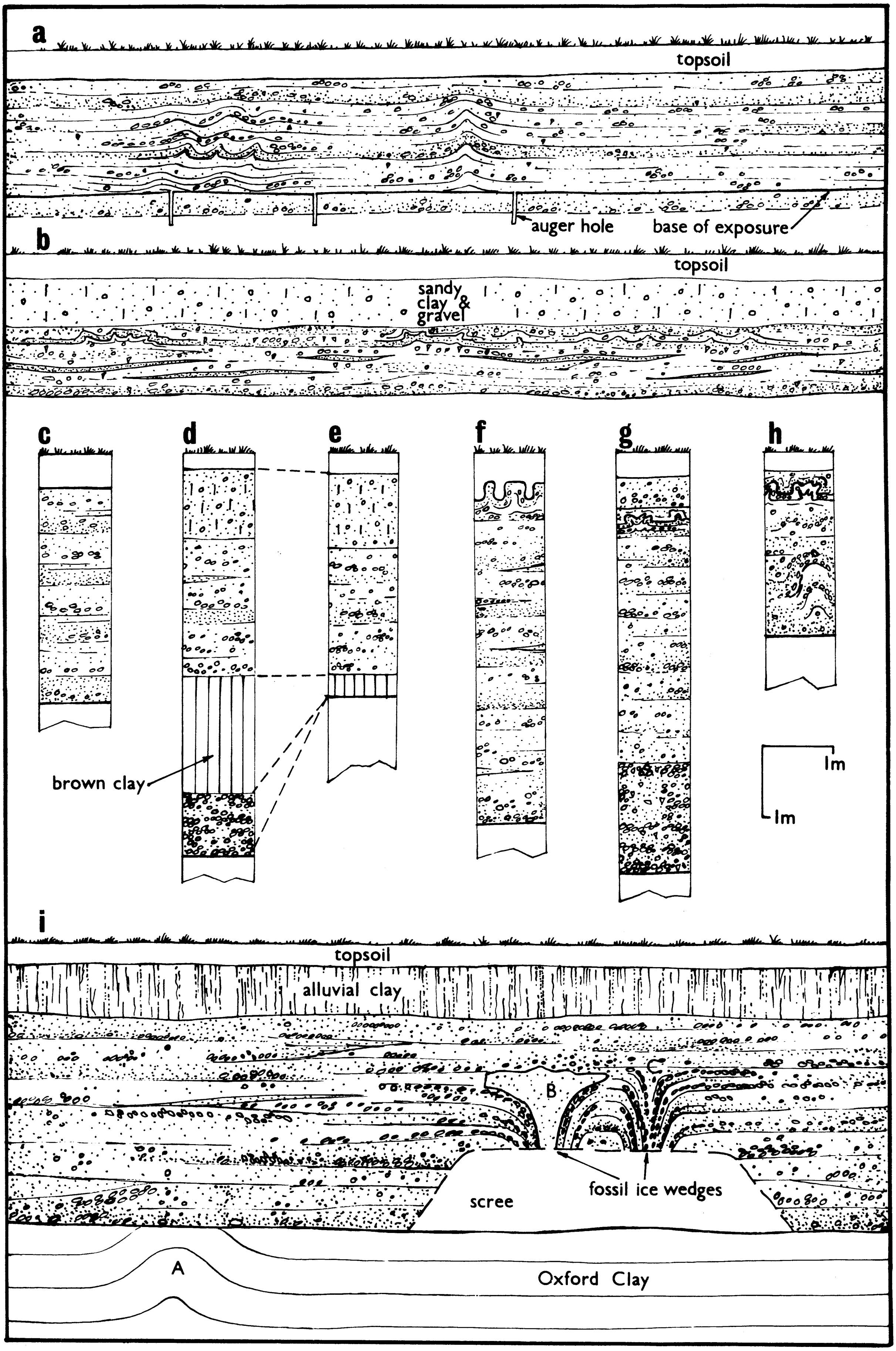
(3) as (2), but with a clay matrix: e.g. Little Billing.

(4) as (1), but with a clay inclusion separating two phases of sand and gravel deposition: e.g. Earls Barton, Woodston.

(5) as (1), but with consolidation of layers up to 0.3 m thick: e.g. Fotheringhay.

Despite the fact that the Second Terrace gravels are often severely disturbed by involutions, it seems likely that they were originally waterlaid and horizontally bedded. It is possible that local variants such as the clay-rich deposits at Billing and Earls Barton may have been formed by material flushed into the main valley by minor tributaries. The Billing terrace remnant is on the downstream side of the outlet of the Billing Brook valley; the Earls Barton terrace occupies a similar situation downstream from the Sywell Brook's outlet. Both these sites could have been supplied by clay from the interfluves. This interpretation is supported by a feature developed in the floodplain gravel sequence, and shown on text-fig. 3. Immediately below the outlet of the Grendon Brook, the floodplain gravel is entirely replaced by clay on the southern edge of the floodplain.

The morphology and stratigraphy of the terrace gravels have far-reaching implications in any consideration of past river processes. But before those implications are discussed,



Text-fig. 3: Sample sections through terrace deposits.
a = Woodston (TL 175954), b = Grendon (SP 880619),
c = My Lady's Lodge (TL 159955), d = Earls Barton (SP 850626),
e = Earls Barton (SP 857627), f = Aldwincle (TL 009815),
g = Nassington (TL 072957), h = Ailsworth (TL 113987),
i = Whittlesey (TL 250977).

there are two controversial groups of features which must be re-examined: the Third Terrace fragments in the Barnwell valley and the isolated inliers of March Gravel in the Fens.

The Third Terrace Sequence in the Barnwell Valley

The Barnwell valley has three small remnants of Third Terrace gravel between Wigsthorpe and Barnwell St. Andrew (TL 046830-046851). It is not unusual for tributary valleys to have terraces: the River Ise has both First and Second Terraces. The Barnwell Brook is, on the other hand, a very minor tributary. The presence of the gravel may be explained in four different ways, as follows:

(1) The gravel is autogenic, i.e. it was produced within the confines of the Barnwell Brook's present catchment area. The difficulty with this interpretation is that the lithology of the Barnwell terraces is so similar to that of the terraces in the main valley that it seems unlikely that they developed independently in a catchment area of only 12 km^2.

(2) The gravel originated in the Nene valley and was washed into the Barnwell valley from its outlet end, i.e. from Oundle. This type of plugging would be possible for a short distance at the outlet of a tributary valley, if the main river was aggrading. Nevertheless, the highest terrace remnant is 4 km up the Barnwell valley, which seems too far for the sediment to be transported up a tributary valley.

(3) The gravel was deposited allogenically, by a distributary of the Nene passing over the sites of Thorpe Waterville, Wigsthorpe and Barnwell, following the general alignment of the dismantled Northampton-Peterborough railway. The Nene of Third Terrace times would, as will be argued below, have been a braided river flowing over a relatively wide belt of gravel occupying a shallow valley. A distributary valley at this site is a real possibility. The terrace gravels, like the braids of the Nene itself, would have surrounded the higher ground of Wigsthorpe Hill. This is the interpretation followed in text-fig. 6a. There are, however, two features which suggest that another explanation needs to be considered. The first is the summit altitudes of the Barnwell terrace surfaces (text-fig. 5) which shows a higher culmination than terraces in the main valley. This may argue for an independent river regime in the Barnwell valley. The second feature is the orientation of the Barnwell valley in relation to Thorpe Brook, which forms the basis of the fourth hypothesis.

(4) Leleux (1970) drew attention to the right-angle bend in the Barnwell Brook at Wigsthorpe (TL 043820), interpreting it as evidence of river capture. She argued that the Barnwell Brook originally flowed southwards, basing her view on an examination of the 'terrace gravel' in cuttings along the disused railway. The imbrication of the pebbles was said to show that the river had flowed southwards. The samples were, however, taken from shallow depth (10-15 cm) and there is a strong possibility that they had been disturbed. One site selected for fabric analysis was actually on a low embankment (TL 046849). Although Leleux's version of the capture can be seriously questioned, the lower Barnwell Brook is nevertheless aligned with the upper reach of Thorpe Brook, which turns suddenly from that alignment about 1.5 km to the south-south-west of the Barnwell elbow. It seems likely that Thorpe Brook and Barnwell Brook were originally one stream, and that the lower Thorpe Brook has lengthened headward to capture the upper Thorpe Brook. The Barnwell Brook, starved of headwater and groundwater, is now fed by one of its former right bank tributaries as its main feeder. Whether the combined catchment areas of the two streams would have supplied enough debris to build the terrace deposits between Wigsthorpe and Barnwell is open to debate; the enlarged catchment area would still have been only 40 km^2.

The issue must remain open. The fourth hypothesis explains the peculiar drainage pattern in the Thrapston-Oundle area and is acceptable on that count. Even so, it is not possible to say when the disruption of the Thorpe-Barnwell stream might have occurred. If it occurred before Third Terrace times, it would still allow acceptance of the third hypothesis. Indeed, the opening up of the interfluve east of Thorpe Waterville by the lower Thorpe Brook would have made access to the Barnwell valley easier for the Nene, so the capture may well be Ipswichian in date. The Third Terrace remnant at TL 040816 must postdate the capture: it lies athwart the original course of the Thorpe-Barnwell stream and would have been dissected if it had predated capture.

The Fen Gravel and March Gravel

Fen Gravel is the term applied to the gravel deposits lining the fenland edge, between the exits of the major valleys and rising above the level of the fen alluvium. The composition of the Fen Gravel is similar to that of the Nene's terrace gravels, with erratics indicating a post-Wolstonian date. Horton *et al.* (1974) suggested that it may be older than the terrace deposits. Whilst this may be true, there is no reason to believe that the gravel is anything but contemporary with the Second or Third Terraces. The Fen Gravel was in fact probably formed by the coalescence of the terrace gravels of the rivers Welland, Nene, Great Ouse and Cam. As such, it seems likely that the deposits were formerly more extensive and have been reduced in area by dissection.

In the following section, the evidence for a Devensian date for the terraces will be discussed. Although it has been argued that there were phases when sea level was similar to that of the present day, the Devensian cold stage is generally held to have been dominated by low sea levels, down to about -100 m OD (e.g. Goudie 1977). It follows that the Nene of First, Second or Third Terrace times would have been a mere tributary to a river three or four times longer than the present Nene, with a North Sea outlet possibly as far out as the Devil's Hole (56° 30'N, 0° 30'E). The Fens and the Wash would have been the meeting-ground for the Witham, Glen, Welland, Nene and Great Ouse, and would presumably have been covered by a wide sheet of terrace gravel crossed by dozens of braided channels. Tidal currents have since dispersed the river gravels laid down on the North Sea bed, so the ancient course of the 'proto-Nene' seaward of the Wash is now unrecognisable.

The gravels were largely cleared from the Fens by rivers in the early Flandrian, when sea level was still relatively low. The 'islands' of gravel scattered across the Fens may be interpreted as dissected remnants of the formerly continuous gravel spread. The isolated remnants are designated March Gravel, after the type-locality, but the gravel of which they are made appears to be identical with the Fen Gravel and the Nene terrace gravel.

The March Gravel exposure at Whittlesey (TL 250977, Q on text-fig. 1, i on text-fig. 3) shows a level-bedded deposit of sand and gravel 3 m thick, resting on a horizontal surface eroded across Oxford Clay at about 2 m OD. The gravel is overlaid by 1 m of alluvial clay and topsoil. The altitude of the gravel bed suggests a correlation with the Second Terrace and it is incorporated as such in the reconstructed profile on text-fig. 5. Sand lenses and occasional pebble imbrication prove that this is a waterlaid deposit. There are no involutions in this exposure, but there are two fossil ice-wedges. Frost-wedge C was evidently opened piecemeal by several phases of wedge formation separated by phases of thawing when stones could fall into and line the wedge. Frost-wedge B contains a sand cast, suggesting that it was formed in one phase, the sand filling the cavity only on final melting.

It has been assumed for a long time that the March Gravel was formed as offshore bars. Baden-Powell (1934) drew attention to the presence of 'marine' shells in support of this view, but admitted that freshwater shells also occur. This may indicate that the evidence has been misread or that the depositional environment was a tidal estuary or, more likely, a delta. Baden-Powell interpreted the remains of timber found in the gravel at March as driftwood, incorporated by chance into the offshore bars. It is simpler to interpret wood remains as indicators of terrestrial origin. The 'offshore bar' is even more eccentric in view of the bones which have been found in the March Gravel. *Rhinoceros*, *Bos*, *Equus caballus* and *Elephas* are all represented. Since these are all terrestrial animals, a fluvial, estuarine or deltaic interpretation makes more sense.

Baden-Powell deduced from the fauna that the climate at the time of deposition was cold-temperate, though not arctic. There is, on the other hand, strong stratigraphical evidence for very cold conditions at the time of deposition. The fossil ice wedges mentioned above show that intense cold accompanied the deposition of layers 1.5 m above the base. Text-fig. 3i also shows a periglacial bulge (at A) developed in the Oxford Clay underlying the basal layers of the gravel. Significantly, the crest of the bulge has been trimmed off by the gravels as they were transported across the site. The presence of the decapitated bulge confirms that intense cold accompanied the deposition of the basal layers of the March Gravel.

The March Gravel is thus interpreted as a cold stage or stadial deposit, just like the Second Terrace gravel with which it was probably once continuous.

The Date and Mode of Origin of the Terraces

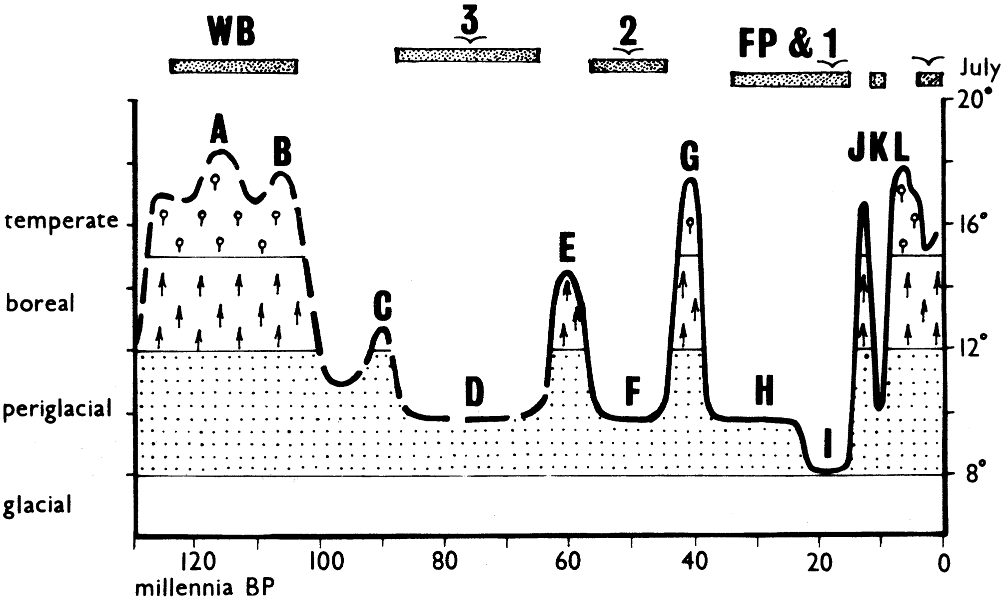
The lithological and stratigraphical similarities between the gravels of the older terraces and those of the First Terrace and floodplain imply formation under similar circumstances. In an earlier paper (Castleden, 1976), the climatic conditions and river behaviour indicated by the floodplain gravels were discussed at length. It was argued that the floodplain gravels were transported and deposited under a periglacial climatic regime, with mean January temperatures as low as -20° C and a short summer thaw lasting perhaps three months. The precipitation stored as snow and ice during the winter was released during the summer to create high flood discharges capable of transporting a very coarse load. The palaeo-climatic indicators for the Second and Third Terraces are coarse sediment, frost wedges, involutions and an eroded bulge.

The braided channels which deposited the floodplain gravel evidently migrated laterally to erode a planar or sub-planar surface. Text-fig. 2 (p.32) shows a typically scalloped pediment flooring the floodplain at Earls Barton. It also shows three Second Terrace remnants with floors which, prior to dissection, would have formed a very similar sub-planar surface 9 m higher than the floodplain pediment. Similar pediment forms are evident at other sites, such as the Third Terrace exposure at Woodston (text-fig. 3a) and the March Gravel at Whittlesey (text-fig. 3i). The recurring pediment form under each of the Nene's terraces gives further confirmation that a similar process or group of interacting processes was responsible for the formation of each of the terrace sequences.

The date of the floodplain and First Terrace sequence is well established by four radiocarbon dates. The earliest date for the basal layers is 28,225 ± 330 BP at Ecton and the sequence culminates at 8,920 ± 160 BP in the surface of the First Terrace at Thrapston (Castleden 1976). Text-fig. 4 shows prevailing July temperatures in central England during the last 130,000 years. This composite graph was drawn from several sources including Coope *et al.* (1971), Lamb (1971), Kenneth & Huddleston (1972), Bowen (1977), Goudie (1977) and West (1977). The floodplain and First Terrace deposit, shown as 'FP & 1', relates mainly to a periglacial sub-stage described in detail by Coope *et al.* (1971) and Morgan (1969) from organic material recovered at Ecton. This cold sub-stage might be called the Ecton stadial. At present, the interstadials have widely accepted names, but of all the British stadials, only the Loch Lomond stadial (11,000-10,000 BP, Mitchell & West, 1976) has been named after a type-locality.

The Second and Third Terraces pre-date the Ecton stadial. They post-date the Wolstonian glaciation which supplied some of the erratic content of the gravel, but that still leaves a long period (i.e. the Ipswichian interglacial and the early and middle Devensian) when they could have been formed. The Woodston Beds (TL 180960) have been identified as Ipswichian estuarine deposits, on the basis of an infinite radiocarbon date, an interglacial flora and a high frequency of fine particles (Horton *et al.*, 1974). The Woodston Beds are overlaid by Third Terrace gravel.

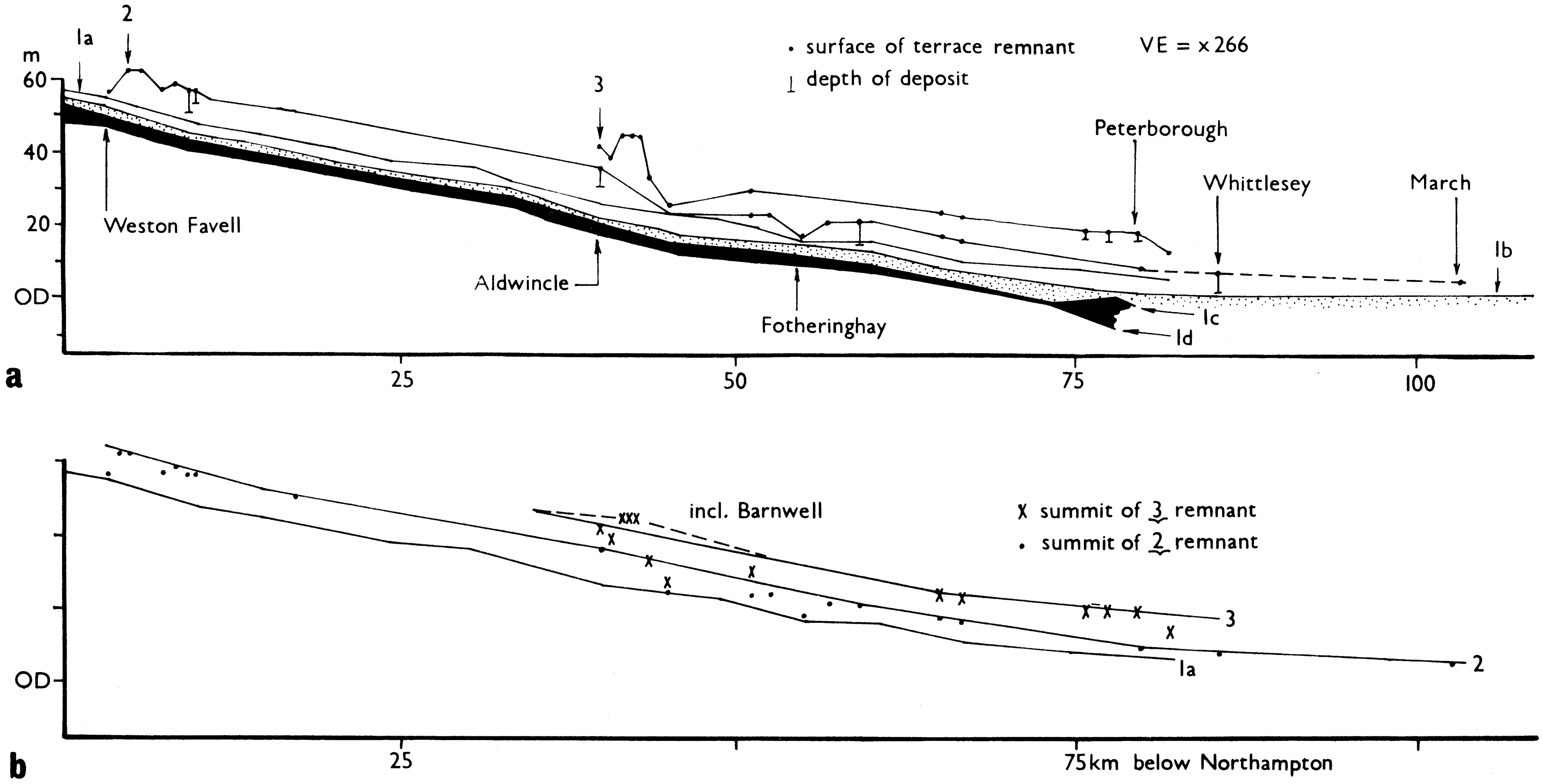
Using the outer limits imposed by the floodplain gravels and the Woodston Beds, together with the knowledge that the terraces are cold-stage deposits, we are left with two obvious 'time windows': the stadials of the early and middle Devensian. The Third Terrace, as shown on text-fig. 4, appears to have been emplaced between 87,000 and 65,000 BP, before the Chelford interstadial. The Second Terrace was emplaced between 57,000 and 45,000 BP, between the Chelford and Upton Warren interstadials.



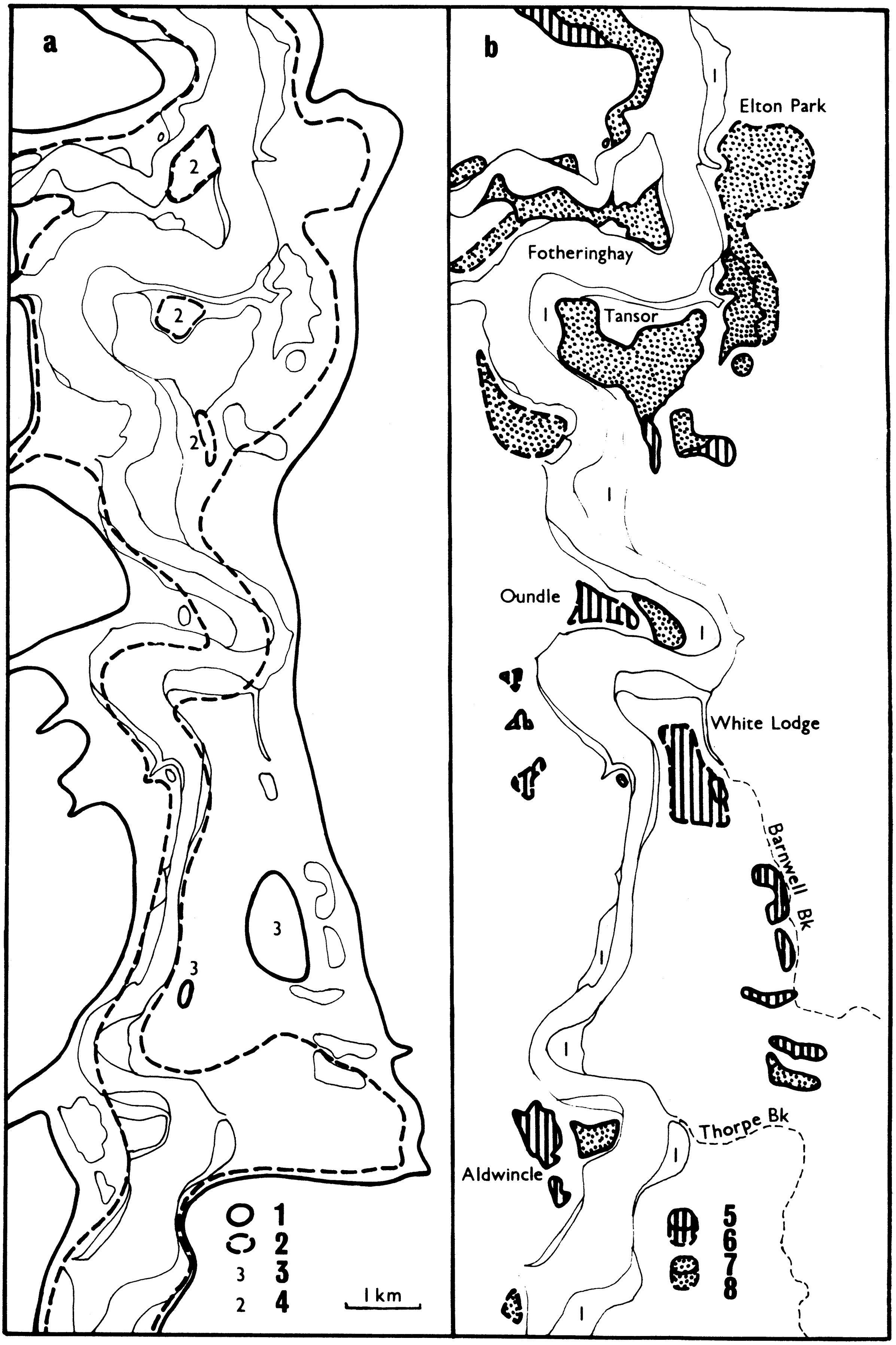
Text-fig. 4: Prevailing summer temperatures in central England during the Ipswichian, Devensian and Flandrian stages.
WB = Woodston Beds, 3 = Third Terrace, 2 = Second Terrace,
FP & I = Floodplain and First Terrace, ~ = Alluvium,
A & B = maxima of Ipswichian interglacial, C = Amersfoort interstadial,
D = Longueville stadial, E = Chelford interstadial, F = Woodston stadial,
G = Upton Warren interstadial, H = Ecton stadial, I = Devensian ice maximum,
J = Windermere interstadial, K = Loch Lomond stadial, L = maximum of Flandrian (present) interglacial; dashed line = not yet proved for central England.

There are, as yet, no radiocarbon dates for either of the older terraces. In view of this, some corroboration was sought for the dates offered above. The Reserve Collection at Peterborough Museum contains many flint artefacts taken from the Second Terrace at Woodston, most of them from pits at Woodston Hill (TL 180975) and found by Edwardian collectors. Of the 77 identified by the writer, 12 were early Acheulian or older, 21 were middle or late Acheulian, 24 were Levalloisian and 20 were Mousterian: none were later than Mousterian. The flints cannot have been incorporated into the deposit until the latest cultural level, i.e. the middle Devensian Mousterian, so they are compatible with the date 57,000-45,000 BP argued above.

The mode of origin of the terraces is assumed to be similar to that of the floodplain and First Terrace sequence. The cold sub-stage phases of lateral abrasion or valley-bottom widening were separated by interludes of vertical incision, so that the pediment forms associated with successive stadials were developed at progressively lower levels. The Second Terrace pediment is 10-17 m lower than the Third Terrace pediment, whilst the First Terrace and floodplain pediment is 8-10 m lower than the Second Terrace pediment.



Text-fig. 5: Long profiles of the Nene's terraces.
1a = First Terrace surface, 1b = Surface of alluvium, 1c = Base of alluvium,
1d = Base of floodplain gravel, 2 = Second Terrace surface, 3 = Third Terrace surface.
5a shows present state of terraces; 5b shows reconstructed culmination levels.



Text-fig. 6: The Second and Third Terraces between Aldwincle and Elton. 1 = Floodplain edge in Third Terrace times, 2 = Floodplain edge in Second Terrace times, 3 = Inliers in Third Terrace floodplain, 4 = Inliers in Second Terrace floodplain, 5 = Third Terrace deposit, 6 = Third Terrace bench, 7 = Second Terrace deposit, 8 = Second Terrace bench. 6a shows the reconstructed floodplain; 6b shows the valley today.

The Long Profiles of the River Terraces

Text-fig. 5a shows the long profiles of the terrace surfaces. The Second and Third Terraces are discontinuous; the summits of the terrace fragments are shown by dots. The lines joining those points show the lowest possible culmination levels of the terraces when they were intact. The reverse slopes must indicate dissected reaches. The second set of profiles, text-fig. 5b, shows tentative reconstructions of the original surface levels. The Second Terrace emerges as sub-parallel to the First Terrace surface.

The Third Terrace surface is open to two interpretations. The Barnwell remnants may be left aside as a tributary series with a gradient independent of that displayed by the gravel spread in the main valley. In that case, the lower, continuous line may be taken. If, on the other hand, the Barnwell valley is treated as the route of an early Nene distributary, the change in gradient could be explained by the substantial inlier of Wigsthorpe Hill; this could have caused a strictly local ponding of Third Terrace gravel, creating a gentler gradient above and a steeper gradient below the obstruction.

Table 4 shows the original surface heights of the terraces, ignoring the Barnwell valley.

Table 4

Reconstructed Altitudes of Terraces

Terrace	Surface height above 1st Terrace surface	Mean	Surface height above River Nene	Mean
3	15-12 m	14 m	20-17 m	17 m
2	9- 3 m	6 m	12- 6 m	9 m
1	0 m	0 m	1- 4 m	3 m

Reconstructions and their Implications for Valley Meander Formation

A tentative reconstruction of the limits of the Nene's floodplain gravel during Second and Third Terrace times is possible, given the interpretation of evidence from field and map which has been discussed so far. Text-fig. 6 shows the results of this reasoning for a short sample reach of the Nene valley between Aldwincle and Elton; text-fig. 6b shows the present distribution of terrace remnants and stripped benches whilst text-fig. 6a shows the probable former extent of the gravels, allowing for the form of the valley sides between the remnants and benches.

The reconstruction favours the third hypothesis; i.e. it assumes that the braided Nene surrounded Wigsthorpe Hill, making the Barnwell valley a distributary valley. As argued above, the reconstruction might alternatively have shown the lower Barnwell Brook and upper Thorpe Brook as occupying a separate valley. It is noteworthy, though, that the Second Terrace gravels also surrounded solid inliers at Tansor and Fotheringhay. This suggests that a pattern of distributaries surrounding occasional remnants of solid rock or even older gravel (e.g. at Tansor) may have been a normal feature of the Nene's Devensian river gravels.

A conspicuous feature of the reconstruction is the difference in width between the floodplain in Third Terrace times and that in Second Terrace times. There has been a progressive reduction in mean width from 3 km (Third Terrace) to 1.5 km (Second Terrace) to 0.5 km (First Terrace). It is possible that the terraces represent progressively shorter phases of lateral planation, but the climatic graph (text-fig. 6) gives no reason to suppose a shortening time scale. It is more likely that a relationship exists between floodplain width and valley depth; as the valley deepens, the floodplain width decreases. The rate of pedimentation would inevitably decelerate as the valley depth increased, since an increasing volume of rock would have to be eroded for each unit of width by which the valley bottom was widened.

The reconstruction also reveals stages in the evolution of valley meanders. The edges of the floodplain in Third Terrace times were irregularly sinuous, but by Second Terrace times the edges of the floodplain were meandering systematically, at least in some reaches. By First Terrace times the floodplain had developed a fully meandering course, with a degree of ingrowth evident at Aldwincle and Oundle.

Valley meanders have therefore evolved during the course of the Devensian cold stage. Successive stadials produced conditions favouring the development of large wavelength meanders in the river's braids. With the increasing depth of the valley and the progressive narrowing of the floodplain, the large wavelength meanders were increasingly imprinted on the valley walls.

Conclusion

Certain broad similarities between the Third and Second Terraces emerge. Their long profiles are sub-parallel, their sediment-size distributions are similar and they both rest on sub-planar erosional floors. The maximum recorded thickness of the Second Terrace (7.6 m) is twice that of the Third Terrace; this is probably due to the greater age of the Third Terrace and its greater vulnerability to erosion owing to its greater altitude.

The terrace sediments are broadly similar to those of the First Terrace and floodplain, except that no peat layers or peat erratics which are common in the floodplain, have so far been discovered in the older deposits. Nevertheless, there is sufficient evidence to conclude that similar river processes and climatic conditions prevailed during the transport and deposition of the three terrace sequences.

The Barnwell valley terrace remnants may be interpreted in two ways. They may have been formed as an integral part of the Nene's floodplain in Third Terrace times, laid down by a major distributary of the Nene flowing round Wigsthorpe Hill. Alternatively, Barnwell Brook may have been continuous with Thorpe Brook in those times, giving the valley floor at Barnwell a larger catchment area to supply it with sediment.

The March Gravel 'islands' in the Fens may also be interpreted as integral with the Nene's floodplain deposits, though in this case with the Second Terrace gravels.

It is evident that pedimentation was associated with the mobilisation of the basal gravels of all three terrace sequences. Pedimentation was characteristic of each major cold sub-stage of the Devensian. It is suggested that the important site at Ecton should give its name to the major stadial between the Upton Warren and Windermere interstadials, thus avoiding the highly ambiguous term 'Late-Devensian'. The type-area for the Second Terrace at Woodston might be used to name the earlier stadial between the Chelford and Upton Warren interstadials, whilst the Third Terrace site straddling the Woodston-Orton Longueville parish boundary could be used to name the earliest stadial. This would give a nearly complete nomenclature for the Devensian as follows:

Devensian sub-stage	Date (years BP)
Longueville Stadial	87,000 - 65,000
Chelford Interstadial	65,000 - 57,000
Woodston Stadial	57,000 - 45,000
Upton Warren Interstadial	45,000 - 39,000
Ecton Stadial	39,000 - 14,000
Windermere Interstadial	14,000 - 11,000
Loch Lomond Stadial	11,000 - 10,000

The river processes of the major stadials (Longueville, Woodston and Ecton) were associated with the formation of two major landscape features; the pediments beneath the river gravels and the large wavelength meanders moulding the valley sides. Lateral corrasion, producing pedimentation, characterised each cold sub-stage and each phase of lateral corrasion in turn brought with it a further stage in the ingrowth of the valley meanders.

Acknowledgements

I should like to thank Mr. T. Cross and Mr. D. Howe, Curator and Assistant Curator of Peterborough Museum, for allowing me to examine the collection of flint artefacts from Woodston. I should also like to thank Dr. R.P. Beckinsale and Professor E.H. Brown, who have encouraged me to develop these ideas.

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PALAEOCURRENT DIRECTIONS AND THEIR BEARING ON THE ORIGIN OF THE BRASSINGTON FORMATION (MIOCENE-PLIOCENE) OF THE SOUTHERN PENNINES, DERBYSHIRE, ENGLAND

by

P.T. Walsh, P. Collins, M. Ijtaba, J.P. Newton,
N.H. Scott and P.R. Turner

Summary

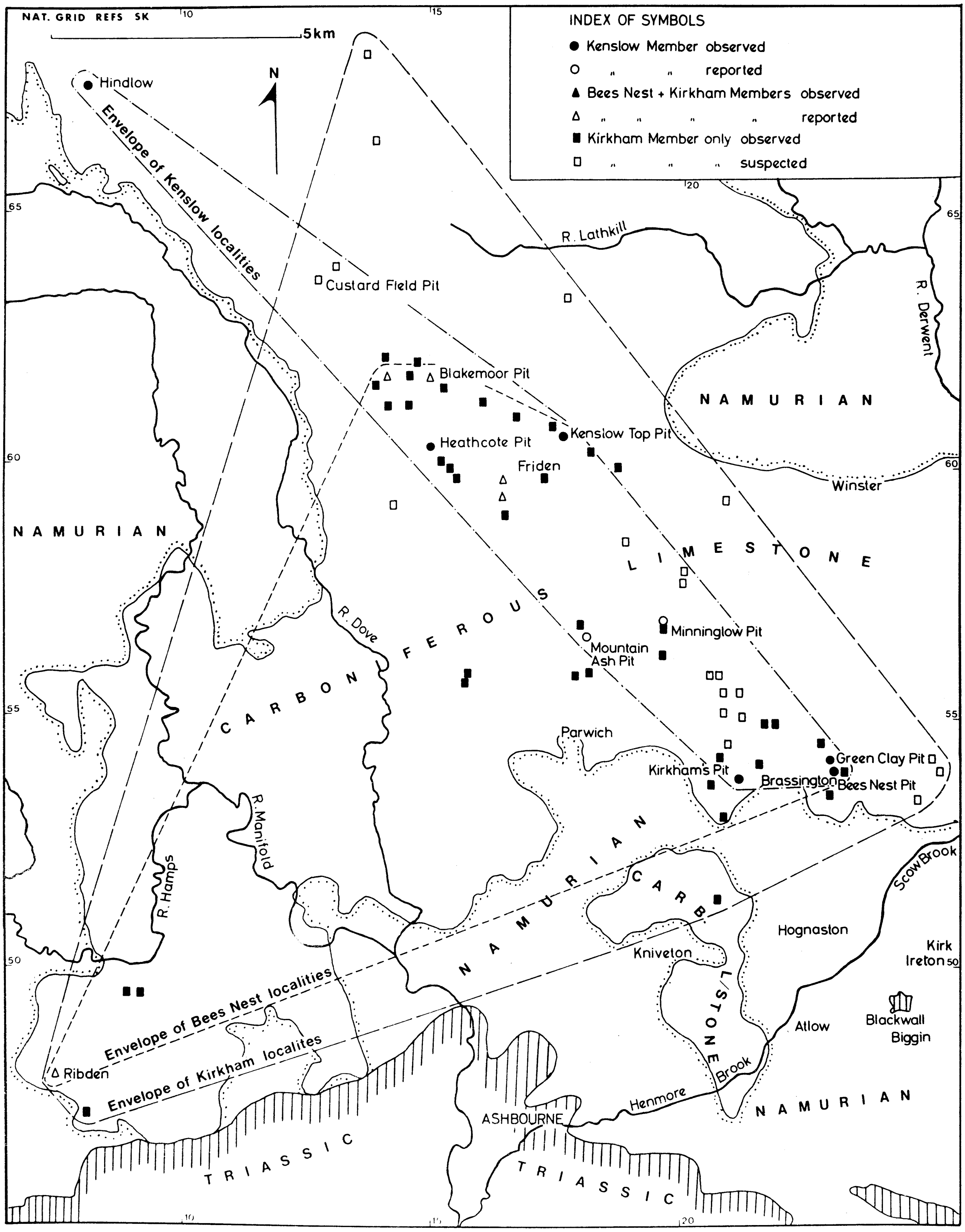
The mid-Neogene Brassington Formation consists of sediment preserved in solution hollows in the Carboniferous Limestone of the Southern Pennines. Measurements of cross-bedding in the arenaceous sediments and pebble orientations in the rudaceous sediments confirm that an important source area, probably a former extension of the Bunter Pebble Bed escarpment, lay due south of Brassington. The identification of a source area south of Brassington implies that the Southern Pennines have been uplifted by over 300 m since the Lower Pliocene, resulting in a reversal in the slope direction.

Introduction

Recent publications have discussed the stratigraphy and palaeobotany of the Brassington Formation and the karstic subsidence mechanisms which have preserved the bodies of sand, clay and gravel in the Carboniferous Limestone at contemporary levels of erosion (Ford & King, 1968 and 1969; Boulter & Chaloner, 1970; Boulter, 1971; Boulter *et al.*, 1971; Walsh *et al.* 1972, and Ford 1972a and 1972b. There is now general agreement that the subsidence outliers are small relics of what was once a widespread, if not continuous, sheet of mid-Neogene sediment which covered the Southern Pennines at an altitude not lower than the present-day summit levels in that area. The presence of this datable sedimentary layer, which was at least 70 m thick in some places, indicates that the Pennine uplift, at least the latest phase of it, was a comparatively late-stage addition to the British landscape, being at earliest Lower Pliocene (Walsh *et al.*, 1972). The sedimentology of the Brassington Formation has hitherto been neglected but a considerable amount of unpublished analytical work by M. Ijtaba and D.B. Thompson has elucidated much about the nature of the source rocks and conditions of deposition. Little previous work has been carried out on the palaeocurrent indicators, and conjecture about the palaeoslope down which Brassington sediments were transported to the Southern Pennines has been based on indirect evidence only. A derivation generally from the south was favoured by Ford & King (1968 and 1969) and Ijtaba (1973), whereas Hughes (1952) suggested that cross-bedding in Brassington sands exposed around Brassington indicated a derivation from the north and east, though he presented no statistical data.

The palaeocurrent studies described here relate only to cross-bedding structures and pebble orientation. Comprehensive measurements were made at all sites available during

Mercian Geologist, vol.8, no.1,
1980, pp.47-62, 16 text-figs.



Text-fig. 1: Map to show -
(1) the localities mentioned in the text, and
(2) the distribution of the Brassington Formation solution subsidence masses.

1975 and 1976. Regrettably only a handful of the sixty or so exposures available during the heyday of sand extraction during the 1940s and 50s (Yorke, 1961) now remain. This may be the first occasion when a palaeocurrent study has been based on evidence fortuitously preserved by solution subsidence mechanisms.

Later sections of this paper are digests of the final year undergraduate Project reports of Collins, Newton, Scott and Turner, to which reference may be made by special request (T.C.U. Department of Civil Engineering, Numbers 859, 792, 797, and 903, respectively).

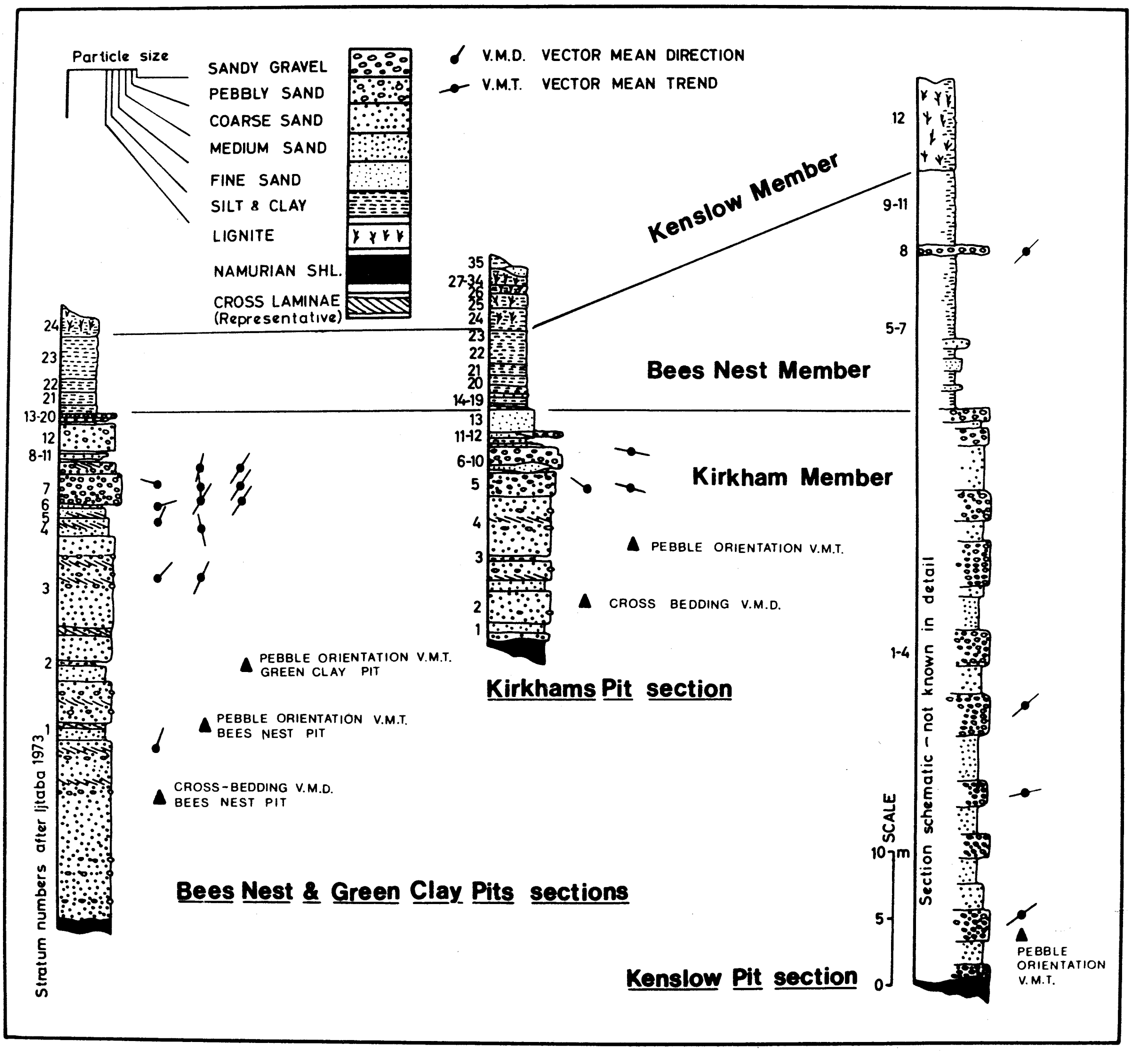
Stratigraphical control

The eight localities where palaeocurrent analyses have been made (text-fig. 1) are not evenly distributed across the area within which Brassington Formation outliers have been reported. None of the subsided sediment masses in Staffordshire is now exposed, while a recent deterioration of sections in the country between Winster and Parwich effectively means that the sites now available fall into two separate groups, a southern group centred around Brassington village (the Bees Nest, Green Clay and Kirkham's Pits) and a northern group around Friden (the Kenslow Top, Kenslow Lesser, Heathcote, Blakemoor and Custard Field Pits). Relative to the envelope which surrounds the outermost known subsidence masses (text-fig. 1), the southern group lies more or less at the south-east corner, whereas the northern group lies midway along the north-eastern side. There is no evidence, however, that the envelopes figured in any way approximate to the margins of the basin of deposition. There is no positive evidence of the former boundary to the area of deposition.

The broad details of the stratigraphy were proposed by Boulter *et al.* (1971) and elaborated by Walsh *et al.* (1972), Ford (1973) and Ijtaba (1973). The tripartite lithostratigraphic division of the formation into Kirkham, Bees Nest and Kenslow Members (text-fig. 2) appears to hold good for all of the sections excavated since 1971 and only two minor revisions need to be mentioned here. In the sections at Heathcote Pit (late 1975) a flora of Kenslow type has been identified by Boulter and Wilkinson (personal communication) from a pale grey clay which is in unfaulted contact with thick gravel beds. Overall stratigraphical relationships in this section were still obscure when it was last examined (March 1976) but it is likely that the underlying Kirkham Member also contains a Kenslow flora. The whole sequence may therefore be approximately of Miocene-Pliocene boundary age (see the discussion of the age of the older Brassington sediments in Walsh *et al.* (1972) and Ford (1972b).

Secondly, it is reported that in late 1975 richly-carbonaceous pale-grey clays were exposed in the trough of a particularly deep subsidence mass at the western end of the Green Clay Pit. Samples proved not to be pollen-bearing, but the carbonaceous layers are undoubtedly in a stratigraphical position analogous to that of the Kenslow Clays exposed about 300 m away in the Bees Nest Pit. This discovery reinforces the view that the Kenslow Clays were as widespread in their development as the earlier Brassington sediments. In recent years the Kenslow flora has been exposed at five localities (Hindlow, Kenslow Top, Heathcote, Kirkham's and Bees Nest Pits). It has also been reported from Minninglow Pit (Howe, 1897) and Mountain Ash Pit (A. Kirkham, personal communication) and is represented by the carbonaceous clays at the Green Clay Pit.

Despite thickness variations, individual beds can quite confidently be traced through the various sections around Brassington (Ijtaba, 1973). Details of the bed-by-bed stratigraphy and sedimentology have not yet been determined for the northern group of sections, though the sudden change from dominantly arenaceous to dominantly argillaceous sedimentation in the Kenslow Top succession could be a very close time-equivalent of the change from Kirkham to Bees Nest Member in the type section at the Bees Nest Pit. A similar sharp sedimentary change is noted at the boundary between Bees Nest and Kenslow Members.



Text-fig. 2: Diagrams to show -
(1) the correlation of the Brassington Formation sediments at the Bees Nest, Green Clay, Kirkham's and Kenslow Top sections, and
(2) a summary of the palaeo-current indicator data.

Lithofacies

The following lithofacies have been recognised in the Brassington Formations:

(i) Sands

The bulk of the Kirkham Member in the southern pits consists of poorly-sorted medium- or fine-grained sand or silty sand, all of an orthoquartzitic composition. General lack of sorting suggests that the sediments were deposited rapidly (Ijtaba, 1973). The grain surface texture studies of Wilson (1979) indicate that the quartz grains from the Kirkham Member are angular to subangular, and that rounded grains are frequent only at certain levels in the Kenslow Top and Kirkham's Pits sections. The angularity appears to be related to the development and retention of euhedral quartz overgrowths on Bunter grains, which presumably predate the deposition of the Kirkham sediments. The bulk of the Kirkham sand is remarkably structureless. Irregular developments of planar, alpha-type cross-bedding form the only common variant.

A comparison of the plots of mean size against standard variation for the Brassington sands with the plots of Friedman (1961) for dune and river sands confirms the alluvial nature of the sediments. On the basis of the above data, one of the authors (Ijtaba, 1973) has considered them to have formed as piedmont fans or sheets, an interpretation which may well explain the lithologically similar succession but fluctuating thickness present in the various southern pits. In many respects, the sands seem to correspond broadly to the channel bar or sand-flat deposits described by Cant and Walker (1978) from the sandy braided South Saskatchewan River.

(ii) Pebbly sands

The pebbly strata of the Brassington Formation are seldom true gravels. Whereas there is a considerable amount of gravel throughout the Kirkham Member in the northern Pits and in the upper part of the Kirkham Member in the southern Pits, it is nearly always a minor fraction of the bulk of the sediment, and the term 'pebbly sand' is the most appropriate in classifications such as those of Folk (1954).

Over 90% of the pebbles in the Brassington Formation are quartzites and most of the remainder are of durable lithologies. Cobbles of maximum $a:b$ cross section 180 x 120 mm are preserved at the Bees Nest Pit. 150 x 100 Kirkham's Pit and 130 x 70 at Kenslow Top. These sizes clearly reflect the considerable competence of the stream flow at certain times in the history of the area of deposition.

Almost invariably, cobbles and pebbles have smooth surfaces and are ovoid in shape; imbrication is rare, reflecting the general absence of discoidal clasts. Thompson (personal communication) considers the coarse fraction to comprise short-travelled and little-modified Bunter Pebble Bed clasts. He also reports that rolled ventifacts are present in small quantities and are locally common and believes them to have formed in the alluvial environment of the Mio-Pliocene when pebbles derived from the Bunter Pebble Beds were first sand-blasted, then eroded, transported and redeposited.

There is a general lack of internal structure in the pebbly sand strata suggesting that immediately prior to deposition, the gravelly sediment moved as mass-flow "diffuse gravel sheets" on channel floors; the gravelly braided stream course deposits described by Hein and Walker (1977) from the Kicking Horse River of British Columbia may offer a broadly comparable modern analogue. Movement of the gravel fraction presumably took place only at peak flood stages in the distributary system and the gravelly bodies then remained as lag concentrates.

(iii) Pebbly clays

This lithofacies, which so far is recognised only from the Kenslow Top succession, is a pebble grade gravel supported by a dominantly clay matrix. Internal stratification is restricted to a feeble parallel alignment of the clasts, which are hardly ever in contact. Since the clay could not have settled from suspension except in near-stagnant conditions, it is considered that this stratum may represent a thin mud-flow deposit (Bull, 1964), although it is hard to fit this into an environmental reconstruction.

(iv) Silts and clays

The bulk of the Bees Nest and Kenslow Members are technically clays, sandy clays and laminated sandy silts. Ijtaba (1973) determined that the clays are dominantly illitic, for which the widespread outcrops of Namurian shales and mudstones at the southern end of the Pennines offer themselves as a fairly obvious source; indeed, derived Namurian miospores have been recognised in the Kenslow clays (Boulter, 1971). The fact that they have not yet been found in the Bees Nest sediments causes no concern for the redness of those clays indicates a strong oxidising environment in the source (and possibly depositional) areas.

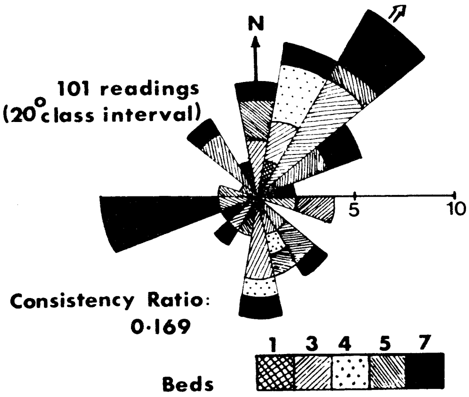
Whereas the cessation of sandy/gravelly sedimentation after Kirkham Member times may simply indicate that the source areas had been stripped of their Triassic cover, it is also possible that a general flattening of the fluvial gradients both in the provenance areas and the basin caused much more vertically--accreting overbank flood-plain material to accumulate (material of silt/clay grade which previously was taken across the basin and out to sea). Many of the fossil plant genera described by Boulter (1971) indicate that some of the Kenslow clays were deposited in swampy conditions.

Cross Bedding Analysis

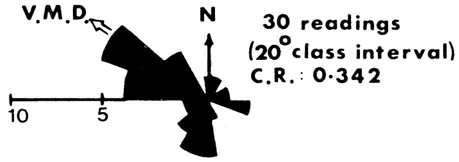
Cross-bedding has been found throughout the entire sequence of the Kirkham Member at the Bees Nest Pit. Altogether 101 sets have been measured, classified (Allen, 1963) and related to the stratigraphy established by Ijtaba (1973); the measurements were made in October 1975. At Kirkham's Pit measurements were more difficult to make, owing to the more rainwashed and structurally distorted sections there; nevertheless, 30 sets of cross-bedded strata were recorded. A careful search was made for cross-bedding structures at Kenslow Top Pit, but despite the extensive exposure there, only four poorly preserved examples were found. The writers conclude that sedimentary processes at Kenslow Top simply failed to create cross-bedding structures to the same extent as in the south. No traces of cross-bedding have been observed in any section of the Bees Nest or Kenslow Members, both of which are dominantly argillaceous. Directional corrections necessary owing to the severe collapse rotation of the Brassington sediments into solution cavities, were accomplished using stereographic nets.

Bees Nest and Kirkham's Pits (text-figs. 3 & 4)

Two vector diagrams have been prepared. The first diagram (text-fig. 3) shows a bed-by-bed plot of the orientation of vectors measured at Bees Nest Pit. The vector mean indicates palaeoflow towards the north-east, but there are subsidiary modes indicating palaeoflow towards the SSE and west. The second (text-fig. 4) shows a plot of all the vectorial data from Kirkham's Pit. There the vector mean is directed towards the north-west, with subsidiary modes to the south and ESE. The stratigraphical framework (text-fig. 2) suggests that the two sequences were broadly contemporaneous.



Text-fig. 3: Bed-by-bed plot of all cross-bedding measurements at Bees Nest Pit.



Text-fig. 4: Plot of all cross-bedding measurements at Kirkham's Pit.

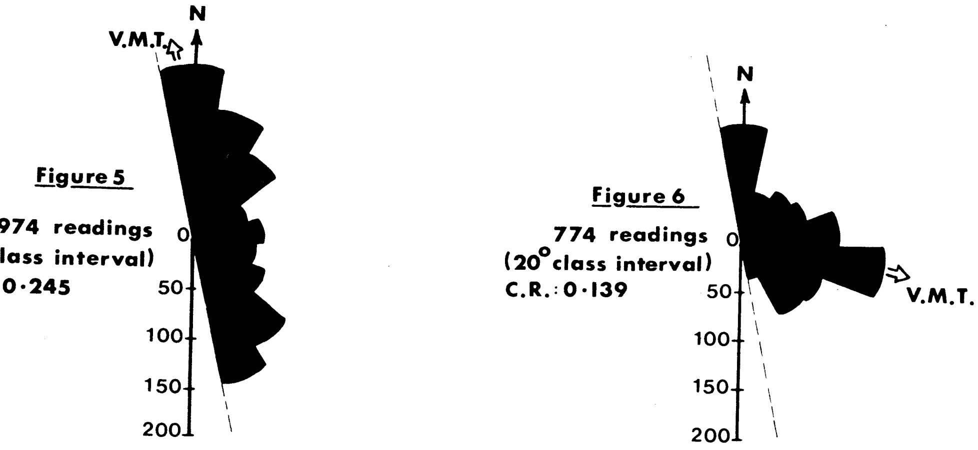
Pebble orientation analysis

Pebble orientation studies were made in March 1976. A total of 3,611 measurements was made at 20 individual sample locations in eight pits. Except in the one case discussed below, gravelly strata amenable to such study were restricted to the Kirkham Member. Azimuths of pebble long axes of planar beds were measured, and in each case the lengths of the *a* and *b* axes were recorded. In the belief that the larger the pebble, the more likely would its alignment indicate the palaeocurrent, only pebbles which had an *a*-axis longer than 20 mm were recorded. Unrug (1957) considered that in many rudaceous sediments, relatively small pebbles simply take up the spaces determined by the voids between earlier deposited larger pebbles. Furthermore, in the belief that, the more elongate the particle, the more likely would its alignment indicate either the palaeocurrent direction or the normal to this (Kalterherberg, 1956), only pebbles where the ratio of *a* to *b* axes was greater than 4:3 were used. Dip and strike values for the host bed structure were recorded by reference to major bedding traces such as continuous clay bands. With a view to trying to determine whether plastic deformation of the host-bed fabrics had taken place during the rotation associated with subsidence, the degree to which the host bed was cemented was noted.

A sample location constituted a pit face having a more or less continuous exposure over an area of not more than 3 square metres. A minimum of 60 measurements were taken at each; in some locations more than 200 were taken. Potter & Pettijohn (1963) stated that, normally, 100 measurements are adequate for statistical purposes. Only a few of the sample locations were bedding surfaces, nevertheless, care was taken to ensure that the number of sections parallel with dip was equal to the number of sections parallel with strike. At some locations the records required no rotational correction as dips were less than 25° (Ten Haaf, 1959); but a correction for rotation was necessary for most locations and this was achieved by stereographic projection and trigonometry.

(i) Bees Nest and Kirkham's Pits (text-figs. 5 & 6)

Two vector diagrams have been prepared. The first, (text-fig. 5), shows a plot of all vectorial data from Bees Nest Pit. There the vector mean trend is clearly established in a N-S direction. The diagram is broadly conplementary to that of text-fig. 3. The second diagram, (text-fig. 6), shows a plot of vectorial data from Kirkham's Pit. The plot is clearly bimodal, with a N-S trend nearly as strongly developed as the vector mean trend of ESE - WNW. This plot is broadly complementary to that of text-fig. 4.



Text-figs. 5 & 6: Rose diagrams showing plots of pebble orientation at the Bees Nest and Kirkham's Pits, respectively.

(ii) Green Clay, Kenslow Top and Kenslow Lesser Pits (text-figs. 7,8,9 & 10)

The results of measurements taken in the Green Clay Pit are of particular interest as all sample locations were in horizontal beds in the troughs of sag-synclines. A total of 553 measurements was taken from gravel strata equivalent to Bed 7 of the nearby Bees Nest Pit section (text-fig. 2). A composite plot of three sample locations (text-fig. 7) represents the data from three gravel layers, each about 0.5 m thick. Unfortunately, the result shows no consistent alignment of pebbles. A composite plot of three sample locations representing the Kirkham Member at Kenslow Top Pit (text-fig. 8) shows a fairly well defined vector mean trend in an ENE-WSW direction.

Of special interest at Kenslow Top Pit is the presence of the stratum of gravelly-clay facies, which lies stratigraphically at about the middle of the Bees Nest Member. This stratum appears to be the youngest pebbly development yet detected anywhere in the Brassington Formation and the only one of post-Kirkham age (text-fig. 2). The plot for the 215 pebbles measured at this sample location is shown as text-fig. 9. The plot is again nearly unimodal, the vector mean trend being well-defined at ENE-WSW; there is a weak subsidiary mode at SE-NW. Two sample locations, both from unknown stratigraphical horizons in the Kirkham Member in the Kenslow Lesser Pit have been combined to represent a composite for the Kirkham Member as a whole (text-fig. 10). The result is comparable to that from the nearby Kenslow Top Pit; there is a strong vector, mean trend at ENE-WSW with a subsidiary mode at SE-NW.

Figure 7

553 readings
(20°class interval)
C.R. : 0·155

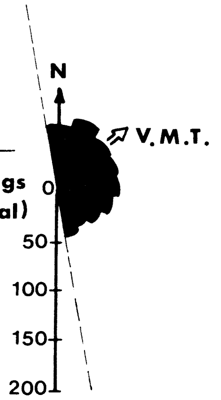


Figure 8

658 readings
(20°class interval)
C.R. : 0·316

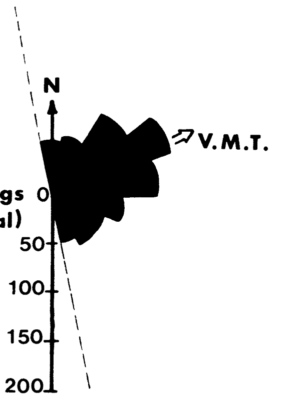


Figure 9

215 readings
(20°class interval)
C.R. : 0·364

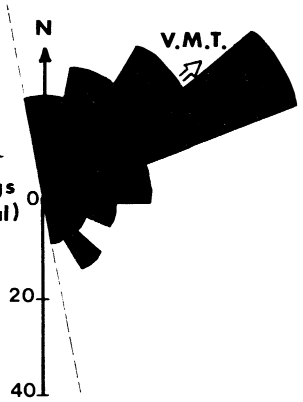
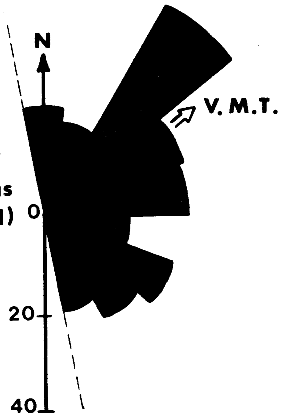


Figure 10

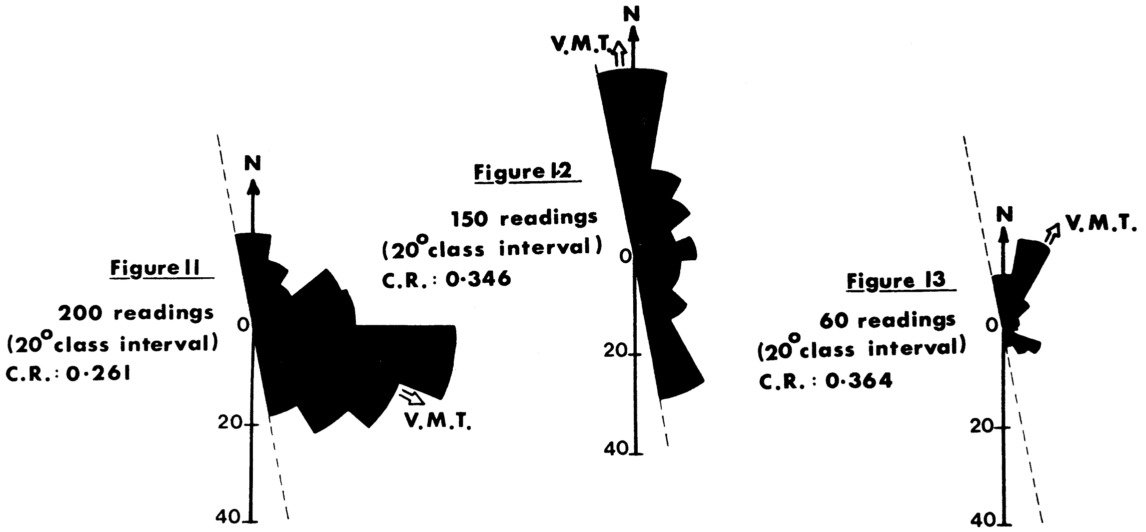
242 readings
(20°class interval)
C.R. : 0·123



Text-figs. 7, 8, 9 & 10. Rose diagrams showing plots of pebble orientations at Green Clay (7), Kenslow Top (8 & 9), and Kenslow Lesser Pits (10). See text.

(iii) Heathcote, Blakemoor and Custard Field Pits (text-figs. 11,12 & 13)

In each of these localities only one sample location from an unknown stratigraphical horizon in the Kirkham Member was established. At Heathcote Pit (text-fig. 11) the vector mean trend is directed strongly at ESE-WNW, with a subsidiary mode at N-S. At Blakemoor Pit the plot is nearly unimodal (text-fig. 12) with the vector mean trend directed N-S. A feeble mode at E-W is also observed. The plot of the horizon in the Kirkham Member at Custard Field Pit (text-fig. 13) is bimodal. The vector mean trend being directed at NNE-SSW; a subsidiary mode is noted at ESE-WNW.

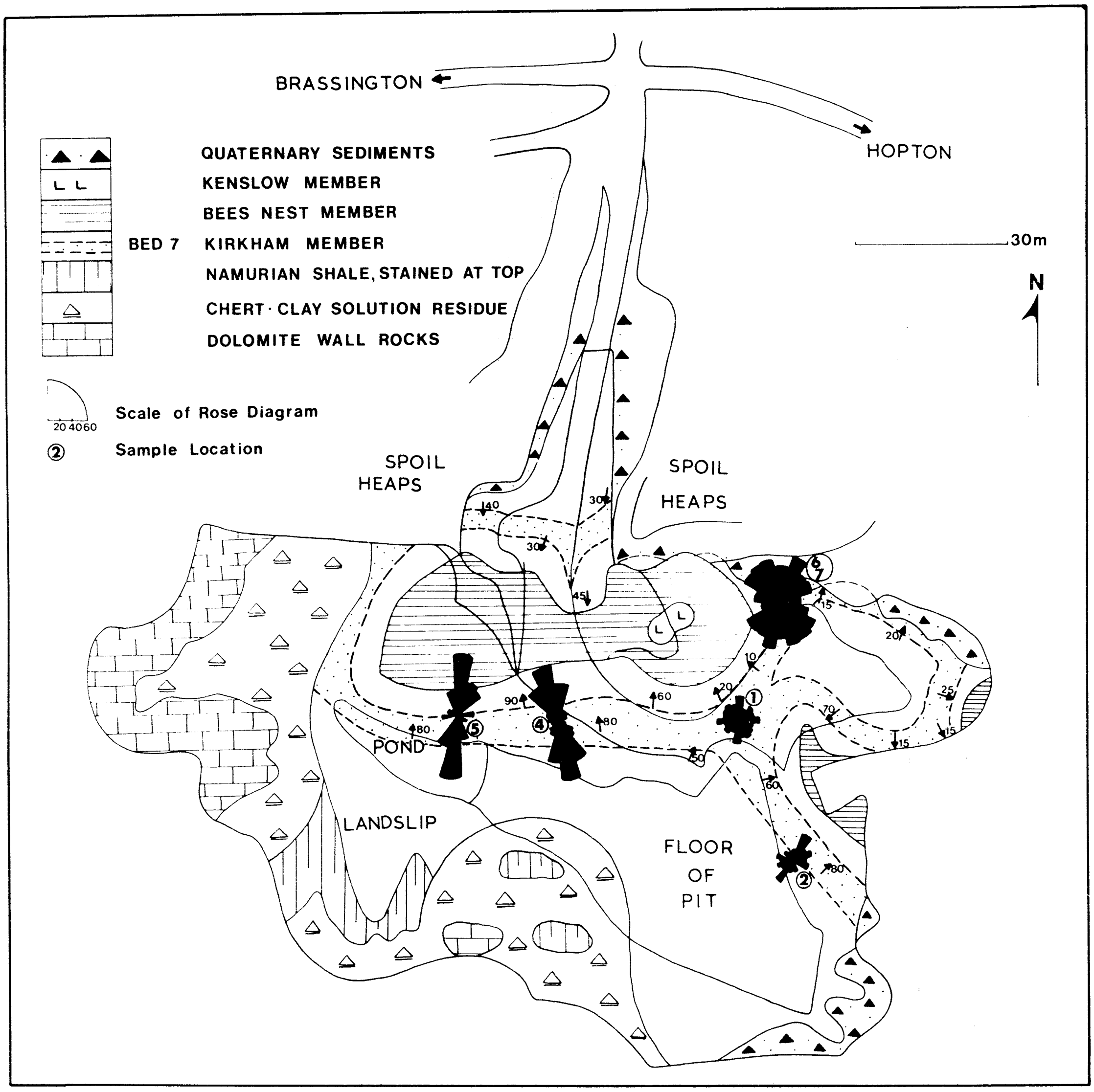


Text-figs. 11, 12 & 13: Rose diagrams showing plots of the pebble orientations at Heathcote, Blakemoor and Custard Field Pits, respectively.

The Validity and Interpretation of the Results

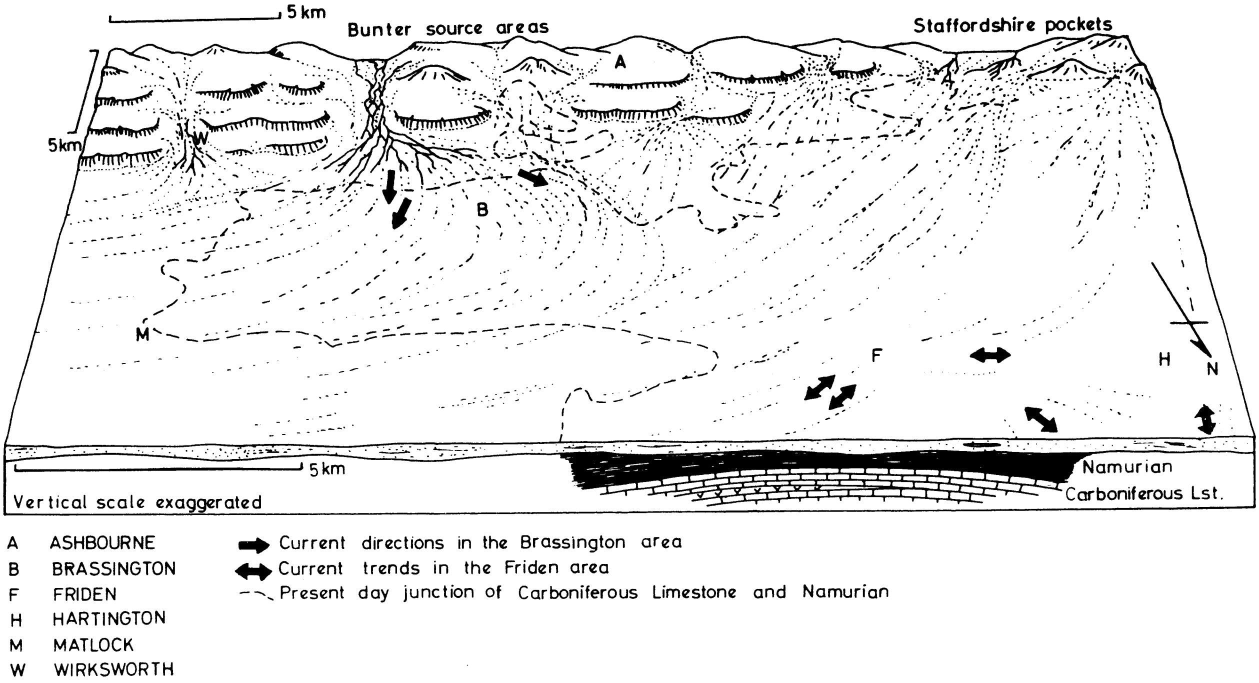
An attempt has been made to establish whether the rotation during subsidence which has affected most of the sections, has caused the palaeocurrent structures to be distorted. Some beds are locally inverted in a bulb-shaped structure at Kirkham's Pit. If it had been found that pebble long-axes were consistently parallel with the dip of rotated beds, this would have rendered the results suspect. It was found, however, that at practically all locations there was a sufficiently-wide range of long axis alignment to deny the possibility that any superimposed tectonic stretching had affected the pebble fabrics. At the Bees Nest Pit, for example (text-fig. 14) there is a remarkably consistent correlation between the vector mean trend from sample location to sample location regardless of whether the beds are steeply dipping or near-horizontal, cemented or uncemented. (In parts of this pit, cemented beds have become dislocated by faulting, presumably a result of subsidence; the cementation may therefore be assumed to be pre-subsidence. Thus it is concluded that subsidence rotation has had no significant effect on the directional orientation of pebble fabrics and the sets of cross-strata in any section studied.

The writers are well aware that there is no universal agreement that the preferred orientations of pebble long axes, even when clearly defined in statistical terms, necessarily gives proof of the direction of current flow in the immediate predepositional environment. However, there seems to be general agreement that in a high energy piedmont or flood-plain environment (*vide* p.51 above) pebbles are likely to have come to rest with their long axes either parallel with (mass moving) or at right angles to (rolling) the direction of flow (e.g. Krumbein, 1940; Ruchin, 1958; Sengupta, 1966; Rust, 1972; Hein and Walker, 1977). In any case it must be remembered that in the Kirkham Member at the Bees Nest and Kirkham's Pits there is a regular interdigitation of beds which yield statistically useful cross-bedding data and beds yielding useful pebble fabric data. Providing that the results from both are closely parallel, the cross-bedding data can clearly help to interpret the flow directions which have produced the pebble fabrics. The composite mean trend (V.M.T.) for the pebble long axes for all the beds at Bees Nest Pit (974 measurements) is 173/353° (text-fig. 5). The vector mean direction (V.M.D.) for 101 cross-bedding measurements is 036° . At Kirkham's Pit, the V.M.T. for 774 pebble measurements is 105/285° (text-fig. 6), whereas the V.M.D.



Text-fig. 14: Map of the Bees Nest Pit to show -
(1) the stratigraphy
(2) the sample locations for pebble orientation studies, and
(3) rose diagram compilations for measurements on Bed 7.

for cross-bedding measurements is 305° (text-fig. 4). The composite V.M.T. for all measurements from all levels in the southern group of pits (2,301 measurements) is 000/180°, whereas the composite V.M.D. for all the cross-bedding directions in the southern sections (131 measurements) is 010°. The writers conclude therefore that comparisons are close enough to deduce that a majority of the pebbles in the Kirkham Member gravels were generally deposited with their long axes selectively disposed parallel with current flows. A fairly consistent northwards directed flow, both in time and space is indicated for the southern group of sections (text-fig. 2).



Text-fig. 15: Hypothetical reconstruction of the palaeography of the Brassington Formation basin of deposition in mid-Kirkham Member times (partly after T.D. Ford)

Palaeogeographical and geomorphological implications

The present results only provide a very localised picture of the palaeogeography of the Brassington Formation in mid-Neogene times. Even if every subsided mass of the original formation sequence so far located had been exposed at the present time, it is doubtful if anything more than a very generalised picture of the distribution pattern of stream flows would have been forthcoming. But, of course, this is only a part of the picture and much can be deduced from complementary sedimentological studies. Several useful conclusions can be made at this stage.

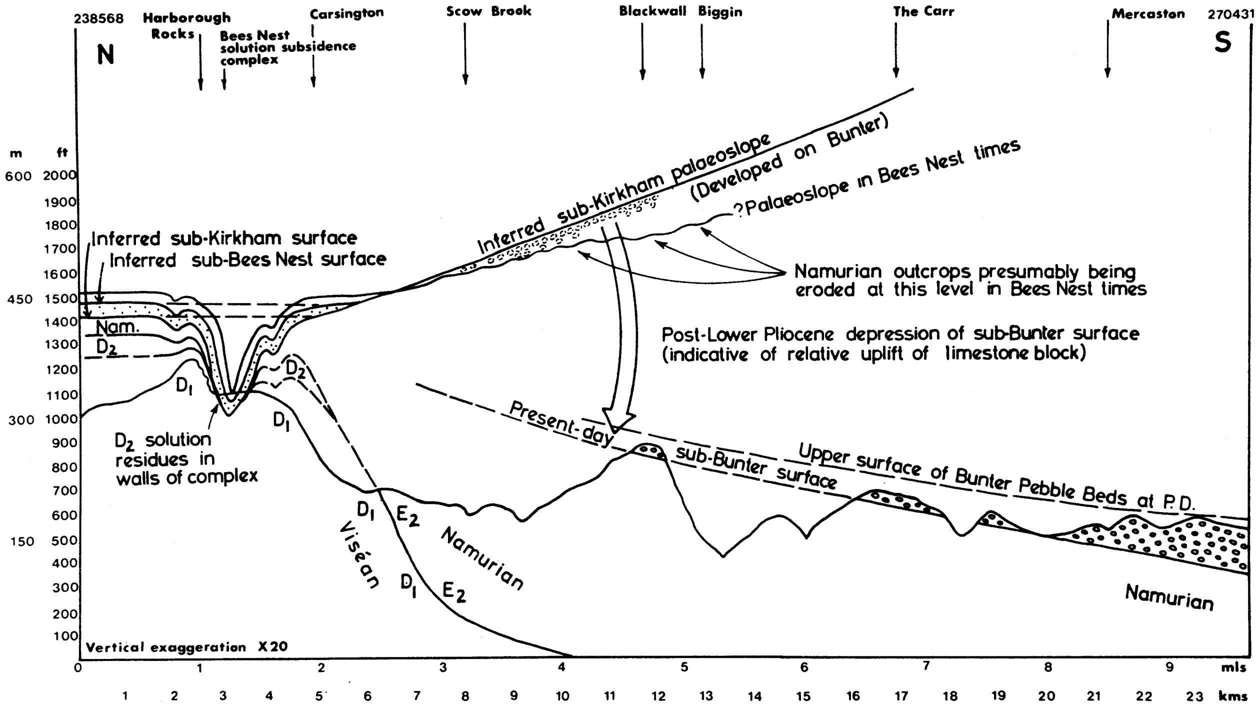
The present results support the hypothesis that an important provenance lay generally to the south of Brassington. Indeed, in view of the great lithological similarities of the sections around Brassington, there may have been a large river which drained an outcrop of rapidly eroding Bunter Pebble Beds in the block of country now cornered by the villages of Hognaston, Atlow, Kirk Ireton and Biggin (text-figs. 1 & 15). However, gravel pockets of supposed Brassington type have been worked near Kniveton (SK212509), so the edge of the depositional area must have lain further south for at least part of Kirkham Member times. Divergence of palaeocurrent directions in the three pits of the southern group suggests the construction of an alluvial fan with distributaries delivering large amounts of coarse sediment near to the edge of a subsiding basin.

There is no justification for conjecturally extending this fluvial pattern to the north because there is no control from cross-bedding structures in this northern group of exposures, and trends established from pebble fabric analysis are very variable. The thick gravel beds as exposed in the Kenslow Top section show that persistent flows of considerable competency took place here throughout Kirkham Member times. The Firms which extract sand and gravel locally for use as refractories believe that the Kirkham Member in the northern group of sections is composed of relatively finer grades of both sand and gravel than the deposits in the south, but the facies is otherwise comparable and it is puzzling that cross-bedding structures are so rare there. It is possible that the northern sediments were formed as another fan, built up, say, from the east or north, which coalesced with that built up from the south.

It is simply not possible to determine whether the general attitude of the palaeoslope which formed the southern margin of the basin altered significantly after Kirkham Member times. Certainly, the supply of gravel into the basin was abruptly terminated and overbank silty-clay deposition rapidly took its place. The gradients on the palaeoslope may have become gentler through the general southerly recession of the Bunter Pebble Bed source. Eventually, there must have been a more or less complete removal of gravel sources from a wide strip marginal to the basin. There seems to be no need to invoke any change in the trend of the palaeoslope. Removal of the Bunter cover (to produce the bulk of the Kirkham Member) could have exposed the underlying shaley Namurian outcrops which are still present in the Hognaston-Atlow-Kirk Ireton-Biggin block. Erosion of the Namurian foundation, and also, possibly, the Carboniferous Limestone of the Kniveton Inlier, would adequately account for the source of the dominantly illitic clays of the Bees Nest Member.

One of the more fascinating, if seemingly intractable problems about the Brassington Formation, is the destination of the drainage beyond the > 220 km^2 wide area within which Brassington sediments have been preserved. Supposed freshwater Neogene sediments have been described from solution subsidence hollows in the Carboniferous Limestone outcrops of north-east Wales, (Walsh & Brown, 1971), and it is tempting to regard these and the Derbyshire Neogene as coeval coastal plain alluvial deposits peripheral to a marine basin centred on Liverpool Bay and/or the Cheshire Basin. Unfortunately, no evidence whatever has yet come to light that these parts were open seaways in the mid-Neogene; nor is there any evidence that such Tertiary Basins as have been discovered on the floor of the Irish Sea have been the sites of internal drainage systems. Perhaps the simplest explanation to fit existing data is that the Brassington mainstream (and others contributing sediment to the Derbyshire Neogene area) were deflected into a more easterly course out of the basin and flowed into the North Sea as a very early analogue of the modern Trent (text-fig. 15). If the thickness of the Brassington Formation preserved in the Derbyshire solution hollows is truly representative of the mean local thicknesses of the prism (i.e. if it is not exaggerated as a result of solution subsidence effects which were concomitant with sedimentation), the total original volume of the Formation must have been in excess of 10 km^3. There can be little doubt that at least some of this now forms Plio-Pleistocene sediment in the North Sea Basins. It is suggested, therefore, that those same streams which deposited the Formation came later, through crustal movements, to remove their earlier-formed deposits eastwards. Hey (1976) has reported the occurrence of Bunter Pebble Bed-type clasts in the pre-Anglian succession of the East Anglian Pleistocene; conceivably at least some of these are Brassington Formation clasts, which have been re-cycled for a second time.

Finally, some comment must be made on the remarkable uplift which must have taken place along the southern end of the Pennines since Lower Pliocene times. Walsh *et al.* (1972) have proposed that the surface on which Brassington Formation sediment was deposited cannot have been much less than 420-450 m A.O.D. (1,400 - 1,500 ft.) in the Brassington area (text-fig. 16). By extension, the Kirkham Member here being some 30 m thick, the surface on which Bees Nest Clays were deposited must have been at about 450-480 m A.O.D. Clearly, at a time when the Bees Nest Clays were being deposited, the Namurian outcrops to the south of Brassington must have been higher still, say a minimum of 60 m. The general level of the provenance area must thus have been at about 510-540 m A.O.D. However, the hill summits on the supposed source area at the present time generally lie at about 240-270 m A.O.D. and at least one of these, that at Blackwall (SK 257497) still possesses what has been interpreted as a capping of Bunter Pebble Beds (Ford, 1972b). D.B. Thompson (personal communication) informs the writers that pebble lithology studies at Blackwall indicate that the percentage of Triassic-type pebbles and ventifacts is about half way between those of the Bunter Pebble Beds proper and the Brassington Formation. By implication, the former sub-Bunter surface cannot have been much lower than the general level of the modern hill summits in this source block.



Text-fig. 16: Diagram to show -
(1) the present-day physiography of the southern end of the Pennines, and
(2) an hypothetical reconstruction of the physiography in Lower Pliocene (Brassington Formation) times.

Thus, in a horizontal distance of no more than 3 km at most, the Lower Pliocene palaeoslope has been reversed in see-saw fashion, the relative swing being of the order of 1 in 10 when expressed as a gradient, and with a relative vertical displacement of 300 m as a minimal effect. Presumably, this was a fairly simple upwarp of the southern end of the Pennines, as nothing suggestive of a southwards-facing fault-scarp has been reported in the upper reaches of the Henmore Brook Valley (hereabouts termed the Scow Brook), where the main effects of the warp must have been felt. Hinges ("Charnières") of similar proportions and age have recently been postulated to explain certain major geomorphological features of the Welsh landscape, e.g. the north-western front of the Snowdonian Block (Battiau-Queney, 1980).

The cause of this remarkable uplift is not known, but it has an interesting association with the Derby Earthquakes of 1903, 1904 and 1906. Davison (1924, p.263) attributed the 'quakes to movement on a fault which trends 026° through Ashbourne and Hognaston at a depth of "several miles". The effects of the Derby Earthquakes show that there are two epicentres, the one 2.5 km east of Ashbourne, the other 5 km west of Wirksworth (these are ca. 12 km apart). On the basis of other recent earthquake effects in the North Midlands, Davison concluded that there is a pattern of interfering active folds of Caledonoid and Charnoid trend in the area. One interpretation of the fault movements is that the Ashbourne and Wirksworth epicentres lie close to the intersection of a Caledonian syncline with a Charnian syncline (Davison, 1924, p.408) which thus coincides roughly with what is considered in this paper to have been an area much depressed since the Lower Pliocene.

Acknowledgements

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THE AMMONITE *EPARIETITES UNDARIES* (QUENSTEDT) IN THE LOWER JURASSIC (SINEMURIAN) OF BRITAIN

by

K.L. Joss

Summary

The Sinemurian (Lower Jurassic) Frodingham Ironstone of Scunthorpe, South Humberside, has yielded two specimens of the compressed asteroceratinid *Eparietites undaries* (Quenstedt). This species, for which there is no previous record from a British locality, is compared with *E. denotatus* (Simpson), *E. fowleri* (J. Buckman), *E. impendens* (Young and Bird) and *E. tenellus* (Simpson). *E. undaries* (Quenstedt) differs from these other British species in being more evolute, with less prominent ribbing, and in having a tricarinate and bisulcate venter on the inner whorls.

Introduction

Recent field collecting by the author from the Sinemurian (Lower Jurassic) Frodingham Ironstone of Scunthorpe, South Humberside, has yielded two ammonite specimens belonging to the genus *Eparietites* Spath, 1924. They are allocated to the species *Eparietites undaries* (Quenstedt), a species common in France. The specimens were found within the top 0.8 m of the ironstone at Winterton Quarry (SE/913200). To the author's knowledge, this species has not been previously described from any British locality.

E. denotatus (Simpson) is common within the top 1.0 m, or so, of the Frodingham Ironstone and is laterally distributed throughout the outcrop from Winterton Quarry in the north to Yarborough Quarry in the south (SE/931102). *E. tenellus* (Simpson) also occur, but is less common. *E. impendens* (Young and Bird) and *E. fowleri* (J. Buckman) have not, however, been recorded from this area.

Systematic palaeontology

Suborder AMMONITINA Hyatt, 1889
Superfamily PSILOCERATACEAE Hyatt, 1867
Family ARIETITIDAE Hyatt, 1874
Subfamily ASTEROCERATINAE Spath, 1946
Genus *Eparietites* Spath, 1924

Type species. *Ammonites tenellus* Simpson, 1855. The holotype from Robin Hood's Bay, Yorkshire, is figured by S.S. Buckman (1912, Pl.54) and is housed in the Whitby Museum (Cat. No.293).

Diagnosis. Asteroceratinid ammonites which have a distinctly keeled venter and narrow umbilicus. The whorl section is compressed, higher than wide, having a maximum width at the umbilical margin. Ribbing is strong and smooth, becoming irregular and fading on the outer whorl. Sutures are simple with wide undivided saddles.

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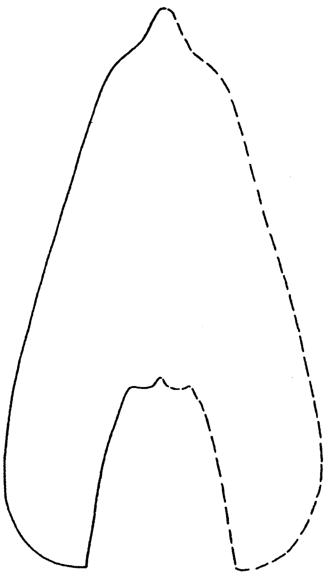
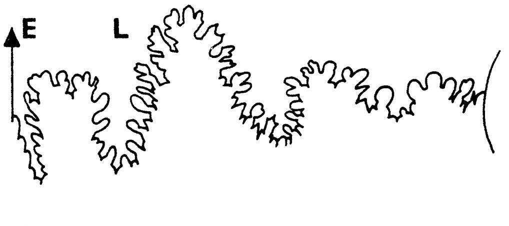
pp. 63-68, 26 text-figs., plate 1



Text-fig.1. Whorl section of *Eparietites undaries* (Quenstedt), No. KLJAM26, at a diameter of 144 mm. Scale 0 10 mm.



Text-fig.2. The external suture of *Eparietites undaries* (Quenstedt), No.KLJAM26. Scale 0 10 mm.

Eparietites undaries (Quenstedt, 1884), Pl.1; text-figs.1,2.

1884 *Ammonites undaries* Quenstedt, p.148, pl.20, figs.2-6.
1966 *Eparietites undaries* (Quenstedt); Guérin-Franiatte, p.319, pls.200-203.

Lectotype. No. Ce 5/20/3 (from Endingen, Wurttemberg, South West Germany), Quenstedt Collection, Geological Institute, Tübingen. Figured by Quenstedt (1884, pl.20, fig.3) and selected as lectotype and figured by Guérin-Franiatte (1966, pl.200).

British specimens. KLJAM26 from the Frodingham Ironstone (Sinemurian), Winterton Quarry (SE/913200), near Scunthorpe, South Humberside, KLJAM3 from the same locality. Both specimens are housed, at present, in the Geology Department, Sunderland Polytechnic (author's collection).

Dimensions. (mm) Table 1

D = diameter, N = number of ribs per whorl, U = umbilical diameter, Wb = whorl breadth, Wh = whorl height.

	D	Wb	Wh	U	N	Wb/Wh	(Wh/D)%	(U/D)%
Lectotype	148.5	37.5	61	45.5	-	0.61	41	30
Pl.1 KLJAM26	144.4	35	64	42	32	0.55	44	29
KLJAM3	125	-	48	43	32	-	38	34

Description. The features described here are mainly those of KLJAM26 because the other specimen is poorly preserved. The whorl section is compressed with convergent sides. On the inner whorls the ventral edge is tricarinate and bisulcate. At the start of the outer whorl, the central one-third of the venter is occupied by a tall, sharp, entire keel, which is flanked by very shallow sulci. On the outer whorl, the high, median keel gradually widens and becomes more rounded. The lateral sulci become indistinct and gradually disappear, forming two smooth bands on either side of the keel and, finally, the keel has concave slopes near the aperture.

There are at least four volutions and each whorl overlaps the previous one by three-quarters. The umbilicus is open (about 30 per cent. of the shell diameter) and the umbilical wall is vertical.

Ribbing is strong on the inner whorls, with 32 ribs per whorl, but weakening, becoming smooth and fading near the aperture on the outer whorl at a diameter of 10 to 12 cm. The ribs are straight until they near the ventro-lateral edge, where they swing adaperturally.

The suture line has a wide and relatively simple ventral lobe and a shorter lateral lobe. The saddles are wide, simple and undivided.

The species may attain a diameter in excess of 30 cm with at least the last whorl being totally without ribbing (Quenstedt, 1884, 148-151).

Discussion

Cross (1875), who was the first to study ammonites from the Frodingham Ironstone, recorded a total of nine species, including *Ammonites scipionanum* Quenstedt and *Am. compressaries* Quenstedt. Hallam (1963), after examining a number of ammonites, both from collections in the Scunthorpe Borough Museum and others collected *in situ*, assumed that these two species belonged to the genus *Eparietites*, which was proposed by Spath (1924) for the group of *Ammonites collenotii* d'Orbigny, *Am. denotatus* Simpson, *Am. tenellus* Simpson and *Am. impendens* Young and Bird. Thus, Hallam recorded *Eparietites denotatus* (Simpson) and *E. tenellus* (Simpson).

Table 2. A comparison of the main morphological features of the British species of the genus *Eparietites* Spath, 1924.

AMMONITE SPECIES / FEATURES				E. undaries (Quenstedt)			E. tenellus (Simpson)	E. denotatus (Simpson)	E. impendens (Young and Bird)	E. fowleri (J. Buckman)
				lectotype	KLJAM 3	KLJAM 26				
Diameter in mm.				149	125	144	68	145	70	63
Umbilical diameter per cent.				30	34	29	21	23	27	28
Umbilical edge			Steep	x	x	x		x		
			Rounded				x			x
			Overhanging						x	
Ribbing	strength		Very strong					x		
			Strong	x	x	x			x	x
			Weak				x			
	spacing		Close							x
			Less close				x		x	
			Wide	x	x	x		x		
	thickness		Fine - acute						x	x
			Thick				x			
			Undulating	x	x	x		x		
Venter	Near the aperture	keel	Median sharp						x	x
			Median rounded	x	x	x	x	x		
		sulci	Wide distinct							
			Flat:- shelf-like						x	
		Concave slopes		x	x	x	x	x		x
	Inner whorls and beginning of outer	keel(s)	Median sharp						x	x
			Median rounded				x	x		
			Tricarinate	x	x	x				
		sulci	Wide distinct	x	x	x			x	
			Flat:- shelf-like				x	x		x
		Concave slopes								

The main morphological features of the British species of the genus *Eparietites* are compared in Table 2. *E. fowleri* (J. Buckman) was figured by S.S. Buckman (1904, pl.37). The holotype (L11158) is in the collections of the Manchester Museum. This species is small; in general about 50 to 60 mm in diameter. It has a percentage ratio of umbilical diameter to total diameter of 28 but the ribs are slimmer and more closely spaced than those of *E. undaries* and the inner whorl margins are less thick, with no umbilical wall.

E. impendens (Young and Bird) was also figured by S.S. Buckman (1919, vol.2, pl.CXX) and the holotype is in the collections of the Whitby Museum (Cat. No.292). The inner margin of the whorl of this species overhangs the umbilicus; hence the name '*impendens*'. However, the inner whorl margins of *E. undaries* are vertical. Also, *E. undaries* is more evolute, has a larger diameter and has thicker, more undulating but less prominent ribbing. Neither *E. fowleri* nor *E. impendens* have been recorded from the Frodingham Ironstone.

Whitby Museum is also the repository of the holotype of *E. tenellus* (Simpson). This is the type species and is also figured by S.S. Buckman (1912, vol.1, pl.LIV). Simpson (1855, p.97) regarded *E. tenellus* as,

> "a more elegant species than the last (*A. impendens* Young and Bird); the radii are less prominent, and the groove on the side of the keel much flatter".

E. tenellus is much more involute than *E. undaries*, having a percentage ratio of umbilical diameter to total diameter of 21, and it is less than half the size (total diameter 68 mm) of the latter.

E. denotatus (Simpson) is the most common species of *Eparietites* present in the ironstone. It was figured by S.S. Buckman (1912, vol.1, pl.LXVII A, B), and the holotype (J3273) is in the Leckenby Collection in the Sedgwick Museum, Cambridge. This species is also more involute than *E. undaries*; the umbilical diameter is 23 per cent. of the total diameter. The inner whorl margins are similar to that of *E. undaries* but the ribbing is stronger and more closely spaced. The species was figured by Wright (1881, pl.XXII B) as '*Arietites collenotii*' but S.S. Buckman (1912, vol.1, p.67b) considered the ribs to be depicted far too strongly. However, Guérin-Franiatte (1966, p.317) suggested that *Ammonites collenotii* d'Orbigny ought to be returned to the genus *Oxynoticeras*.

Thus it is concluded that *Eparietites undaries* (Quenstedt) is more evolute than any of the other British species of the genus and may attain a much larger diameter. It is tricarinate and bisulcate on the inner whorls. The ribs are thick, not very prominent and less close than those of *E. denotatus* or *E. impendens*.

Acknowledgements

Grateful thanks are extended to Dr. M.K. Howarth (British Museum, Natural History), Dr. W.B. Scott and Mr. N.J. Horrell (Geology Department, Sunderland Polytechnic), Dr. G.P. Larwood (Department of Geological Sciences, University of Durham) members of the staff of the British Steel Corporation, Scunthorpe and to Mr. R.D. Pallister (Languages Department, Easington Comprehensive School). I would also like to acknowledge the help given by the staff of Whitby Museum and by Mr. R.B. Walker (Curator of Natural History, Scunthorpe Borough Museum).

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Plate 1.

Eparietites undaries (Quenstedt), No. KLJAM26, x 0.7

EXCURSION TO THE DINANTIAN CARBONATES OF THE WIRKSWORTH - CRICH AREA

Leader: Paul H. Bridges — Sunday, October 14, 1979

The purpose of this excursion was to unravel some of the evidence for the conditions of carbonate deposition and diagenesis on the southern and eastern margins of the Derbyshire limestone platform during Brigantian (late Dinantian, D2 - P2) times.

Coal Hills Quarries (disused); Wirksworth SK 286 553 (Tarmac Roadstone Ltd.)

The party of about 60 first visited a fine 'reef knoll' complex developed in the Cawdor Limestone (Walkden *et al.* 1979). The area was lightly shrouded in autumn mist. Close examination of one 'knoll', approximately 40 m in diameter at its base and 6 m high, showed it to be composed of crudely bedded skeletal wackestones locally passing into lenticles of skeletal grainstones and patches of intraclast and fenestral rudstones (text-fig. 1). The fauna largely consisted of small, thin-shelled productids with their delicate spines preserved, disarticulated crinoid columnals and numerous fenestellid bryozoa. Micrographs of the fenestral rudstones showed that the former system of highly irregular cavities with productids and fenestellids had been infilled by a radial-fibrous cement. The term carbonate mound was preferred to 'reef knoll' in order to avoid the implication that the shelly benthic fauna formed a skeletal framework in a manner similar to modern patch reefs.

Just 80 m to the north, members of the party investigated the well bedded limestones which had formed on the lee side of the carbonate mound. Thickly bedded units of coarse skeletal grainstones and rudstones alternated with more thinly bedded, finer grained and more bituminous units of limestones. The skeletal grainstones and rudstones were composed of highly comminuted and abraded thick-shelled gigantoproductids and crinoids. Micrographs showed that in some instances the outer laminated part of gigantoproductid shells, with well developed pseudopunctae, was intact, but in most fragments, this layer had been removed by abrasion leaving a thick (up to 1 cm) inner layer of coarse prismatic spar. The bituminous limestone yielded specimens of gigantoproductids with the valves still articulated together. Micrographs revealed the presence of numerous endothyrid foraminifera. One crinoid calyx was also discovered.

It was suggested that the finer grained, bituminous limestones represented the host substrate for many of the gigantoproductids, while the skeletal grainstones and rudstones represented shell debris which had been heavily and repeatedly reworked before being finally deposited in the environment to the lee of the carbonate mounds.

Hopton tunnel Sk 265 547 (High Peak Trail)

After lunch, and with visibility much improved, the party made a brief visit to the exposures of Matlock Limestone situated on the High Peak Trail. Well bedded skeletal grainstones with nodular development of chert were traced westwards into heavily dolomitized and partially silicified carbonates. Micrographs showed that the dolomite varied from finely to coarsely crystalline, but relics of the former shell debris could generally be discerned. Cryptocrystalline and microcrystalline quartz were developed as small and irregular patches. It was uncertain whether the dolomitization had been caused by upward moving fluids accompanying late Carboniferous mineralization, or by downward moving brines associated with desiccating playa lakes developed in Permo-Triassic times.

Cliff Quarry (disused section) Crich SK 345 553 (Owners: Butterley Aggregates; access-Crich Tramway Museum)

Finally, the party travelled to see the finely exposed Matlock Limestones at Crich (Smith *et al.* 1967). The lower part of this sequence of well bedded limestones showed a distinctive pattern of sedimentation. The succession included a series of units ranging from

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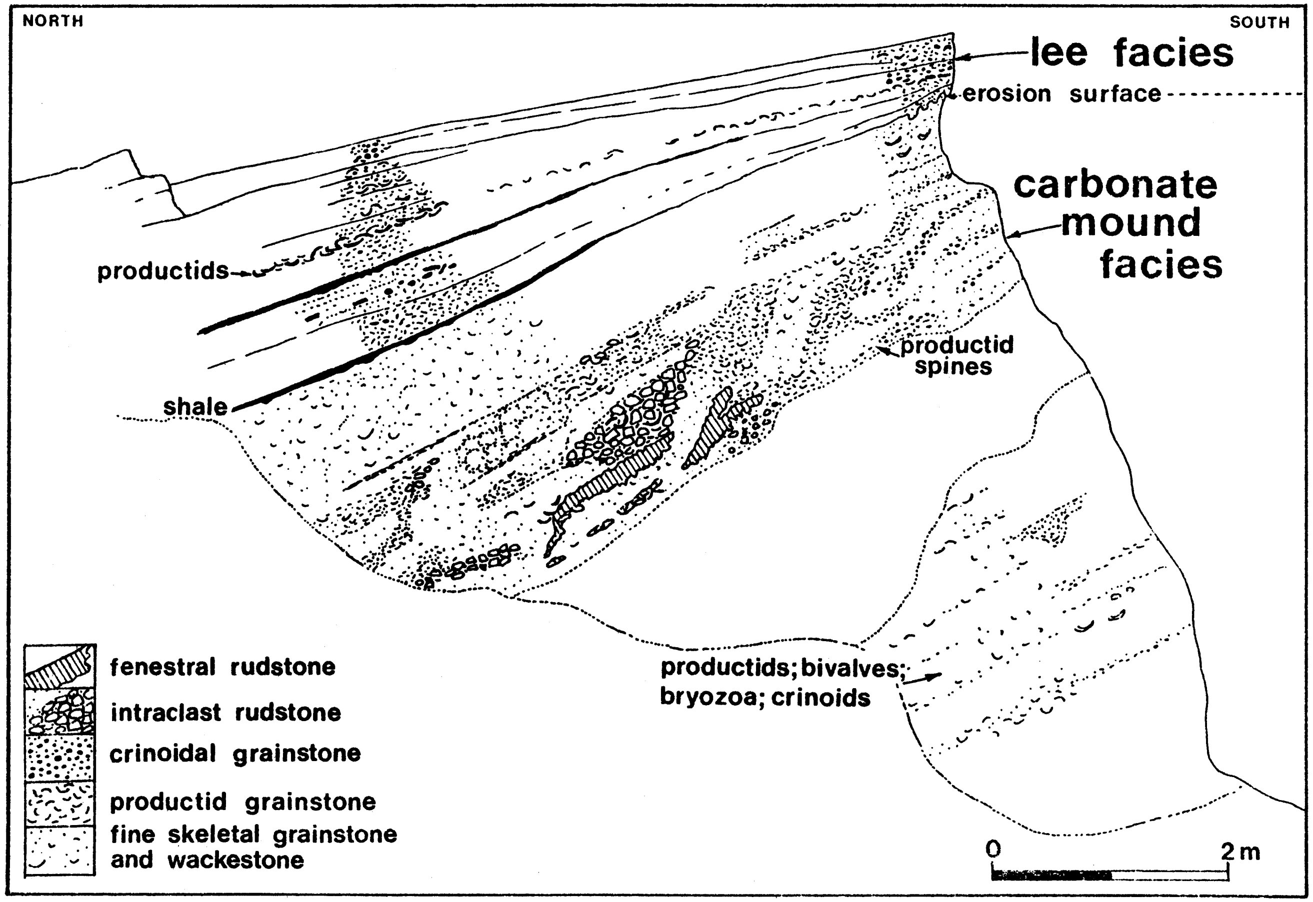
1980, pp.69-71, 1 text-fig.



Text-figure 1: Diagram showing a section through the northern (leeward) margin of the carbonate mound in Coal Hills Quarry. Crudely bedded, fine skeletal grainstones and wackestones predominate, but they are interrupted by a conspicuous northward dipping zone characterized by irregular lenticles of coarse skeletal grainstones, intraclast rudstones and fenestral rudstones. Towards the top of the sequence coarse productid and crinoidal grainstones of the lee facies rest erosively on the carbonate mound facies.

1.5 to 4.0 m thick, each dominated in its lower part by sand grade skeletal packstone with scattered broken valves of brachiopods. Locally there were horizons of coarse skeletal grainstones. These packstones and grainstones were composed of finely comminuted productids, terebratulids, crinoid columnals, productid spines, bryozoa, ostracods and foraminifera. Most of the grains were partially micritized. However micrographs taken of peels taken from the upper parts of the units showed a higher concentration of peloids and a reduction in the proportion of identifiable skeletal debris. These peloids generally occurred as a packstone but locally they were matrix-supported and formed a peloidal wackestone, with small fenestrae of cryptocrystalline quartz. The top surface of these units was erosional and displayed an array of irregular trochoidal scoops and ridges generally 3 - 10 cm in relief. There were however, no laminated carbonates (reminiscent of karstic soilstone crusts) which have been discovered elsewhere in rocks of Brigantian age in Derbyshire (Walkden, 1974). From comparison with modern carbonates in Shark Bay, Australia (see Hagan & Logan, 1974) it was suggested that each unit reflects a period of gradually shoaling water. Further work in progress, was necessary to confirm this.

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BOOK REVIEWS

ANDERTON, R., BRIDGES, P.H., LEEDER, M.R. and SELLWOOD, B.W.
A dynamic stratigraphy of the British Isles; a study in crustal evolution
Allen & Unwin, 1979, 301 pp., illustrated text-figs., soft back - £7.95

The title of this book suggests that stratigraphy and geological history are to be combined, with the British Isles as the centre of the arena. Previous books on these subjects (Rayner, D.H. and Bennison & Wright) were written before plate tectonics, as a method of crustal evolution, could be included, so that the text reviewed here must be a considerable advance on previous texts.

The content of the book and its arrangement also differs from previous texts in that there is much new information, and the restrictive straight-jacket System descriptions is overthrown for a more logical tectonic framework. Thus the book commences with early crustal formation on a global scale and later the British Isles includes at least the adjacent sea areas. The early Iapetus Ocean dominates the account of the late Pre-Cambrian and Lower Palaeozoic and later the British Isles is considered as a margin of the European Continent. Contents are completed with 'the Present' and a look into the future.

The book is well illustrated and much of the detail of the evidence (the boring aspect for many undergraduates) is presented in text-figs. and tables, many reminiscent of those in the Special Report Series of the Geological Society of London - 'A correlation of the....rocks of the British Isles.' Some of these reports had not been written when 'A dynamic stratigraphy...' was prepared so that there is a certain amount of imbalance in the detail correlation of some areas at certain times. Some of the tables and figs. (p.95) contain a surfeit of information not easily comprehended even by a specialist. Many figures are cluttered by dense symbols masking lettering (13.13 - I had to mention that one). The text contains many esoteric terms, making it difficult for the average reader, but it is stated that a minimum first year geology University course is necessary, but which University? Are other institutions of higher education or the membership of parochial geological societies thereby excluded?

The book follows the unfortunate modern trend (in my view) of starting with generalisations and conclusions, presenting much of the evidence in the tables and figs., or routing the reader to a bibliography which itself is only the start of the search. Arguments and hypotheses are presented with the minimum of evidence. There should be more reference to fossil evidence still the major basis for correlation and for palaeoecology. The sedimentology is excellent but the palaeontology leaves much to be desired. What has happened to the Jurassic zones? How are systems and stages defined?

Palaeogeography is illustrated in many maps and diagrams but the overall impression is a bit disjointed in that the overall picture of successive geographies is not presented on a standardised map. It is suggested that maps similar to those of Wills, brought up to date, could appear at the end of each section or chapter.

The text is presented in a two column format which assists reading and allows the page width to be increased a little. It has been well proof read and considering that there are four authors, the text is remarkably uniform in style.

This is a book to be recommended certainly to University undergraduates and also to others interested in the evolution of the British Isles area, with help from other bibliographical sources.

F.M. Taylor

BURNS, T.L., & SPIEGEL, H.J., *Earth in Crisis*, C.V. Mosby Co., 1980, St. Louis and London, 2nd Ed., 549 pp., illustrated text-figs. and half-tone plates. Hard covers £11.75.

'Earth in Crisis' is intended for 'freshmen and sophomore general education students', that is, first and second year American university students, and indeed it does have the flavour of a subsidiary subject textbook, covering a bewildering amount of material but often in a rather sporadic and superficial manner. Geology, oceanography, meteorology and astronomy are treated in four separate sections, the first and last of these forming the major part of the book. Of all four, I felt that the astronomy section was the most successful, although I should hastily state that the geology part is the only one on which I can comment with any but the most elementary knowledge of the subject.

The geology section comprises a disappointingly potted account, slick and easy to read, but lacking in imagination in the more exciting areas of the subject. It begins with chapters on minerals and rocks, containing some appallingly poor photographs of rock specimens although the effect is somewhat alleviated by some spectacular plates of large-scale features. Igneous and surface processes are dealt with, followed by a depressingly brief account of fossils and the geological record. The chapter on 'Diastrophism' fails to generate any excitement or feeling of discovery - it should be compared (very unfavourably) to the, admittedly wider scale, book by P.J. Wyllie - 'The Way the Earth Works'. The final chapter on U.S. National Parks is of limited value only, to British students. Certain irregularities and omissions are apparent - to cite one, for example, some attention is paid to James Hutton and the Vulcanists, but no mention at all is made of Werner and his Neptunean school.

It is the authors' desire that the oft neglected 'social, economic and environmental considerations' be comprehended along with the physical phenomena, and their attempts to include these in the text come as a welcome change from the rather narrow approach of many mineralogy texts.

Questions and activities for the student at the end of each chapter are intended to 'involve thought...instead of memorisation', and to this end some are naturally more successful than others. I always feel that such additions command more student attention when interspersed with the text rather than being at the end of a chapter or section - although there is always the danger that such a highly thought provoking question/activity could seduce the hitherto engrossed student from his reading!

Finally, the Prologue should prove a stimulant to all jaded Freshmen. It should be read with a heavy mid-west accent, preferably with the theme music from '2001: a space Odyssey' playing in the background. We journey into the book 'from some remote part of the universe at the speed of light with the freedom of a god'! Disregarding our by now infinite mass, we approach the solar system, with planets which 'have no light of their own and reflect only that which their giant master sends them', including 'an incredibly beautiful ringed sphere called Saturn' and 'a breathtakingly beautiful blue planet' - Earth.

Who would miss it?

Edwina Cosgrove

L.B. HALSTEAD, 1975. *The evolution and ecology of the Dinosaurs.* Illustrated by Giovanni Caselli. London; Peter Lowe/Eurobook. 116 p. £2.75.

L.B. HALSTEAD, 1979. *The evolution of the Mammals.* With 8 double-page illustrations by Sergio and many other illustrations. London: Peter Lowe/Eurobook. 116 p. £4.50.

These two works form part of a planned series which will explore the life of the past in brief form with ample colour illustration: a third, *The evolution of Early Man* by Bernard Wood, is also to be published shortly. The page size is large, 21 x 27 cm ($8\frac{1}{4}$ x $10\frac{1}{2}$ inches) and the use of colour illustration lavish; both books are extremely attractive to handle and to read. Though apparently designed primarily for a juvenile market, they must not be dismissed merely as "children's books"; they provide admirable epitomes of available information on the groups with which they treat and can be read with profit by anyone wishing to expand their knowledge of fossil vertebrates.

The earlier of the two works appeared at a time when a rethinking of traditional attitudes to dinosaurs (a "dinosaur renaissance", some have called it) was just gathering momentum. For too long, dinosaurs have been dismissed as brainless automata, living long lives at a slow pace, as if the 78 r.p.m. speed of life of mammals were being replayed at 16 r.p.m.! The idea was, from the outset, absurd; after all, the dinosaurs not only ousted the paramammals from dominance in the terrestrial environment, but also managed to retain dominance for over 100 million years--an achievement inconceivable for such "automata"!

With this century-old misconception now properly discarded, the dinosaurs can now be seen as they were; as a group whose lengthy evolutionary success was merited both by their physiological design and by their capabilities for relatively advanced social behaviour. As we now know from the evidence of fossil footprints, herbivorous dinosaurs travelled in mixed-age herds which may even have been "structured", with the younger, more vulnerable animals at the centre; and some, at least, of the carnivorous dinosaurs hunted in packs. The evidence for herd and pack behaviour comes also from skeletons; the *Iguanodon* herd from Bernissart in Belgium; the coelurosaur (*Coelophysis*) pack from Ghost Ranch, New Mexico; and herds of mixed-age ceratopsians recently discovered in the Alberta Badlands by Dr. Philip Currie of Alberta Provincial Museum. There is evidence that, like their relatives the crocodiles, dinosaurs guarded their nests; certainly a Mongolian ceratopsian nest with eggs had a slain coelurosaur (properly named *Oviraptor*!) beside it. Moreover, a nest with abandoned eggshells, recently found in the Cretaceous Two Medicine Formation of Montana, had 18 baby hadrosaurs in it. Their skeletons suggest they were at least 1 - 2 weeks past hatching and their continuing association with the nest strongly suggests they were being tended by adults! This is behaviour far in advance of that of which the generality of living reptiles are capable.

On the question of dinosaur warmbloodedness, Dr. Halstead's views need to be stressed;

> 'Dinosaurs were not warm blooded in the same way that birds and mammals are. [The latter] keep their internal temperature steady by burning up their food quickly--a high metabolic rate--and insulating their bodies with fur and feathers while dinosaurs relied on their large size.
>
> Dinosaurs were simply too big to have a high metabolic rate. They would have had to burn up such vast quantities of food that they would have had to eat for more than 24 hours a day to keep going--and this is obviously an impossibility. [However] As an animal grows larger, it takes longer to warm up or cool down. When it reaches a certain size the process is so slow that it is almost unnoticeable. The temperature inside the animal's body stays the same all the time and we say that it is warm blooded.

> Both types of warm-blooded animals must have a network of veins and arteries to carry the blood to the various parts of the body. With such a large body bulk, the dinosaurs had to be particularly efficient at this and under the microscope it is possible to see a whole pattern of very fine blood vessels in a dinosaur bone. Their blood supply to the bone was in fact better than a man's."

This work is not altogether up-to-date, naturally enough in a field in which advances are coming so fast. Thus it was sent to press too early to discuss Hopson's theory that the skull enlargements and horns of hadrosaurs were used in part in fighting, in part as display and loudspeaker devices; nor could mention be made of the recent discoveries of truly giant sauropds in Utah which almost dwarf *Apatosaurus* and *Brachiosaurus*--so recent indeed that no formal names have been attached, only the nickname 'Supersaurus" to a form that may have been around 35 metres (110 feet) long and "Ultrasaurus" to a *Brachiosaurus*-like creature not quite so long, but yet more massive.

I noted just a few errors. On p. 13, *Paleoparadoxia*, stated to be a sea cow, is in fact a desmostylid. On p. 17, the Swanage reptile track is misinterpreted, this was not a single bipedal dinosaur with a broad trackway 'taking small steps'', but two dinosaurs travelling fast, side by side, and taking long strides. The Stonesfield discovery of *Megalosaurus* occurred, not in 1822, but prior to 1818. It is unfair, however, to charge Halstead with error in his theory concerning the different environments of juvenile and adult hadrosaurs (p. 96) since, at the time he wrote, little was known of the abundant hadrosaur tracks, both adult and juvenile, in the same late Lower Cretaceous environment in the Peace River Canyon, British Columbia; and indeed his theory may be applicable, for all I know, to later hadrosaur genera!

I am puzzled as to how Halstead can accept a transition between the gliding reptile *Podopteryx*, with its small flying membrane between its limbs (specifically between humerus and femur and attached to its flanks) and much larger one between hind limbs and tail (see figure, p. 48), and the pterodactyls, with the flying membrane sustained by an elongate digit of the hand, extending to the flank but *not in any way involving* the hind limb. (Reconstructions showing the membrane attaching to the hind limb are incorrect; there is no fossil evidence for such attachment). Such a transition seems to me in the highest degree unlikely; surely an independent ancestry for the pterodactyls is more probable?

Nevertheless, this account of dinosaur evolution, and of the ecology of Mesozoic times, remains an accurate enough summary of modern views even now, five years after its first publication.

The evolution of the Mammals is of especial interest in being the only general book on such a topic to be written since Scott's *A history of land mammals in the Western Hemisphere* (1913); and it is only regrettable that his book is not so lengthy and detailed as was Scott's. (May one hope it will be the prelude to a more extended treatment?) Very much of its contents will thus be unfamiliar to most readers. As in the first book, the overall approach is chronological, the faunas of each geological period being successively examined. This approach perhaps worked rather better with the dinosaurs, for the Mesozoic periods were longer and the groups involved were fewer and more uniform in character. With the briefer periods of the Cainozoic it becomes harder to use this approach, especially when following the stories of a much greater diversity of animal groups. Occasionally the result is misleading: the pronghorns, for example, are mentioned only on p.75 and the text would leave an uninformed reader with the impression that they are entirely extinct. (In fact one genus, *Antilocapra*, not only survives but is relatively common in the prairies of the northern U.S.A. and Canada). Sometimes indeed the chronological straitjacket has caused the author such difficulties that it has almost been shrugged off (as, for example, in treating the horses, pp. 60-61); but in general Dr. Halstead has managed to tell a clear enough story within this self-imposed restriction.

Once or twice, a knowledge is assumed that most readers simply will not have; when bandicoots are said to be like African elephant-shrews, for example (p. 14), will the comparison really help many readers? A few misprints have survived uncorrected: the name of the carnivorous marsupial *Thylacoleo* is twice mis-spelled (p. 101), as is that of the mustelids (p. 81). Some statements seem to me hard to justify. Are human beings truly the most widespread animals (p. 15)? Surely mice and rats are not only more numerous, but also survive in many places--small islands, in particular--where humans do not? Were the baluchitheres truly the *largest* land mammals (p. 43)? Maybe they were the tallest; but what price the much more massive hornless rhinoceros *Paraceratherium*? The dismissal of the problematic astrapotheres as "adapted to a hippopotamus-like life" (p. 55) is in my view a misleading over-simplification, and I would certainly challenge the statement on p.12 that "Animals without secondary palates use their teeth mainly to prevent food from escaping from their mouth"!

From his comment on p. 66 that large peccaries died out 10,000 years ago, it is evident that Dr. Halstead was not aware of the remarkable discovery in 1975 of a large species hitherto known only from fossil bones in the Pleistocene, *Catagonus wagneri*, not only live and well but even relatively abundant in western Paraquay--the first new, large land animal to be discovered since since the okapi! Halstead's failure to mention the calcichordates in his discussion of vertebrate origins (p. 21) may simply indicate non-acceptance of Jefferies' theories on the critical evolutionary significance of those organisms. In contrast, his citation of *Petrolacosaurus* as a progenitor of dinosaurs and birds presumably predate the recent work showing this genus to be, not a diapsid reptile, but an early araeoscelid with a euryapsid skull.

The artists who illustrated these books deserve great credit, for they have added greatly not only to their decorative quality, but also to the ease with which the scientific information may be comprehended. The illustrations by Giovanni Caselli to the first book are not always successful--his *Thrinaxodon* (p. 25), for example looks wooden and his *Lystrosaurus* (p. 28) look peculiar--but many others are extremely vivid and memorable, for example his swimming brontosaurs (pp. 56-57) and his battling pachycephalosaurs (pp. 88-89). It is less clear who is responsible for the illustrations in the second book. "Sergio" is credited only with the eight very splendid double-page illustrations, but there are many other excellent and spirited colour depictions (that of *Glyptodon*, p. 55, perhaps the finest), either by "Sergio" or some other artist; perhaps the author's wife, Jennifer Middleton Halstead, an accomplished biological artist, deserves the credit for them?

All in all, these extremely attractive books can be recommended, not only for purchase by civic, school and university libraries, but also by anyone who is interested in the history of life on earth and wishes to know more about it. Such books are a pleasure to own and to look at, as well as to read; and, despite my few carpings above, reflect credit alike on publisher, artists and author.

William A.S. Sarjeant

Secretary's Report for 1978

In the Society's fifteenth year the membership remained around 500 and the indoor and field meetings were well attended.

There had been sixteen meetings during the year, four day excursions, one weekend, one week excursion and an afternoon meeting held at the Institute of Geological Sciences, Keyworth, Nottingham. The indoor meetings consisted of four lectures, a joint meeting with the Matlock Field Club, a Presidential Address, an Annual Dinner and the Annual General Meeting followed by a lecture.

Fifty members attended the Annual General Meeting in March. The election of officers took place and the serving President, Treasurer and Editor were proposed from the chair. Mrs. Morrow had resigned as Secretary of the Society having been associated with Council from the Society's founding in 1964, and its Secretary for the last eight years. Nominated by Council as Secretary, I and the other officers were duly elected to serve for 1978. Mrs. Morrow was most warmly thanked for all her untiring work for the Society, and I too would like to record my thanks. I was very grateful for all the help she willingly gave in my first year of office. One ordinary member of Council was due to retire and I had to be replaced, so that two new Members of Council were elected to fill these places. A vote of thanks was proposed to the retiring Council member, Mr. H. Key. Professor Lord Energlyn would be retiring in the following August, and in appreciation of his services to the Society, it was proposed that he be made an Honorary Member, to which the assembled members were in full agreement.

The meeting had run very smoothly with no other business, and was followed by a lecture given by a member of the Society, Mr. P.I. Manning from the Institute of Geological Sciences, Keyworth. He talked of the geology and his experiences in Ethiopia. After his lecture he mentioned that cores had been taken from the area of the new Keyworth Headquarters and which might prove of interest. A date a month hence was arranged for these to be viewed by any member wishing to visit Keyworth.

In the middle of March, Dr. G.R. Coope of the University of Birmingham lectured on 'a beetle's eye view of the last glaciation', his talk being enthusiastically received by the large audience present.

The last indoor meeting of the season, held in April was given by Dr. F.M. Taylor, who gave a lively talk on Precambrian Fossils. The recent re-examination of rocks at one time thought to be unfossiliferous, had shown evidence of life; some of the evidence tending to stretch the imagination a little.

The following afternoon, Sunday, was spent at the Institute of Geological Sciences, Keyworth, where about thirty members gathered after accepting their kind invitation, and were given a most warm welcome. Drilling methods, the cores demonstrating the Mercia Mudstones were shown and a talk on the work of the Industrial Mineral Assessment Unit given.

The weekend excursion in May was based at Ludlow, and as usual proved a great success. The leader, Mr. W.J. Norton, Curator of the Ludlow Museum, met the large group of members at the Museum Lecture Room for an introductory talk on the geology of the Ludlow Anticline area, which the party then visited. The following day Wenlock Edge, Morville 'fish' locality, quarries at Creton and Titterston Clee Hill were visited before the party regretfully returned home.

The excursion in June to the Fen Area was very well supported, being led by Mr. D.N. Robinson the University Resident Tutor at Alford, Lincolnshire. He had promised

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no hammer work, but demonstrated the features of Heath and Fen. Included, too, was an escorted walk around Baston Fen Nature Reserve, and finishing at Boatmere Haven, where reclamation work is continuing.

Mr. T. Charsley of the Institute of Geological Sciences, Leeds, led the party to the Ashbourne Area in July. He had recently been mapping the area for his department and was able to show the results of some of his work to the enthusiastic members.

The week's excursion took place towards the end of July, and the party was based at Stirling University, a very beautiful setting. Mr. S.K. Munro of the Institute of Geological Sciences, Edinburgh, had very kindly organised the leaders of each day's excursion for us. All but one, Mr. N.E. Butcher, were from his department in Edinburgh. Mr. Butcher from the Open University in Scotland, took us on an exhaustive tour of the Stirling area. The geology, and scenery, were also enjoyed in the Loch Tay area, Gargunnock Burn Section, Balmaha in torrential rain, and a sunny day examining the downbent section of the Tay Nappe at the Highland Border. We do appreciate the help given by Mr. Munro, Dr. C.G. Smith, Mr. M.A.E. Browne, Mr. W. Henderson and Dr. D.J. Fettes, all of Edinburgh, and Mr. N.E. Butcher. They gave their time most willingly and the Society are very grateful for their efforts.

The Quaternary Geology of the Coventry area was the subject of the September excursion. Professor F.W. Shotton of the University of Birmingham had kindly agreed to lead members, and a most interesting day was spent amongst more recent deposits.

The season ended with an excursion to Luton in October. Dr. A. Ludford met the party, who on this occasion travelled in cars. The day was spent examining the Lower and Middle Cretaceous of the area.

The first indoor meeting took place in November and Dr. W.J. Wadsworth, University of Manchester, lectured to a large audience on volcanoes. He discussed their various behaviour patterns and ways in which man can utilise their energy and material.

In December Dr. B.J. Taylor of the Institute of Geological Sciences, Keyworth, talked of some aspects of Mesozoic geology of eastern Alexander Island, Antarctica, illustrating his lecture with slides taken whilst working with the British Survey. He talked of many puzzling features of the landscape which he, and his audience, found fascinating.

1979 started with the joint meeting with the Matlock Field Club at Tawney House, Matlock. Mr. P.F. Jones of Derby Lonsdale College of Higher Education, spoke of 100,000 years of mud and slush, and the changing views on the landscape evolution in Derbyshire. The subject was most appropriate to the conditions - a cold spell with snow and a rapid thaw that day, had made it a very wet and muddy journey. But in spite of this and a petrol shortage, about forty people, half of them Society members, attended the meeting.

An evening for members to show slides of the weeks spent in Ayr and Stirling was arranged for the middle of January. Blizzard conditions kept all but ten hardy members from attending, nevertheless enough slides had been brought to make it a worthwhile evening.

The Fourteenth Annual Dinner in February was held at a different venue. The Post House at Sandiacre was chosen, and as usual it was a very successful social occasion.

The Presidential Address took place in February to mark the anniversary of the founding of the Society. The President, Dr. W.A. Cummins, giving his third and last Address, allowed the members to listen in on his thoughts on the mechanism of how Mountain Chains could rise and fall, and demonstrated his theory with slides and diagrams.

1978 was a most successful year with interesting meetings and field excursions. We were grateful to our leaders, Mr. W.J. Norton, Mr. D.N. Robinson, Mr. T. Charsley, Prof. F.W. Shotton and Dr. A. Ludford, and to our speakers, Mr. P.I. Manning, Dr. G.R. Coope, Dr. F.M. Taylor, Dr. W.J. Wadsworth, Dr. B.J. Taylor, Mr. P.F. Jones and our President.

There were eleven monthly circulars sent out during the year giving notice of meetings and Society affairs. The postage continued to increase and the Society is grateful to those members who willingly deliver by hand circulars in their own vicinity.

The membership of the Society remained steady and was as follows:

Honorary	Ordinary	Joint	Junior	Institutional	Total
3	253	106	14	114	490

There had been two issues of the Mercian Geologist published during 1978/79. Volume 6, Number 4 in April 1978, and owing to the resignation of typists at the University, Volume 7, Number 1 was not published until January 1979.

The Society Exhibit, which displays and publicises the Society, had been to the Conference of the Association of Teachers of Geology, held in Derby.

The Society again wished to express its appreciation and was deeply grateful to Professor Lord Energlyn and the University of Nottingham, for allowing us the excellent facilities for meetings and activities.

In conclusion, may I thank everyone for their patience and understanding in my first year of office.

W.M. Wright

Corrections

The following corrections have been requested for text-fig. captions in D.D.J. Antia's paper: Sedimentology of the type section of the Upper Silurian Ludlow-Downton Series boundary at Ludlow, Salop, England, contained in Vol. 7, No. 4 of the Mercian Geologist.

p.294, text-fig. 3, correction to read:

Grain size (L) in μm is given on the x axis.

p.306, text-fig. 10, correction to read:

Size measurements in μm.

THE MERCIAN GEOLOGIST

Journal of the East Midlands Geological Society

The journal first appeared in December 1964 and since that time 28 parts, comprising 7 volumes have been issued; the last, Vol.7, No.4, in April, 1980. The Mercian Geologist published articles especially on the geology of the Midlands of England, but other articles have been published which are of current interest to geology generally. Contents include original papers, review articles, biography, bibliographies, excursion reports, book reviews and the Secretary's report on Society activities.

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Authors intending to submit manuscripts of papers for publication in the Mercian Geologist are asked to follow the format of papers included in a recent number of the journal, and if possible to provide two copies. As the journal is read by Members with a wide spectrum of geological interest and ability, authors are asked to ensure adequate introductions for their papers, particularly, if the subject has not been reviewed in the journal over the last few years. The paper should be complete in itself, without the need of the reader to refer to specialist journals not easily available to the average Member of this Society. It follows that the length of the paper may be greater than that published by some other journals but authors are asked to be as lucid and concise as possible and to avoid repetition.

Text-figs. normally occupy a full page of the journal, but part diagrams can be fitted into the typed page. Double page diagrams have been published with a single fold but each printed page has to be folded by hand. The standard reduction by our present printing process is approximately x 0.75. Thus the optimum size for the original diagram, including space for caption, index and explanation if required on the diagram, should be 285 x 190 mm. (285 x 380 mm with a single fold). Greater reduction is possible but care must be taken with the original to ensure that at the final reduced size (230 x 155 mm; or 230 x 310 mm) the smallest letters are no smaller than 1 mm and that there is a similar minimum spacing between letters and lines. Bar scales (metric) should be provided as the exact reduction cannot be guaranteed.

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