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Contents

MERCIAN NEWS

Bakewell for Bargains!

John Aram writes: The 9th and 10th October 1999 found the largest gathering in the region of geological dealers, suppliers, collectors, academics and amateur enthusiasts for 'The Rock Exchange'.

Under the control of the Peak Lapidary and Mineral Society and the guidance of Les Fox, this annual event takes place in the Lady Manners School near Bakewell. For two days the school Sports Hall, Drama Hall, canteen area and even the corridors are taken over by dozens of displays and stands, selling and demonstrating everything and anything related to geology. Free parking is provided in staff and coach parking areas, with the overflow onto mown grass and an adjacent sports field.

This year my eye was caught by machines to crack open geodes, hands-on demonstrations of gold panning, and guidance in polishing rock slices. Magnetite crystals from Shetland vied for my attention with haematite from Cumbria and fluorite from the Pennines. Increasingly rare trilobites in mudstones from North Wales contrasted with large numbers of finely detailed and prepared trilobites from North Africa. Bargain bins, oddments and special show prices contrasted with a gem-quality sapphire in its matrix with a four figure price tag. No doubt the many specialist dealers and part-time collector/dealers who are attracted to this show from all parts of Britain help to create a wide range of prices and quality of specimens.

The bargains? One member of EMGS went home the proud owner of a 'nearly new' lap for polishing his rock specimens (bought at a fraction of its 'new' cost). A Rockwatch member came from Coventry to spend his pocket-money on trilobites; when he left he not only had five new specimens to add to his collection, but had also been given a large bag of 'interesting pieces' of trilobites by one of the stall-holders. Myself? In addition to the new millenium supply of white card trays to store specimens, and the 'write-on' plastic self-seal bags (I have promised to maintain much better records of my specimens), a small, battery-powered ultra-violet lamp has been added to my equipment, and a splendid new specimen of green fluorite from Wearsdale can now been seen in my cabinet. They were all bargains!

Put next year's show dates (7th and 8th October, 2000) into your diary. But take a warning; allow yourself plenty of time (and money) for your visit. Selecting a bargain can take time, and there are so many choices to make.

The Flying Finns . . .

Roger Peart (BGS) writes: Late June 1999 saw the completion of data acquisition for a collaborative airborne geophysical and environmental trial survey of four sites in the East Midlands. This was part of the first project under a recently agreed Memorandum of Understanding between the British Geological Survey (BGS) and the Geological Survey of Finland (GTK). The work was co-sponsored by the Department of the Environment, Transport and the Regions and the Environment Agency.

The survey was flown using the elegant and powerful de Havilland Twin Otter based at Tollerton Airport near Nottingham. The main objective of this trial was to test the effectiveness of the GTK electromagnetic (EM) system in the rapid mapping of polluted groundwaters that may occur in the vicinity of certain landfill sites and colliery spoil heaps. GTK have proved the value of their system in such applications in Finland and BGS decided to test the method in the generally less favourable UK environment. In addition to EM, gamma spectrometer and magnetic total field and horizontal gradient data were also collected. These additional data will also be of both geological and environmental significance.

The four areas targeted are Shirebrook, the Trent Valley immediately north east of Nottingham, Langar-cum-Barnstone (all in Nottinghamshire) and Wolvey near Rugby. The preliminary results are very encouraging and several of the features detected will be investigated by ground survey in the near future. The fully processed data will be available for licencing in due course.

Rockwatch 1999 — Rockhound Challenge winners

John Aram writes: The 1999 Rockwatch competition results have just been announced, and once again entries from local children featured strongly in the final stages of the judging.

Katy Flinn from Nottingham received a special prize in the 12-16 Rock Artist competition for her beautiful hand-made book of illustrations of geological specimens; the first prize going to Stef Gladders of York for an original 3-D cave model.

Emily Ratcliffe of Sleaford created a rotund papier-maché woolly mammoth that earned her a Highly Commended in the very competitive under 12 years class of the same section of the competition. The winner was an impressive collage made by Thomas Baird from Northern Ireland.

The Rock Reporter under 12 class was won by Laurie Whitaker from Shropshire, with an illustrated account of a trip to Clee Hill with the Shropshire Geological Society, while the 12-16 prize went to "The Palaeontology Post", a newspaper written and produced by Kathy Marshall of Leeds.

Jane Robb won the under 12 Rockhound prize with a folder describing and illustrating her geological collection and the mini-museum in her home in East Lothian. Winner of the 12-16 competition and 'Rockhound of the Year 1999' was 12 year old Alex Ayling of Sandhurst, for an outstanding report of his collecting work, laboratory preparation and study of micro-fossils.

If you know of any keen young geologists, do tell them to watch out for details of the 2000 Rockhound Challenge. The prizes in each class are worth up to £100 worth of geological materials, specimens, equipment and books!

Sculptured Stones at Rufford Country Park

Alan Filmer writes: Fashion in gardening has currently moved to hard landscaping, with plants sometimes playing merely a supporting role. In this garden, created by Gerry Price, this idea has been taken to its ultimate conclusion with scarcely a plant in view. However, for a geologist with an interest in garden design and sculpture, it is full of interest. The garden was created in June 1999 and will be removed in June 2000. It is laid out like a conventional garden with curved island beds but planted with rocks and stones and having mulches of different coloured, textured and sized pebbles or chippings. Among these there are a number of sculptures carved from various types of stone and in differing stages of completion.

The garden provides an interesting geological trail in a compact area, with plenty of scope for trying to identify the rock types and processes that are in evidence. Rufford Country Park is on the A614 between Nottingham and Ollerton. Entrance is free with a parking charge only at weekends and Bank Holidays. To find the garden, park in the main car park and walk through the old stable block and courtyard. Enter the sculpture gardens and turn left.

Trent Trends, Nottingham University, 16th October 1999

Phillip and Judy Small write: This conference was held in the Djanogly Arts Centre, Nottingham University, and was organised by the Trend and Peak Archaeological Unit and C.B.A. East Midlands. A series of excellent speakers reviewed the discoveries and developments in archaeology in the Trent valley over the last 45 years and discussed the new techniques that were being applied.

Several members of the EMGS were present and were pleased to find how the geology of the Trent valley had played such a major part in the development of early civilisation. Identification of sites may involve both aerial and geophysical techniques. Scientific backup for archaeology now involves the talents of many other experts.

The Trent, the third longest river in England, is fed by the Dove and Derwent, which both rise in the Peak District. In early post-Devensian times, enormous quantities of gravel were brought down by meltwaters into the braided river systems of the wide Trent valley. As the river meandered across the valley floor, palaeochannels were left behind which are now frequently exposed as the gravel is extracted. This has led to the discovery of many important artefacts such as bridges, fish weirs and the Bronze Age Aston log boat. The gravel excavations need continuous pumping. Artefacts and wooden structures have often been well preserved by the high water table but need urgent attention when exposed to air and sunlight. Sands and well-preserved organic-rich mud deposits are often related to the palaeochannels and these may contain plant and animal parts which can be identified by experts. Beetle wing cases are often well preserved and give good information about the environment in which they lived. Plant material is also of value. Oak tree trunks are of particular importance as dendrochronology can often give a reliable date for worked wood and associated artefacts.

There are only a few professional archaeologists working in the Trent valley and much valuable help is provided by enthusiastic amateurs. Dr Chris Salisbury, who is also a keen EMGS member, has spent much of this spare time studying the Trent valley. For many years he has been regularly visiting many of the gravel pits and has a good rapport with the quarry staff. He is often contacted when something interesting has turned up. His major contributions to local archaeology were freely acknowledged by many of the speakers.

News items for the Mercian

To mark progress into the new millennium, the EMGS editorial board aims to expand the news sections of the *Mercian Geologist* in order to reflect the many aspects of local geology with which Society members are involved. Future issues will feature more short items, on, for example, significant temporary exposures, geological events, important sites within the East Midlands and small items of local research, beside devoting pages to the publication of longer papers. We will therefore welcome any text (with or without illustrations) that is sent in by members.

Please send any material to the new editor, Tony Waltham (see notes for contributors at the end of this issue). A single copy is all that is needed, and the style can be very informal; just call the editor if you have concerns about any drawings or photographs. Don't hold back or delay with your contributions, especially in the spring months when issues are prepared for printing. We hope that this way forward will make the *Mercian* an active record and forum of its members, in a style that befits an active local society.

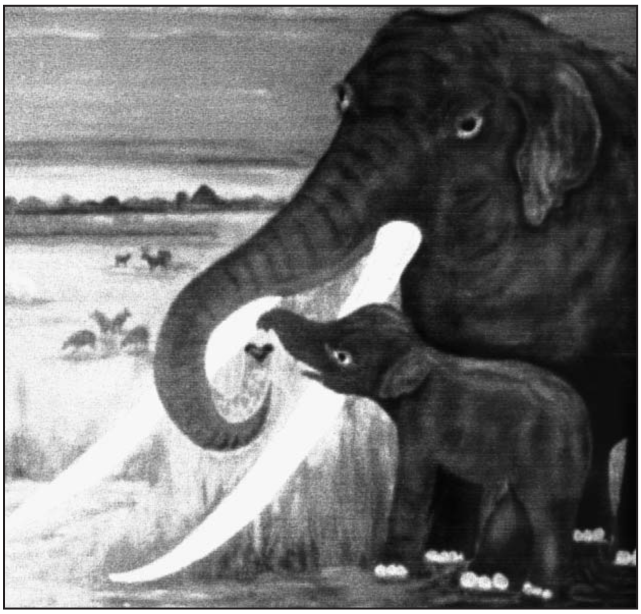
REPORT

Cool Peterborough — An Ice Age spectacular

This exhibition about ice-ages at Peterborough Museum and Art Gallery was inspired by the discovery in 1996 of a considerable part of the skeleton of the straight-tusked elephant *Palaeoloxodon antiquus*. The bones were found in a sand and gravel quarry operated by Lafarge Redland at Deeping St. James. The quarry normally exploits the Late Devensian (cold stage) gravels of the Welland valley. The skeleton was preserved, however, in the silts and clays of an abandoned river channel within much older (warm stage) Ipswichian gravels underlying the Devensian deposits. The sands deposited by this ancient 'proto Welland' river have been dated as 117,000 years BP by thermo-luminescence techniques. The present-day river Welland flows within a hundred metres of the site.

The exciting find of the elephant was well worth its own exhibition at Peterborough Museum, and preparations were put in hand. As time progressed, the plans grew to encompass a more wide-ranging display of all the animals whose remains have been found in the gravels, and the ice age exhibition took shape. It comprised three stages:

1. The Ipswichian warm period which contained the elephant, together with hippopotamus, beaver, fallow deer and brown bear;
2. The Late Devensian, with mammoth, horse, bison, reindeer, woolly rhinoceros;
3. The early post-glacial (Holocene) period, from which a near-complete skeleton of *Bos primigenius* (wild ox, or auroch) had been discovered in the Nordolph peats, at Whittlesey, at about the same time as the elephant was found.



Palaeoloxodon antiquus from the painting by Alan Dawn.

The Museum has a considerable collection of all these remains. To them were added, during the course of preparation, half the pelvic girdle of a mammoth, and part of the vertebral column of a horse. New finds are made regularly.

The elephant bones were prepared with the advice of Dr Tony Stuart, of Norwich Castle Museum, who supervised the excavation of the West Runton elephant, and of Nigel Lark, who is conserving and replicating the West Runton specimen. It was decided to display not only the bones of these creatures but also to illustrate their environments with large scale paintings and to show their actual size by means of life-size cardboard cut-outs. The elephant had to be scaled down a little to fit into the gallery, but bison, horse, rhino, hyena, auroch, reindeer and fallow deer were all true to size. Except for the elephant, which was cut out in hardboard, all the rest were constructed from glued-up cardboard boxes and scrap materials, costing nothing except for the paint and glue.

Explanatory texts were prepared and the whole show came together by May 1999. Dr Adrian Lister of University College London performed the opening ceremony before an invited audience of about 130 people. The exhibition ran until the end of November 1999 and proved highly popular, attracting many hundreds of visitors throughout the summer. The entire project was carried out by voluntary work, mainly by members of Stamford and District Geological Society.

The exhibition was supported by generous grants from the following: Lafarge Redland; the COPUS fund; The Earl FitzWilliam Charitable Trust; Stamford Geological Society; Friends of Peterborough Museum and Art Gallery; Anglian Water; Pedigree Petfoods and the Stamford Mercury, plus many individual subscribers. The East Midlands Geological Society contributed £500 towards the cost of casting the elephant skeleton.

A booklet entitled "Cool Peterborough" was prepared to accompany the exhibition, but also stands alone as an excellent introduction to the Quaternary history of the region. It describes how the environments, flora and fauna of the Peterborough area have changed during the Quaternary, commencing with Ipswichian Interglacial and continuing through the Late Devensian glaciation to the present day. It is well illustrated with maps, stratigraphic sections and profiles through the Quaternary deposits, and includes some of Alan Dawn's superb hand drawings of elephants, rhinoceros and aurochs.

Printing was sponsored by Kall-Kwik Print Copy Design of Peterborough. The booklet is available from the City Museum and Art Gallery, Priestgate, Peterborough PE1 1LF, price £2.50, plus postage and packing. Proceeds from the sale go towards casting of the exhibits for permanent display.

Compiled by the Editor from contributions by Alan Dawn and Alan Filmer

REPORT

Peak District Mining Museum Matlock Bath, Derbyshire

This summer (1999) Peak District Mining Museum is 21 years old. Planned, constructed and operated by members of Peak District Mines Historical Society, it had taken a year for the first stage to be ready for opening and is still steadily developing. The project was initially sparked by the need to remove and then display the 1819 Wills Founder water-pressure pumping engine. This was half-buried in silt some 360 feet underground in the Winster mine, in a chamber which was normally flooded and likely to be lost for ever. Originally it was part of an attempt in the 1840s to sink below the toadstone, a volcanic basaltic lava, to the unknown and, thus, undoubtedly fabulously rich deposits below. This was not to be, but now the thirty feet high engine sits in a dry shaft right at the centre of the Museum.

Out of some twenty seven or so rocks and minerals which have been mined in the Peak, until iron and coal supplanted it, lead was for some 3500 years the most important. The main ore is galena which occurs in rakes (mineralised wrench faults), pipes (infilled or metasomatised stratiform deposits) and in widened joints known to "t'oad man" as scrins. A rich deposit of copper ore was mined at Ecton and nearby on the Derbyshire/Staffordshire border. Several minor minerals were often mined also, such as haematite and limonite, zinc blende and calamine and, mainly this century, the former waste or gangue minerals fluorite, barite and calcite have been worked on a considerable scale. Only one underground mine, Milldam at Hucklow, is still active for vein minerals, though another, at Middleton-by-Wirksworth, mines high grade limestone on a considerable scale.

For two centuries Derbyshire was the economic centre of the world lead industry. After the Dissolution of the Monastries in the 16th Century the availability of vast amounts of church roof-lead ruined the European lead industry and, out of the ashes, rose the Derbyshire industry. New smelting technologies made huge amounts of earlier waste-ore available from old hillocks: in the mid 17th century perhaps 40,000 people were dependent in the Peak on lead's prosperity. New skills in driving soughs or drainage tunnels in hard rock — including very early use of black-powder (i.e. gunpowder) — and then the development of steam power made huge quantities of lead ore available. About 1730 for example, Yatestoop mine in Winster probably had the World's greatest concentration of steam power, with three certainly and, possibly, four Newcomen engines installed (though the total power was probably hardly more than a family car can produce today). Fifty years later saw the beginning of a long decline which lasted until Mill Close Mine, Britain's largest ever lead mine, closed in 1939. Probably some two million tons of lead ore have been mined in total, with production now confined to by-product lead. The only lead now smelted in the Peak, however, comes from secondary sources, mainly batteries.

The oldest artefacts include a ceremonial lead axe from Middle Bronze Age times which was found at the hillfort on Mam Tor at Castleton and, about to come to the Museum, a bone tool from Ecton, recently radiocarbon dated at 3800-3600 years BP. The earliest major artefacts are a substantial number of lead ingots from the Roman period, though no certain mines have yet been located. About thirty ingots or pigs have been found on land, inscribed with "LVT" the mark for Lutudarum, reasonably established as the settlement now under Carsington Water near Wirksworth. But over 200 more ingots, some at least from Derbyshire, have been found in a Roman wreck off Ploumenac in Normandy — one marked ICENI, the tribe whose western border was probably the Trent. This river has always, with the Idle and Don, been an outlet for Derbyshire lead. Visitors to Nottingham's Brewery Yard can see a large pig of lead recovered from gravels near Colwick, marked with the monogram LW. The writer sees this as a particularly good omen! The Museum has about half a dozen lead ingots in its collection.

Until its poisonous properties outweighed its utility, *Lead the Precious Metal* (the title of a book published as recently as 1924*) was the equivalent of modern plastic. In a large house, such as Bess of Hardwick's late 16th century Hall (built with money earned by three deceased husbands from lead, iron, coal and land) the metal and its compounds were used lavishly. Her stone initials on the roof line were anchored in lead and the roof, gutters and downpipes were of the metal. The windows "Hardwick Hall, all glass no wall" were, of course fitted in lead cames. Water was kept in cisterns of lead, delivered in pipes of lead and sprayed in fountains from ornamental (lead) figures. Inside the house the tables and sinks were sometimes lead covered, and lead with tin was used as pewter or with tin and silver as a solder. Expensive tea and other spices arrived in lead-lined boxes and tobacco was traditionally kept in its lead jar. White, orange or red lead (oxycarbonate and oxides of lead respectively) would have been used in paints or as a base of other colours. Red lead was a major component of lead crystal glass too. White lead had even greater utility — perhaps as the glaze for Wedgwood's creamy Devonshire Ware, or for a perfect white face foundation powder, with linseed oil to waterproof the canvas roof of carriages, for enamelled trinkets, even as a poultice for a bruised thumbnail. It might also have been used for whitening bread (a well-located cornmill was said to be next to either a chalk pit or a paupers' grave yard and a white lead works!). Other salts such as the soluble acetate "sugar of lead" were useful for sweetening wine and for treating unfortunate ailments such as syphylis. And, for the sporting

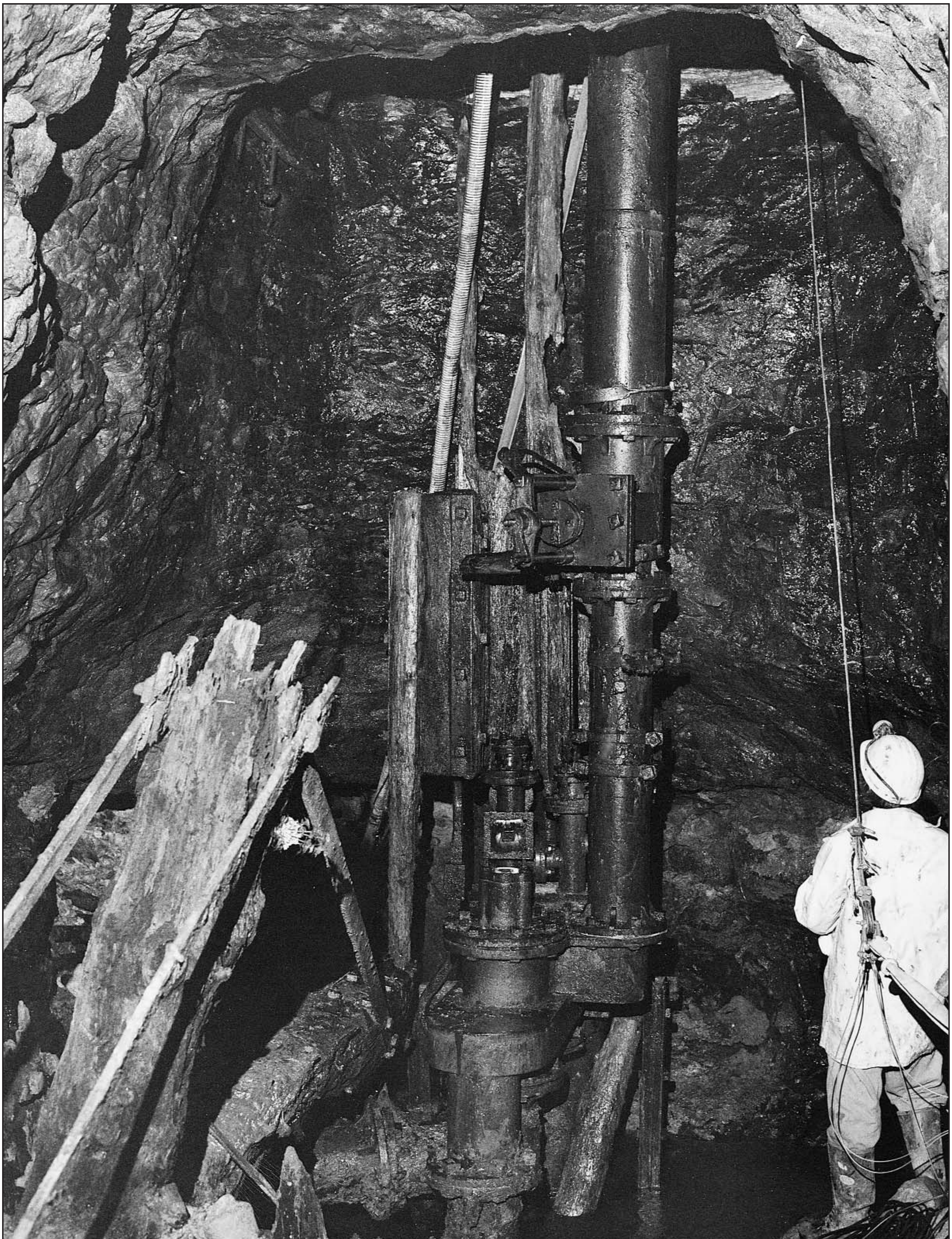


Fig. 1. The Wills Founder pumping engine at its original site deep in the Winster mind. The mine chamber is normally flooded, and the pumping engine is now in the Museum at Matlock.

Fig. 2. Pushing an ore tub through the Temple Mine at Matlock; this section of tunnel was driven in the dolomitised Matlock Limestone.

weekend, or for use of the regiment in times of war, lead was irreplaceable for shot and bullets. And at the end of a lead-shortened life, a lead-lined coffin.

The effect on the landscape was great too. The rakes and scrins still dominate wide areas of landscape in and alongside the Derwent Valley between Wirksworth and Castleton — there are especially good examples on High Tor at Matlock Bath. The mining villages and towns, mostly in decline until recent commuting habits reversed the trend, form some of the most unspoiled in the Peak: Wirksworth where the lead mining Barmoot Court still sits; Bonsall; Winster (Derbyshire's third largest settlement at its peak around 1750); Youlgreave (from *Auldgrove* or Old Mine); Ashford; Eyam and Bradwell. On the streams and rivers are the remains of leats and weirs of the smelting mills, the main user of water power until the usurper, cotton, took advantage of the decline. And in the soil, levels of lead contamination on old mine and smelting sites are high enough nowadays almost to be thought of as ore.

So the museum is about lead and lead mineral deposits, about the countryside around, about people and their houses and how they won the metal from the earth. At present we are developing our displays to tell something of the history of geology and how mineralisation occurs, including a recently installed display of one of the country's finest collections of minerals, that of Professor Howie of Deere, Howie and Zussman book-fame. Professor Howie liked our displays and felt a small museum would cherish his collection more than a larger: there are now about 200 of the most mouth-watering items on display, including the eponymous Howieite. Over the road, visits can be made to our lead and fluorite mine, with one of the best exposures of basaltic lava (toadstone) visible — the site of the only authenticated gold discovery in the County. The Museum is open every day (Telephone 01629 584322). For visiting groups the Society's field centre at Magpie Mine, Sheldon near Bakewell, has basic hostel accommodation.

* Harn, Orlando, C. 1924. *Lead the Precious Metal*. Jonathan Cape.

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The Growth of Geological Knowledge in the Peak District

Trevor D. Ford

Abstract: The development of geological knowledge in the Peak District from the 18th century to the present day is reviewed. It is accompanied by a comprehensive bibliography.

Introduction

Geology has changed in the last two centuries from a largely amateur "gentleman's" science to a professional vocation. The results of professional investigation in the Peak District have been built on the amateur foundation and the works cited in this review demonstrate the change in approach. The Geological Survey commenced a professional approach in the 1860-1880 period, continued during World War I and in the 1950s, but it was not until the 1970s that some intensive economic investigations were pursued. The Geological Survey's activities in the 20th century were concurrent with the development of Geology Departments in the nearby Universities, where research grew slowly after World War I and more rapidly after World War II. However, there is still room for amateur investigation, as shown by the activities of such organizations as the East Midlands Geological Society.

As far as is known, the only previous attempts to survey the growth of geological knowledge in the Peak District were by Challinor (1949-1951), whose viewpoint was biased towards the western margins of the Peak District, and the present author, who gave an outline of research on the limestone massif in the introduction to his book on the Limestones and Caves of the Peak District (Ford, 1977). This review is an expanded version of a talk given at the Symposium held at the University of Derby on March 16th 1996, that date being the centenary of the first extra-mural classes in geology taught in Derby.

There are many published contributions to the geology of the Peak District which space precludes mentioning herein. Only those works representing significant advances are included. Readers are referred to Ford and Mason (1967) and Ford (1972) for comprehensive bibilographies up to those dates. Since then the pace of research has increased and a steady flow of publications has appeared since the above-mentioned bibliographies.

Historical perspective

The Pioneers. The principles of stratigraphy are often said to have been first formulated by William Smith in Somerset where there was an economic stimulus with a coalfield adjacent to lead mines in the limestones of the Mendip Hills, plus a sub-Triassic unconformity and overlapping Jurassic. Similar stimuli occurred elsewhere in other mining fields, particularly in the Peak District where the lead miners made practical use of geological principles as early as the 17th century (Rieuwerts, 1984). In the 18th century the course of the initial part of Cromford Sough followed the strike of the limestone/shale contact where excavation was easier through shale. The position of the contact was obtained by down-dip projection from the outcrop showing that the soughers had some appreciation of concealed geology. The lead miners also used the basic principles of stratigraphy and structure to predict whether or not they would intersect toadstones in driving other soughs in the 18th century (Fig. 1).

Whilst most of the lead miners' knowledge was never written down, some of it has been preserved in the appendix to "An Inquiry into The Original State and Formation of the Earth" by John Whitehurst (1713-1788) (see Craven, 1996). This appendix recorded the strata of limestone and interlayered toadstones on either side of the Derwent Gorge at Matlock by means of some of the first stratigraphical sections ever published (Whitehurst, 1778). The positions of some mines and mineral veins depicted on Whitehurst's sections confirms that he acquired some of his knowledge about their disposition from the lead miners. However, he misunderstood the nature of the bouldery alluvium beneath the river bed and invoked a "gulf" full of boulders extending to an unknown depth (Fig. 2). Whitehurst realized that there was a syncline between Matlock and the Ashover inlier, but he found it difficult to show curvature of the strata on his sections and accommodated the axis with boulders filling another, downwards-expanding "gulf".

A disciple of Whitehurst's was White Watson (1760-1835). His geological tablets and Delineation books (1811; 1813) extended Whitehurst's principle of a regular stratigraphical succession in the Matlock area throughout the Peak District and into the Derbyshire coalfield. He established a stratigraphical column of 36 units in Derbyshire, noting subtle differences in both lithology and palaeontology of limestones, shales and gritstones. White Watson's inlaid marble tablets were at first diagrammatic representations of folded limestones and lavas, flanked by scarps of overlying shales and gritstones, but later he compiled detailed sections across much of the county, basing the first on drawings by Farey (Ford, 1960; 1995; Torrens, 1994). White Watson built up large fossil collections for sale, 500 at a time, and some of these form the basis of museum collections today. Watson and his colleague William Martin set out to produce an illustrated catalogue of Derbyshire fossils but it was eventually published by

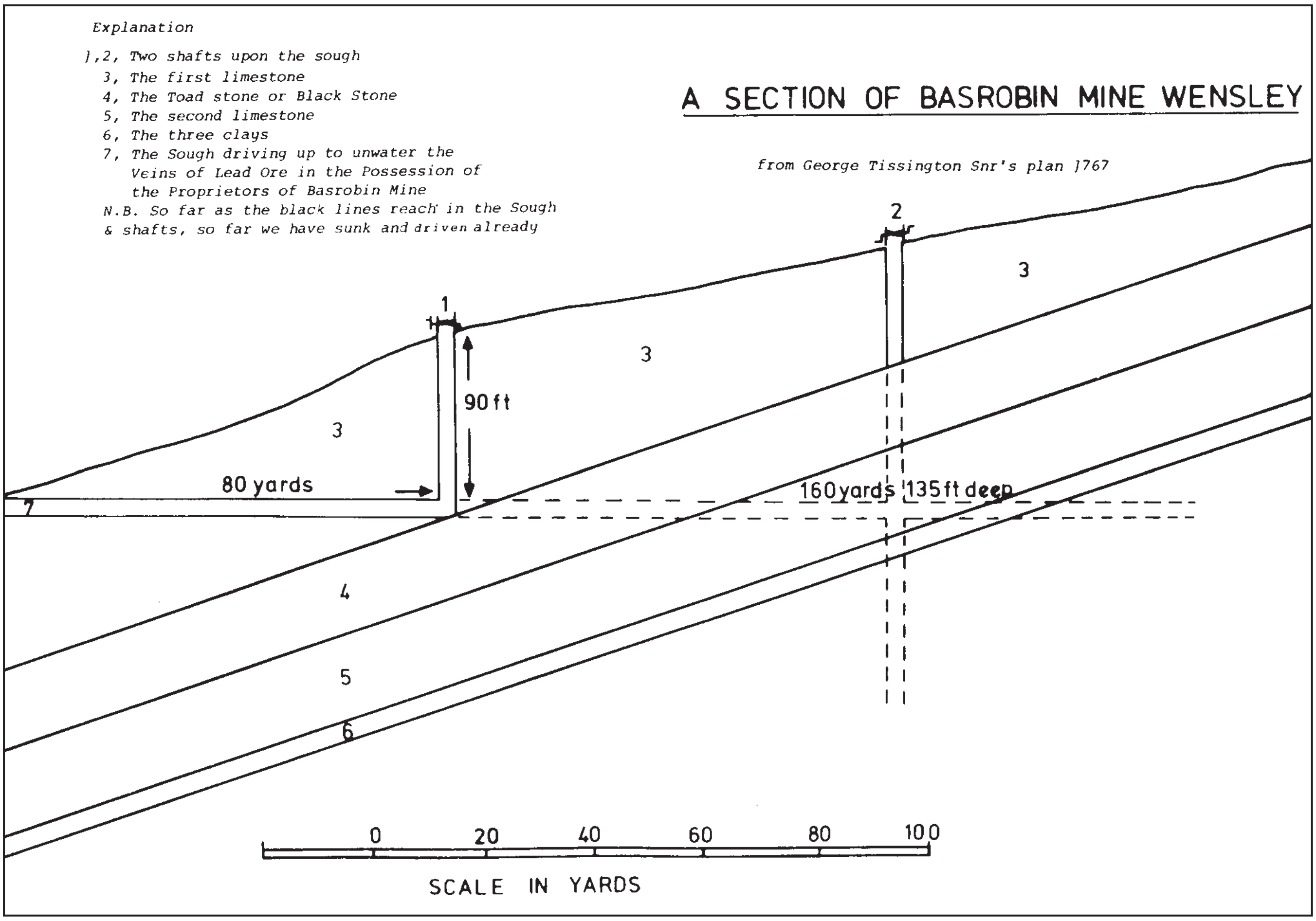

Fig. 1. A section of Basrobin Mine, Wensley, shows the lead miners' prediction of strata to be penetrated (after Rieuwerts, 1984).

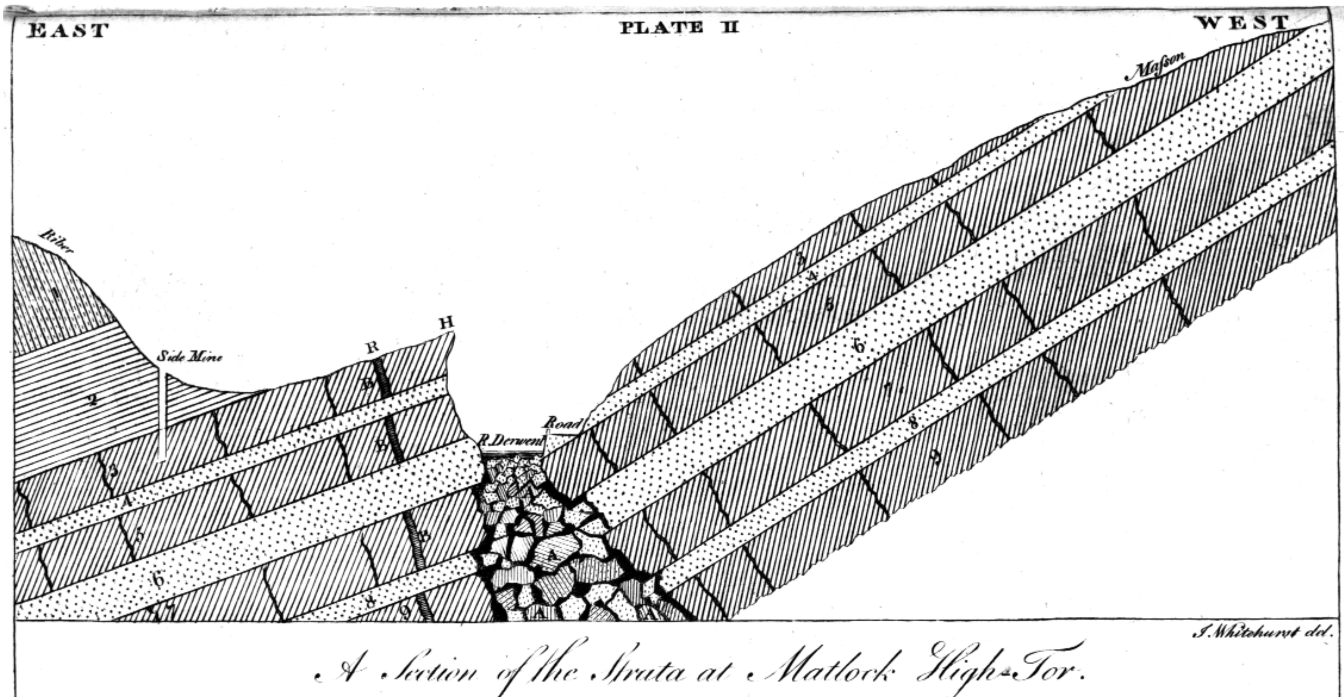

Fig. 2. A section across the Derwent Gorge at Matlock, showing alternating limestones and toadstones and the gulf full of broken rocks beneath the river (Whitehurst, 1778).

Martin alone (Martin, 1810). Unfortunately Martin used a non-Linnean trinomial system of nomenclature so that his names were later declared invalid according to the Rules of Zoological Nomenclature, though some were adapted and are still used for some well-known species, e.g. “Conchylolithus Anomites Pugnus” is still known as *Pugnax pugnus*.

John Farey (1766-1826) inspired Watson’s later more detailed sections. Farey was a polymath who published in various subjects, notably mathematics, music and geology (Ford and Torrens, 1989). He prepared long stratigraphical sections of various parts of Britain on rolls of paper: these unfortunately remained unpublished until discovered by Ford (1967). One such unpublished section lay across the Ashover anticline (Fig. 3). John Farey was a friend and disciple of William Smith and came to Derbyshire in 1807 to produce what was in effect the first district memoir (Farey, 1811). This catalogued the strata of Derbyshire in such a way that a simple stratigraphical map could have been produced, although his book contained only a simple outline geological map. Farey started work on a detailed geographical map of Derbyshire in the style of Smith’s county maps but it was never completed and the manuscript has only recently been discovered by Hugh Torrens in a Californian library! Farey also drew a coloured, manuscript geological map of the Ashover inlier, recently published by Torrens (1994), which is comparable to modern maps. Perhaps more important is that Farey recognized the nature of faulting and his book contained fold-out sheets of explanations of different classes of fault. However, he overstated his arguments by assigning parts of the unconformable contact between limestones and Edale Shales to a Great Peak Fault. White Watson later corrected Farey in showing that the basset (outcrop) of the shale/limestone contact was without faults over much of its course (Watson, 1813).

These three pioneers, Whitehurst, Farey and White Watson, set geology on its feet in Derbyshire in much the same way as William Smith did around Bath, but they did not really get the credit they deserved as founders of the science of stratigraphy. Perhaps this was because three men were involved instead of one; perhaps the fact that they were not involved in canals as parts of a national transport system pushed them into the background. Even so, Farey was the first to publish William Smith’s system of a stratigraphical succession and he helped Smith to extend his work over much of England.

All three pioneers also expressed ideas on the origins of toadstone, effectively supporting Hutton and Playfair in regarding toadstones as ancient volcanic rocks. Farey went so far as to suggest that it was satellite attraction which raised the Masson anticline at Matlock, but White Watson disagreed and argued that volcanic pressure from within the Earth was a much more likely cause of up-folding. Whitehurst and Farey published brief notes on the origin of mineral veins by lateral secretion. Watson also put forward ideas on the origin of the mineral veins from volcanic sources but only in unpublished lecture notes. White Watson was the first lecturer on geology in Derbyshire, delivering talks in Bakewell on a variety of geological topics for some 40 years until his death in 1835. A bound volume of printed sheets (effectively lecture notes) and sketches which he used as visual aids survives in Derby Reference Library.

Among the few other early geologists who may be considered alongside the pioneers is John Mawe (1766-1829) (Torrens, 1992). Mawe’s book (1802) preceded both White Watson and Farey, but he was more concerned with mines and minerals. Even so, he provided an early stratigraphic account and section of the Castleton area. Profiles along several valleys showing the disposition and faulting of some of the toadstone outcrops were given in a little known private publication by Hopkins (1834).

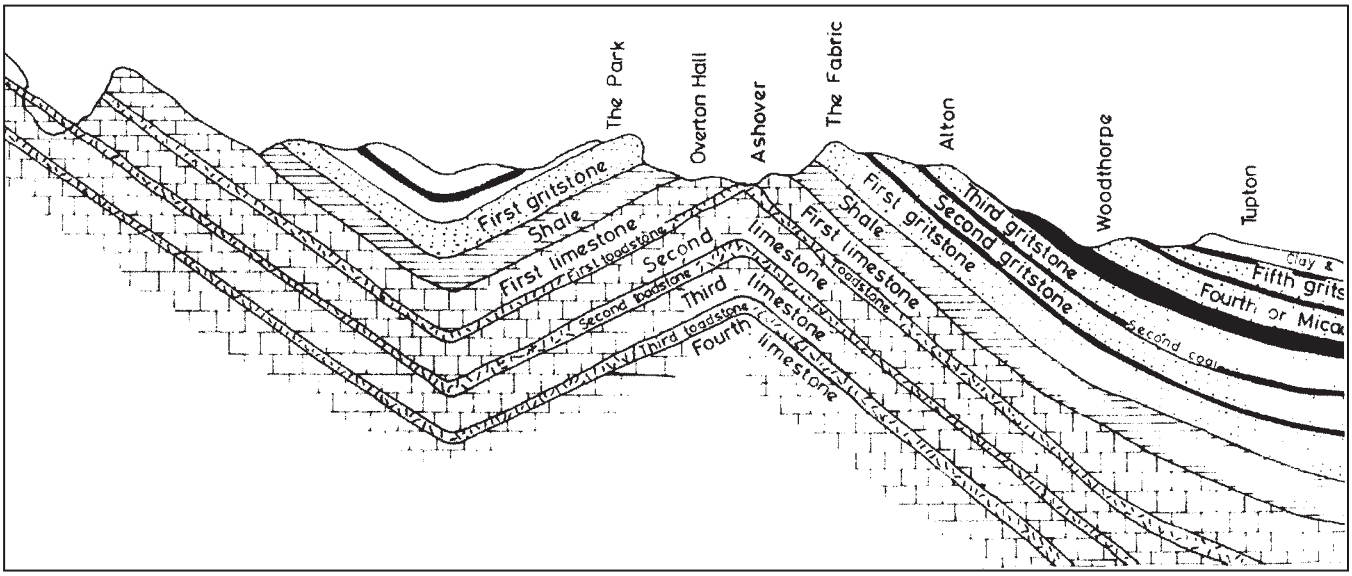

Fig. 3. A section of the strata from Matlock across the Ashover anticline from an unpublished diagram by John Farey (1808).

Mid to Late 19th century prehistory. Though White Watson mentioned the occurrence of bones of ancient animals in caves, e.g. an "elephant's" skull in Ball Eye Cavern near Bonsall, it was not until the 1820s that the concept of antediluvian animals came to the fore through the work of Dean William Buckland at Oxford. One of his examples was the rhinoceros skeleton found by lead miners in the Dream Cave near Wirksworth (Buckland, 1823). Unfortunately the specimen has not survived so it is impossible to identify which species of rhinoceros was found there. Both Darwin's "Origin of Species" in 1859 and the growth of prehistoric archaeology elsewhere had their spin-offs in the Peak District, where cave excavation reached a climax with the finding of Devensian faunas at Windy Knoll and other caves (Dawkins, 1874; 1875; Dawkins and Pennington, 1877; Pennington, 1874; 1875; 1877). Contemporary excavations at Creswell on the Derbyshire-Nottinghamshire border yielded both extinct mammals and human artefacts (Mello, 1876) and inspired a more intensive search in the Peak District, but it was not until the turn of the century that a "Pliocene" fauna was found in a fissure at Doveholes (Dawkins, 1903); it was later re-determined as Cromerian (Spencer and Melville, 1974). Some of the above writers and others speculated on the relationship of such deposits to early ideas of glaciation and denudation. The concept of denudation chronology, however, was slow to develop and little was published on the subject until the 1930s.

Mid 19th century Consolidation. The middle part of the 19th century was a period of consolidation rather than major advances in geological knowledge. There was much theoretical development of the subject elsewhere but the Peak District played little part in it.

Systematic knowledge of the fossils of the Peak District grew in the mid to late 19th century with the publication of several Palaeontographical Society monographs on brachiopods (Davidson, 1858-1863), corals (Milne-Edwards and Haime, 1852-1854), trilobites (Woodward, 1883), Foraminifera (Brady, 1876) and ostracods (Jones *et al.*, 1875). Numerous papers discussed less important groups of fossils. These and the early monographs have been superceded by later revisions but, to this day, there is no published, illustrated catalogue of the many Carboniferous fossils from the Peak District.

The growth of mineralogy as a science stimulated the catalogue of Greg and Lettsom (1858), which provided descriptions of some new minerals in Derbyshire, in particular matlockite and cromfordite (the latter now known as phosgenite).

Geological Survey officers commenced work in the Peak District in the mid-19th century and produced the early hachured 1 inch to 1 mile maps and memoirs (Green *et al.*, 1869). These collated geological knowledge, incorporating data from the lead mining industry. However, they failed to systematize Whitehurst, Watson's and Farey's subdivisions of the limestone succession, and their maps coloured all the limestone outcrop in the same shade of blue, making no distinctions between the limestone formations that were to be named later.

Stokes' (1879) review of the economic geology of Derbyshire provided a survey of a variety of mineral products with commercial potential, including lead and zinc ores, iron ore, fluorspar, baryte, calc-spar, chert, umber and coal. His later review of the then declining lead mining industry in 1880-83 included a map of the veins and a few geological observations.

20th century Geologists and Geological Institutions. Much of the early growth of geological knowledge in the Peak District can be put down to the work of amateurs or semi-professionals such as White Watson and Farey (1811). Professionals started to enter the area with early Geological Survey (Green *et al.*, 1869, 1887) and it was not until the early 20th century that academic geology was developed in the Universities of Sheffield and Manchester and later in Nottingham. Derby had to wait many years before an Earth Sciences Department was established in its College of Higher Education, recently established as the University of Derby. The small numbers of staff in the University Geology Departments before World War II meant that few had much opportunity for research either in the Peak District or anywhere else; post-graduate students were a rarity. Such research as was done was mostly concerned with practical geology in the coalfields either side of the Peak District. However, Fearnsides (1933) gave an early structural analysis of the Peak District and its surroundings. His colleague in Sheffield University, Shirley (together with Horsfield) (1940, 1945) followed with detailed mapping of the Carboniferous Limestone. Of museum geologists, only Jackson (1925; 1926; 1927) made any significant addition to knowledge with his studies of Millstone Grit stratigraphy and palaeontology around Edale and Castleton.

While the general distribution of underground water resources was well known, it was not until 1929 that the data were collected in a Wells and Springs Memoir (Stephens, 1929). The geochemistry of these waters was later investigated by Downing (1967) and Edmunds (1971). The underground catchments were delineated by Christopher *et al.*, (in Ford, 1977) and the lead miners' soughs catalogued by Rieuwerts (1987).

The search for oil resources during World War I was largely abortive but the oil seeps at Hardstoft maintained an interest in the Peak District (Falcon and Kent, 1960). Boreholes in Edale and Alport in 1938 and later at Gun Hill, Staffs (Hudson and Cotton, 1945), enabled detailed correlations and facies analyses but failed to yield hydrocarbon resources.

The Geological Survey started a re-survey of the Peak District in the late 1930s but it was put into abeyance during World War II and not continued until the 1950s. The set of maps and memoirs covering the whole Peak District was completed in the 1980s.

Re-investigation of mineral resources during World War II produced reports on fluorspar and baryte. Although an economic memoir on the lead mines and veins was started by C. A. U. Craven and J. V. Stephens of the Geological Survey in the 1950s, it was never completed and there is still no comprehensive overview comparable with the descriptive memoirs compiled for the North Pennines and Cornwall. Reviews of South Pennine baryte and fluorspar resources were compiled by Dunham and Dines (1945) and by Dunham (1952). Detailed studies of the limestone and dolomite resources were produced by the Geological Survey in the 1980s (see summary by Harrison and Adlam, (1985)).

Specific advances

Carboniferous Limestone. Whitehurst (1778) and Watson (1811) established a sequence of alternating limestones and toadstones, and Farey (1811) named these, in downward succession, the 1st Lime, 2nd Lime etc. Furthermore, Farey's simple outline map differentiated the 1st Lime as covering roughly the area of outcrop of Brigantian strata as known today. After these pioneer studies, little progress was made towards establishing a detailed stratigraphical succession within the limestones for another 50 years.

The early work of the Geological Survey (Green *et al.*, 1869, 1887) did not attempt to subdivide the Carboniferous Limestone. Soon after Vaughan's establishment of a zonal scheme based on corals and brachiopods in the Avon Gorge at Bristol, Sibly (1908) was able to show that most of the White Peak was composed of limestones belonging to Vaughan's uppermost zones (D_1 and D_2). This was restated in Fearnsides' (1932) review.

In the pre-war run-up to the Geological Survey's remapping, Cope (1933, 1939) described and named the sequence in the most fully exposed section of the Wye Valley. Shirley and Horsfield (1940; 1945) followed with detailed stratigraphical papers on the Castleton and Monyash-Wirksworth areas. Unfortunately, they misunderstood the relationships of massif and reef limestones around Castleton, regarding the latter as submarine screes banked against cliffs eroded into a massif of older limestones (Fig. 4). An alternative insight into facies relationships was provided by Hudson and Cotton's (1945) analyses and detailed stratigraphical sections derived from the deep boreholes in Edale, Alport and Gun Hill. The contrasts between massif, reef and basin facies were shown to have resulted from sedimentation on a block surrounded by deeper water. Soon afterwards, the rubber chemist and amateur geologist Parkinson (1947) reinterpreted the relationships at Castleton showing that the reef facies was contemporary with the massive facies, with a lateral passage between the two. Parkinson (1953) elaborated on the structure of the Castleton reef belt, providing palaeo-contours of the fore-reef slope. The palaeocology of the specialized reef faunas reflected the facies changes both at Castleton and in the similar reef belt on the western margin of the limestone massif around Earl Sterndale (Wolfenden, 1958) (Fig. 5). The complex facies relationships in the Dovedale-Manifold Valley area were investigated by Parkinson (1950), and the adjoining Weaver Hills by Ludford (1951). Some revision became necessary as a result of joint studies in the intervening area (Parkinson and Ludford, 1964).

The "reef" facies, variously referred to as knoll-reefs, apron reefs and build-ups, are perhaps better called mud-mounds in view of their lack of an organic framework like modern coral reefs (Bridges and Chapman, 1988; Bridges *et al.*, 1995). Though the evidence is limited, it seems certain that the mud-mounds were built by microbial action (Gutteridge, 1995) particularly by algae and Cyanobacteria (Pickard, 1996). The shape of the mud-mounds was controlled by the depth of water at initiation and by the rate of subsidence. On ramps (sloping sea floors), contemporary mud-mounds could be wide and low in shallow water but narrow and highly domed at the margins of deeper water

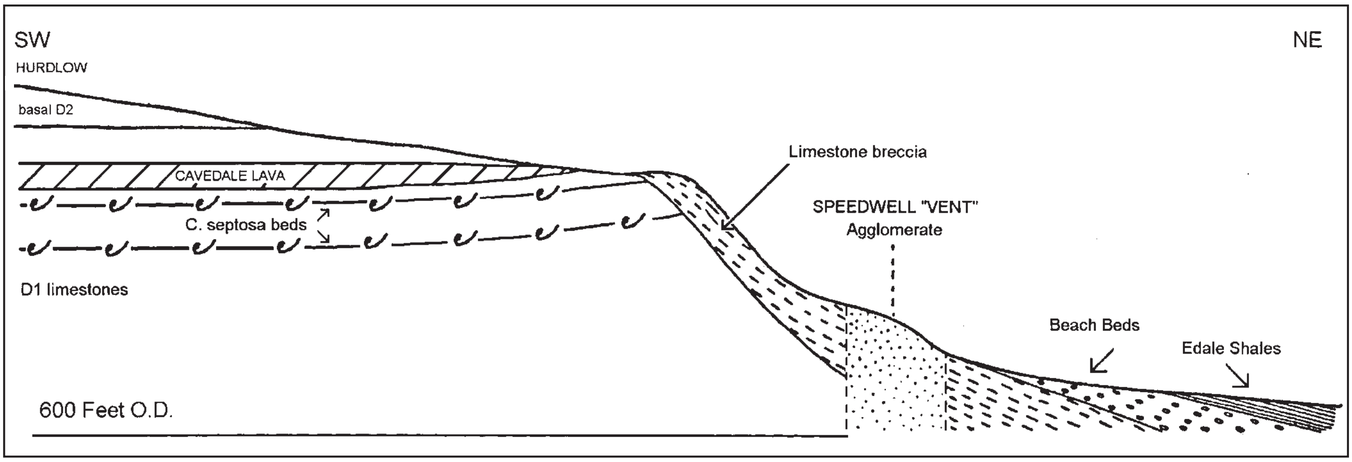

Fig. 4. Shirley's proposed relationship of the "reef" limestones lying unconformably against an eroded cliff of the massif limestones (modified after Shirley and Horsfield, (1940).

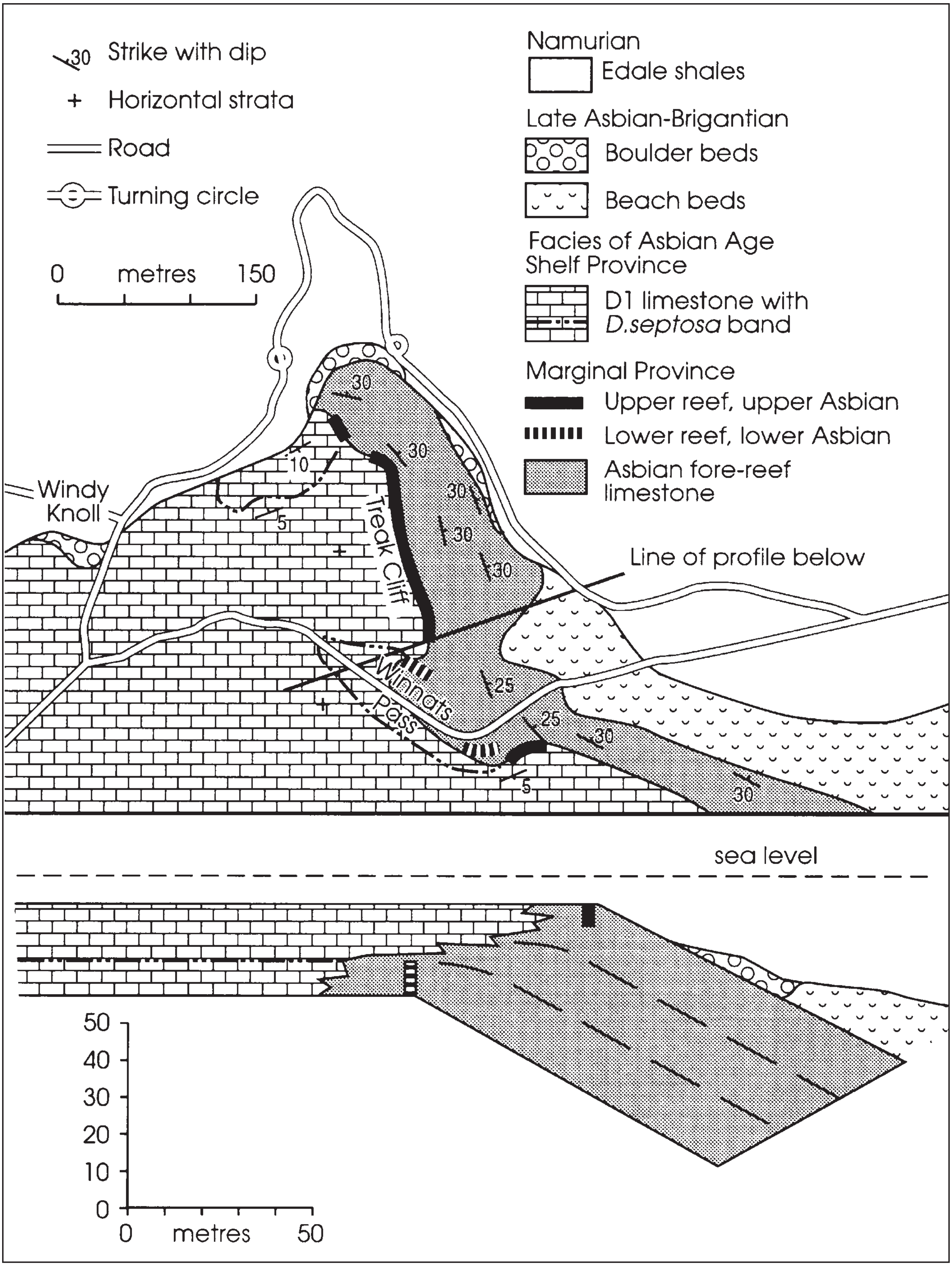

Fig. 5. Sketch map and section of the facies relationship of the reef and massif limestones at Castleton (modified after Wolfenden, 1958).

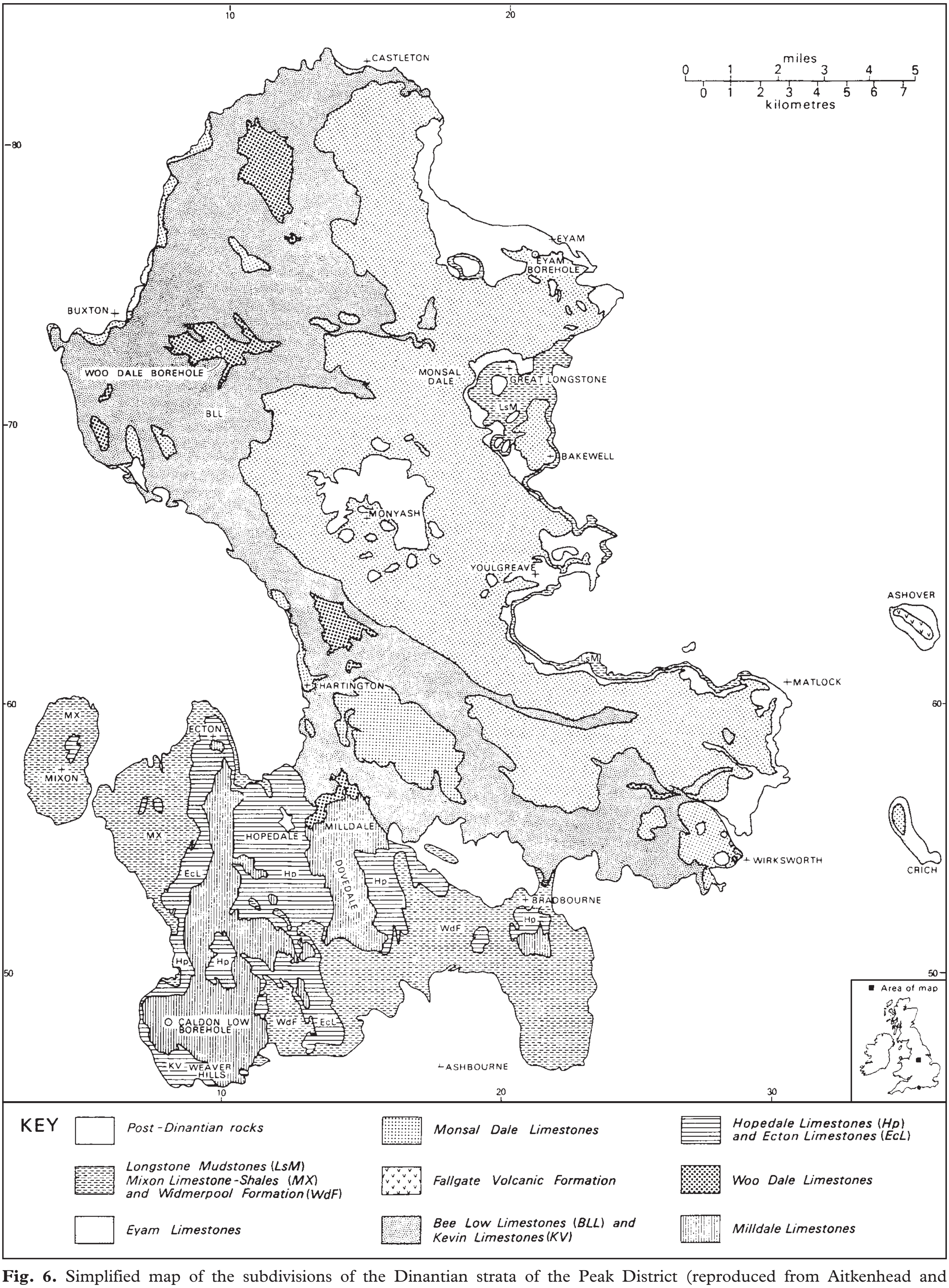

Fig. 6. Simplified map of the subdivisions of the Dinantian strata of the Peak District (reproduced from Aitkenhead and Chisholm, 1982, by permission of the Director of the British Geological Survey; © NERC).

basins (Gutteridge, 1995; Bridges *et al.*, 1995). Bioclastic limestones rich in crinoid debris both flanked the muds-mounds and accumulated on platform margins (Gawthorpe and Gutteridge, 1990). Some degree of water-depth control on the distribution of various species of brachiopods, molluscs and trilobites was deduced by the palaeobathymetric studies of Broadhurst and Simpson (1973).

The Woo Dale borehole extended knowledge of the concealed sequence beneath the lowest exposed beds (Cope, 1949; 1973). It penetrated 273m of largely dolomitic limestones resting on pre-Carboniferous volcanic rocks beneath the Wye Valley (Cope, 1949; 1973). The Woo Dale limestones themselves were shown to be partly dolomitized by Schofield and Adams (1985; 1986). The Eyam borehole, though starting at a higher horizon, penetrated over 1600m of limestones with anhydritic beds at the bottom before entering slates of probable Ordovician age (Dunham, 1973). This thick sequence demonstrated that transgression on to the Derbyshire massif started much earlier (Tournaisian?) than at Woo Dale, and that the basement surface was either sloping or faulted.

The higher (Brigantian) part of the sequence was investigated around the Hope cement quarry (Eden *et al.*, 1964) where the marginal complex is largely a series of mud-mounds and shoals of crinoidal calcarenite. Farther south, the Asbian-Brigantian sequence and accompanying lavas were mapped in Monsal Dale by Butcher and Ford (1973). A deeper-water facies with thin dark limestones, some of which are laminated with small slump structures, occurs in the mini-basin around Ashford-in-the-Water (Adams and Cossey, 1978). The flanking highs had contemporary mud-mounds near Monyash (Gutteridge, 1987; 1995). Microfacies in the Asbian marginal reefs and lagoonal limestones around Hartington were studied by Sadler (1966). The sequence in the main part of Dovedale, with its complex of “reef” limestones of two different ages, was described by Parkinson (1950). The marginal reefs in upper Dovedale were later shown to bear a close resemblance in both age and palaeontology to the marginal reefs of Castleton (Wolfenden, 1958). The sequence in the basinal facies of the Manifold Valley to the west, though much disturbed by both folding and faulting, was delineated by Prentice (1951). In the far southwest of the White Peak, the Weaver Hills stratigraphy was described by Ludford (1951). The earlier series of reefs in the Dovedale area were later shown to be relatively deep-water mud-mounds comparable to the Waulsortian facies of Belgium (Miller and Grayson, 1982; Bridges and Chapman, 1988; Bridges *et al.*, 1995). Across the Castleton-Bradwell margin of the massif, late Dinantian (Brigantian) sedimentation was shown to be an accumulation of migrating shoals of crinoidal calcarenite in contrast to the marginal “reef” complex in Asbian times (Gutteridge, 1989; 1990; 1995; Gawthorpe and Gutteridge, 1990).

Cyclic emergence of the carbonate-covered Derbyshire Block with the intermittent formation of palaeosols and palaeokarstic surfaces was deduced from sections along the Wye Valley (Walkden, 1974) and in the Wirksworth-Grangemill area (Oakman, 1984; Walkden *et al.*, 1981). At Crich, the cyclic nature of the Brigantian sequence was related to transgression-regression cycles (Bridges, 1982). The effect of this emergence on diagenesis, with resultant multiple generations of cementation, was subsequently discussed by Walkden and Williams (1991). Using cathodoluminescence to distinguish successive phases, the later phases of diagenesis have recently been related to mineralization and to hydrocarbon emplacement (Hollis and Walkden, 1996).

Dinantian sedimentation in the concealed Edale Basin was first investigated following drilling of the Edale borehole (Hudson and Cotton, 1945b). A more detailed interpretation was given by Gutteridge (1991), who also suggested that the adjacent limestone massif might be bounded by concealed basement faults.

Dolomitization is widespread in the upper limestones of the southern Peak District (Parsons, 1922). Although commonly attributed to the sub-surface effects of a Permian transgression, it is usually regarded as an early phase of mineralization (see later section on mineralization).

Silica is common in some limestone formations in the form of chert nodules, authigenic quartz, silicified fossils or as quartz rock. On the other hand, some limestones, particularly mud-mounds, are almost devoid of silica. Whilst some of the distribution in Brigantian beds has been ascribed to mobilization of silica from altered volcanics (Orme, 1974) no full study is yet available. Massive cherts in the highest beds around Bakewell were once mined for use in the Potteries (Bowering and Flindall, 1998).

Palaeontology has been incidental to most of the stratigraphical and sedimentological studies. Lists of fossils were given in many publications but there were few illustrations and no guide to identification. Parkinson (1954), however, laid some of the foundations of statistical palaeontology with studies of brachiopod populations and community growth patterns based on collections from the fore-reef limestones of Treak Cliff, Castleton. Facies control of faunal distribution around Castleton and upper Dovedale was noted by Wolfenden (1958) and in the Brigantian mud-mounds near Monyash by Gutteridge (1990; 1995 and Bridges *et al.*, 1995). Tilsley (1988) noted that, at Castleton, trilobite remains seemed to be concentrated at intermediate depths on fore-reef slopes. The Eyam borehole enabled Strank (1985) to describe the Tournaisian to Brigantian evolution of foraminifera and other faunas.

The Geological Survey returned to the Peak District during the 1950-1970 period, as a result of which maps at 1:50,000, 1:25,000 and 1:10,000 (or 10,560) scales are now available. Descriptive memoirs also cover the whole Peak District (Smith *et al*., 1967; Stevenson and Gaunt, 1971; Aitkenhead *et al*., 1985; Chisholm *et al*., 1988). Nomenclature was standardized and a summary map produced by Aitkenhead and Chisholm (1982) (Fig. 6). The series of formational names produced in different parts of the Peak District was also systematized by Aitkenhead and Chisholm (1982) (Fig. 7), although some revision became necessary owing to the later recognition of subtle facies changes around Matlock (Chisholm *et al*., 1983). Although not usually listed among the main authors, the Geological Survey's biostratigraphers, notably

DINANTIAN STAGES	*REGIONAL FORMATION NAMES*	*LOCAL AND EARLIER CLASSIFICATIONS*: Wye valley *(Cope 1933, 1937 & 1958)*	Matlock area *(Smith and others 1967)*	Wirksworth area *(Frost and Smart 1979)*	Monyash and Wirkswoth *(Shirley 1953)*	North-east of Hartington *(Sadler and Wyatt 1966)*	Wolfscote Dale & Alsop Moor *(Parkinson 1950)*
BRIGANTIAN	LONGSTONE MUDSTONES		Cawdor Group	Cawdor Shale			
	EYAM LIMESTONES	Ashford Beds		Cawdor Limestone	Cawdor Limestones		
	MONSAL DALE LIMESTONES	Monsal Dale Beds Priestcliffe Beds Upper Lava Station Quarry Beds	Matlock Group	Matlock Limestone	Lathkill Limestone		Alsop Moor Limestone
ASBIAN	BEE LOW LIMESTONES	Miller's Dale Beds Lower Lava Chee Tor Rock	Hoptonwood Group	Hootonwood Limestone	Via Gellia Limestone	Upper Limestones Lean Low Beds	Wolfscote Dale Limestone
HOLKERIAN	WOO DALE LIMESTONES	Daviesiella Beds	Griffe Grange Bed			Hard Dale Beds Vincent House Beds	Iron Tors Limestone

DINANTIAN STAGES	*REGIONAL FORMATION NAMES* (Aitkenhead & Chisholm, 1982)		*LOCAL AND EARLIER CLASSIFICATIONS*: Mixon & Manifold Valley *(Hudson in Hudson and Cotton 1945a)*	Manifold Valley *(Prentice 1951)*	Dovedale & Swinscoe *(Modified from Parkinson 1950 and Parkinson and Ludford 1964)*	Weaver Hills *(Ludford 1951)*
BRIGANTIAN	MIXON LIMESTONE - SHALES and WIDMERPOOL FORMATION		Mixon Limestone - Shales	Posidonomya Beds	Hollington End Beds	Waterhouses Limestone
ASBIAN	ECTON LIMESTONES and HOPEDALE LIMESTONES	KEVIN LIMESTONES	Mixon Limestones and Ecton Limestones	Brownlow Mudstones Apestor & Warslow Limestones Waterhouses Limestone and Crassiventer Beds	Bull Gap Shales Gag Lane Limestone	
HOLKERIAN	MILLDALE LIMESTONES	MILLDALE LIMESTONES	Manifold Limestones with Shales	Manifold Limestone-with-Shales	Milldale Limestone	Forest Hollow Beds Manifold Limestone-with-Shales
ARUNDIAN			Calton Limestones	Massive Series		Cauldon Low Limestone and Weaver Beds
CHADIAN				Cementstone Series		Solenopora Beds
COURCEYAN	RUE HILL DOLOMITES REDHOUSE SANDSTONES (Carboniferous or Devonian)					

Fig. 7. Stratigraphic tables of Dinantian subdivisions in the Peak District: a. Central, northern and eastern Peak District; b. southwestern Peak District (Stage boundaries are uncertain in the southwest) (reproduced with modifications from Aitkenhead and Chisholm, (1982), by permission of the Director of the British Geological Survey; © NERC).

M. Mitchell, W. H. C. Ramsbottom. N. J. Riley, and A. R. E. Strank identified thousands of fossils listed in the Memoirs and contributed much to understanding of the stratigraphical and structural relationships. The Survey also published 1:25,000 scale maps of educationally important areas (Edale and Castleton, Millers Dale, Matlock and Wirksworth) with concise descriptions in their margins. Almost the whole White Peak area was covered at the latter scale in maps accompanying the limestone resources assessment reports noted below.

As part of the general systematization of chronostratigraphy and nomenclature in the Lower Carboniferous (Avonian, later Dinantian), a series of stages were defined in accordance with the rules of stratigraphic nomenclature (George, 1972; George *et al.*, 1976). Based on fossil assemblages from type-sections in various parts of Britain, the stages seemed to correlate with transgression-regression cycles identified by Ramsbottom (1973). The stages Courceyan, Chadian, Arundian, Holkerian, Asbian and Brigantian (Fig. 7) replaced the old coral-brachiopod zones, K, Z, C, S and D, which could only be applied to the shallow water shelf facies. The first of these stages (Courceyan) appears to have little or no representation in the Peak District, though some of the Rue Hill Sandstones at the bottom of the Cauldon Low borehole in the Weaver Hills (Chisholm *et al.*, 1988) may be of this age or possibly even late Devonian.

Substantial surface and subsurface lithological detail was provided by the surveys of limestone and dolomite resources carried out by the Institute of Geological Sciences for the Department of the Environment by Cox and Bridge (1977), Cox and Harrison (1980), Harrison (1981), Bridge and Gozzard (1981), Gatliff (1982) and Bridge and Kneebone (1983). Many shallow boreholes yielded both lithological and stratigraphical detail for almost the whole limestone outcrop. The results were summarized by Harrison and Adlam (1985).

The Toadstones. The assemblage of basalt lavas, tuffs and ashes commonly known as toadstones intrigued early geologists in view of the late 18th century controversy between Werner, who thought that all ancient basalts were precipitates from a primaeval sea, and Hutton, who correctly regarded them as volcanic outpourings. As noted above, Whitehurst, Watson and Farey were adherents of the Huttonian theory. They thought that there were two principal horizons of toadstone in most of the Peak District, but Hopkins (1834) argued that there might be three toadstones in some locations but only one in others (Fig. 8). Later, as many as seven toadstone horizons were identified in Mill Close Mine at Darley Dale (Traill, 1939; Shirley, 1949).

The end of the 19th century and early 20th saw a major advance in knowledge with the publication of Allport's (1874) and Bemrose's (later Arnold Bemrose) works on the petrography of the lavas and ashes (Bemrose, 1894). Bemrose later mapped the

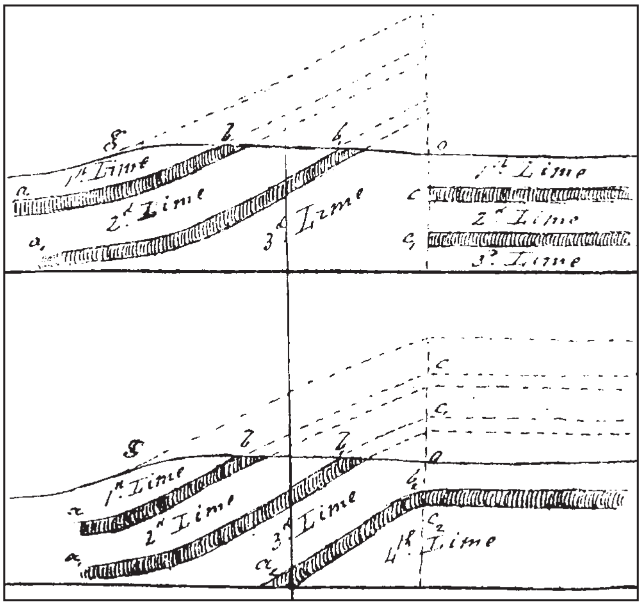

Fig. 8. Alternative sections with of two or three toadstones, near Aldwark (from Hopkins, 1834).

distribution of toadstones throughout the White Peak (1907). His mapping demonstrated the presence of several main lava flows as well as sheets of tuff and patches of vent agglomerate. A few sills were also recognised. Although there are two main lavas in both the Castleton-Millers Dale and the Matlock areas, they lie at different horizons and later work showed that a simple correlation of the lavas in those areas was misleading. Bemrose's studies could have provided the basis for a detailed stratigraphical map of the White Peak's limestones, but he was content with mapping the toadstones and giving a general review of the area (Bemrose, 1910a). Wilcockson (in Fearnsides, 1932) and later Macdonald *et al.* (1984) added petrographical detail showing that the basalts ranged in composition from olivine-rich alkaline basalts to olivine-poor tholeiites. Detailed studies of the lavas in the Matlock area arising from the limestone resources investigations noted above led to the Lower Matlock Lava being recognized as multiple lava flows, intercalated with thick tuffs (Chisholm *et al.*, 1983). Webb and Brown (1989) provided both a new map of the toadstone outcrops (Fig. 9) and a digest of geochemical data.

Interbedded with the limestones both above and below the main lavas are thin greenish clay layers known as wayboards. Their origin as volcanic ash falls, sometimes accompanied by soil-forming processes, was described by Walkden (1972), who found that some ash falls were sufficient to result in temporary emergence above sea level.

The basalts of Calton Hill, near Taddington, were found to include the unusual feature of olivine nodules (Bemrose, 1910b). The opening of a quarry there in the 1920s, in what appeared to be a volcanic neck, stimulated research into these basalts, particularly by the Russian emigré Tomkeieff (1928). The basalts included massive, columnar and vesicular varieties, and there was secondary

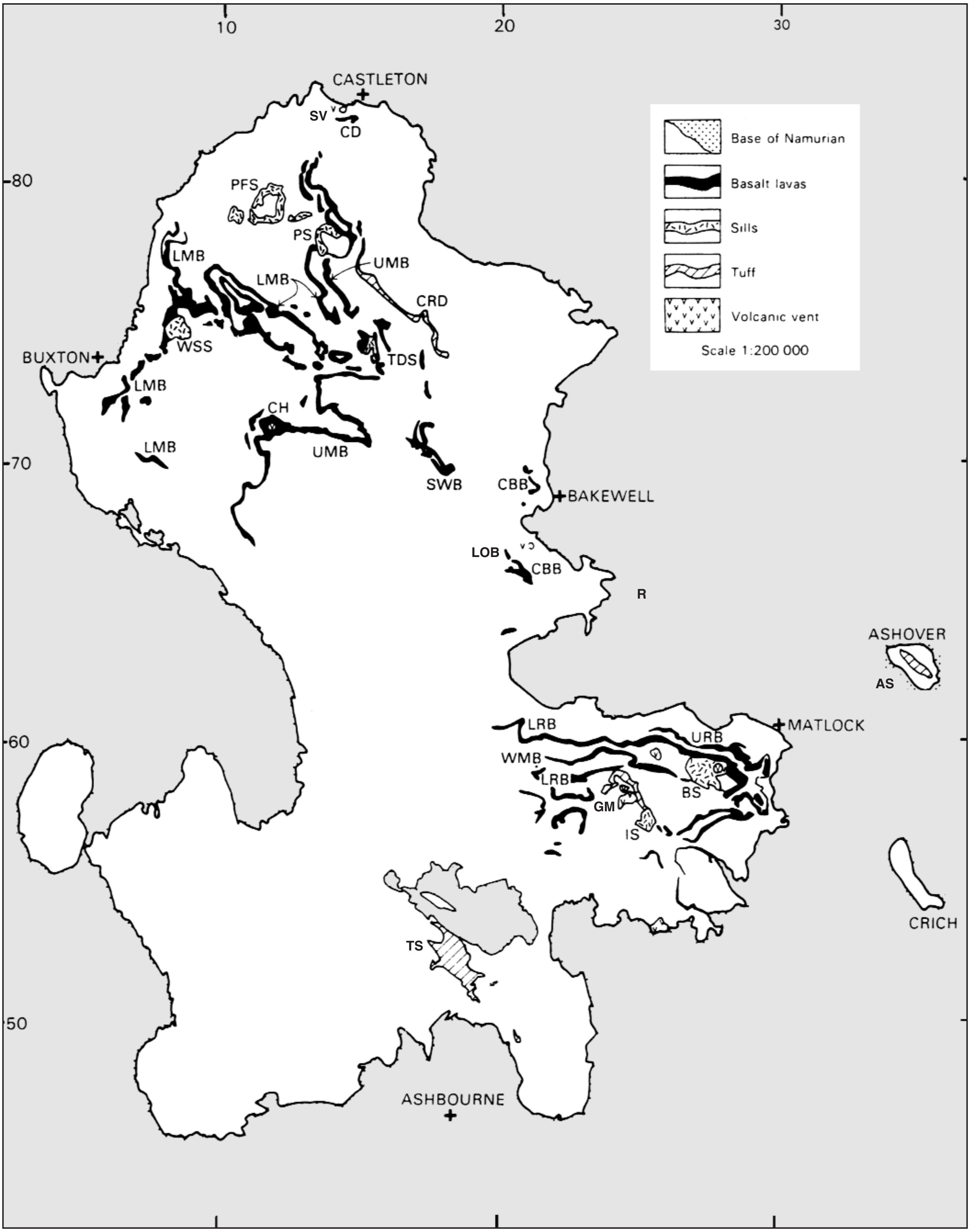

Fig. 9. Distribution of Carboniferous lavas, vents and sills. LAVAS: UMB, Upper Millers Dale; LMB, Lower Millers Dale; CD, Cave Dale; CRD, Cressbrook Dale; SWB, Shacklow Wood; CBB, Conksbury Bridge; LOB, Lathkill Lodge; LRB, Lower Matlock; WMB, Winster Moor; URB, Upper Matlock; R. Rowsley Boreholes. VENTS: SV, Speedwell; CH, Calton Hill; GM, Grangemill. SILLS: PFS, Peak Forest; PS, Potluck; WSS, Waterswallows; TDS, Tideswell; BS, Bonsall; IS, Ible; TUFFS:TS, Tissington; AS, Ashover (reproduced from Webb and Brown, 1989, by permission of the Director of the British Geological Survey; © NERC).

mineralization with many quartz veins containing hematite inclusions. A pattern of boreholes sunk by the quarry company to prove resources showed that the whole pile had a saucer-shaped base; no feeder pipe was detected. Olivine nodules within the massive basalt were shown by Hamad (1963) to contain a small proportion of pyroxenes. It is still debatable whether the nodules represent concentrations of ferro-magnesian minerals brought up from deep in the magma chamber or whether they might have been derived from the Earth's mantle. The former seems to be the favoured hypothesis at present.

A borehole beneath the cement works at Hope revealed an unexpected pile of mostly pillow lavas (Fearnsides and Templeman, 1932). These appear to be marginal to a tuff mound later found beneath the adjacent quarry (Eden *et al.*, 1964; Stevenson and Gaunt, 1971).

In 1933 Cope described tholeiite dykes in Great Rocks Dale. In 1997 he proposed that these might represent feeders for the lavas. Elsewhere the lavas were thought to emanate from scattered vents, though demonstrating the physical connection has not generally been possible.

As noted in the Carboniferous Limestone section above, the officers of the Geological Survey re-surveyed the Peak District after World War II, thereby providing the first detailed maps of toadstone outcrops since Bemrose (1907). During this resurvey, boreholes near Ashover demonstrated a thick volcanic pile beneath that anticline (Ramsbottom *et al.*, 1962). Later, Walters and Ineson (1981) provided a detailed analysis of the volcanic history.

Millstone Grit. At the base of the Millstone Grit succession, the thick marine Edale Shales were at first correlated with the Yoredale Beds of the North Pennines until palaeontological work showed that this was partially incorrect and that the lower Yoredales were of Dinantian age. The basal contact of the shales with the limestone, regarded as due to a fault complex by Farey (1811) and the early Geological Survey (Green *et al.*, 1869; 1887), was shown to be at least partly a buried-landscape type of unconformity by Jackson (1925) and Hudson (1931); they demonstrated that the shales were banked against eroded fore-reef beds largely of Asbian age. A massive boulder bed at the shale/limestone contact around Treak Cliff, Castleton, indicated that perhaps 100m thickness of Brigantian limestones had been removed in latest Brigantian to earliest Namurian times (Simpson and Broadhurst, 1969). Their implication was that uplift of comparable magnitude had taken place and that the limestone had been eroded subaerially.

The thick sequences of alternating shale and coarse sandstone (gritstone) noted by Watson (1811) and Farey (1811) forms the Millstone Grit frame around the White Peak, culminating in the plateau of Kinderscout in the north — the so-called Dark Peak. Farey's unpublished section of 1808 numbered Grit horizons in upward order (Fig. 3). The beds were mapped by early officers of the Geological Survey (Green *et al.*, 1869; 1887) who laid the foundations of the sandstone nomenclature used today, namely Shale Grit, Kinderscout Grit, Chatsworth Grit, Ashover Grit and Rough Rock. However, the equivalent beds in northeast Staffordshire were unfortunately referred to as First Grit, Second Grit, etc., leading to mis-correlation (Fig. 3) until it was sorted out by the palaeontological work of Hind (1897, 1898), Jackson (1926, 1927) and particularly Bisat (1924). Bisat notably established the Namurian age of the Millstone Grit by goniatite correlation with the Belgian sequence. A series of mainly proto-quartzitic sandstones in the lower part of the Millstone Grit was later named the Minn Beds in north Staffordshire (Holdsworth, 1963; Ramsbottom *et al.*, 1978).

In post World War II times the details of the Namurian strata have been mapped and described in Geological Survey Memoirs (Eden *et al.*, 1957; Smith *et al.*, 1967; Stevenson and Gaunt, 1971; Aitkenhead *et al.*, 1985; Chisholm *et al.*, 1988). The mapping stimulated sedimentological studies by contemporary academics, notably Allen (1960), Holdsworth (1963) and Collinson (1968; 1969). Bisat's (1924) notation of goniatite zones E_1, E_2, H, R_1, R_2, and G was replaced by a sequence of stages named after type areas; Pendleian, Arnsbergian, Chokerian, Alportian, Kinderscoutian, Yeadonian and Marsdenian. The relationship of local successions to these stages was discussed by Ramsbottom *et al.* (1978) (Fig. 10). These chronological stages were regarded as almost synchronous with a series of transgression/regression cycles referred to as mesothems (Ramsbottom, 1977). Eleven mesothems were recognized, but the concept was later regarded as too simplistic by Holdsworth and Collinson (1988). Applying the hypothesis of sequence stratigraphy, Read (1991) referred the lower parts of each sandstone/shale cycle to a low-stand system tract, whilst the massive sandstones represented high-stand system tracts and the whole package was explained as due to glacial-eustatic sea-level oscillations. The concept of sequence stratigraphy now proposes that the simple early idea of repeated rises of sea-level should be replaced by one involving both rises and falls.

The sedimentology of the Millstone Grit was outlined as early as 1859 by Sorby, and enlarged upon much later by Gilligan (1919), who explained the Millstone Grit as the deposit of a massive delta, building out southwestwards into the Pennine Basin. The coarse sandstones of the north and east flanks of the Peak District exhibit current-bedding that indicates derivation from the north and northeast. Preceded by the deep-water Edale Shales, the deltas did not build out into the Peak District until Kinderscoutian times. Remnants of the Edale Shales on top of the limestone massif show condensed sequences which contrast with the thick

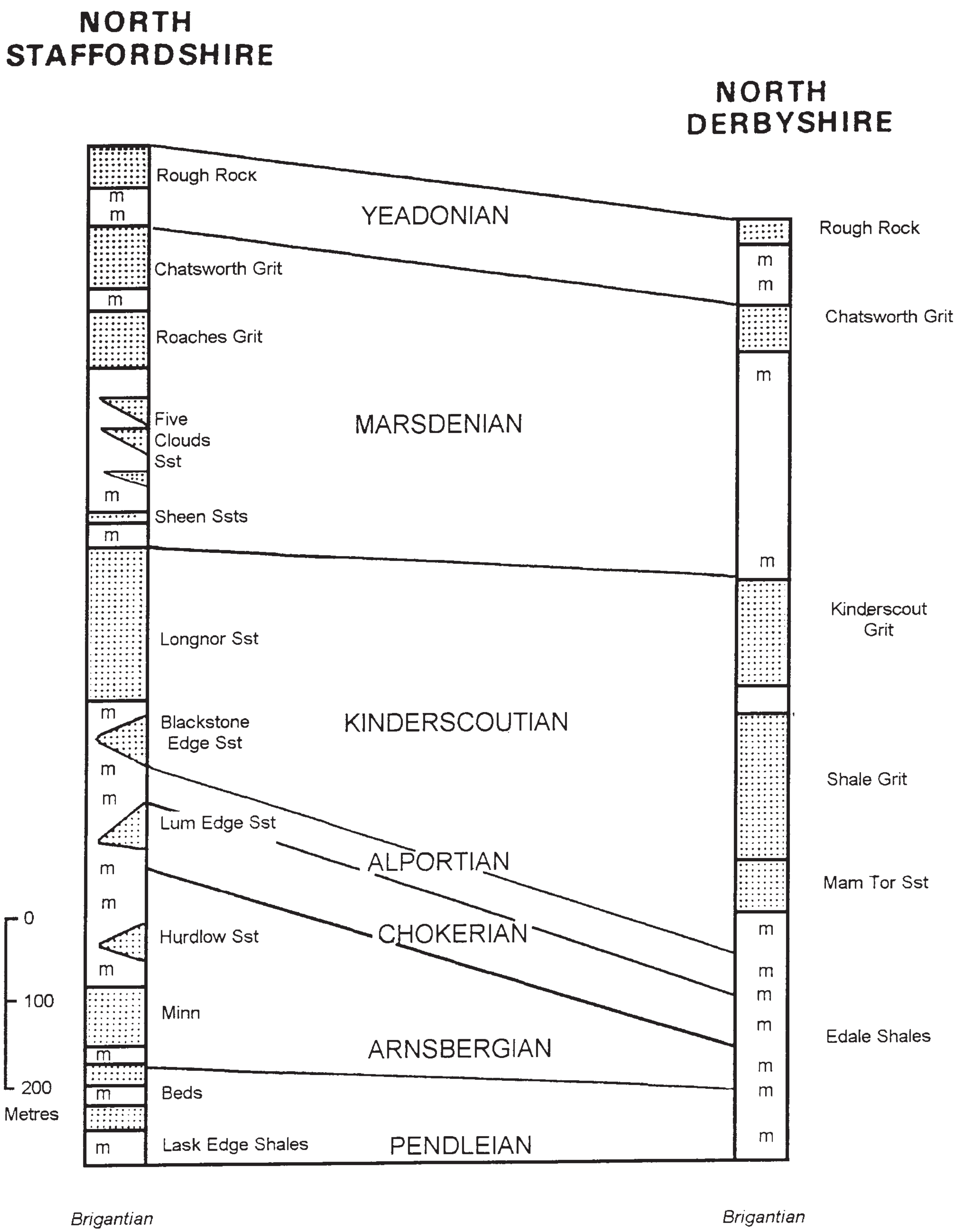

Fig. 10. Namurian correlation between North Staffordshire and North Derbyshire (after Ramsbottom *et al.*, 1978).

mudstones of the Edale and North Staffordshire 'Gulfs'. The deltaic sandstones have a variable content of feldspar and mica indicating a source in metamorphic rocks like those of the Scottish Highlands.

By contrast the earliest sandstones, the Minn Beds of the Staffordshire Gulf, were proto-quartzitic turbidites of Pendleian to Kinderscoutian age. They were deficient in feldspar and mica and were derived from a southerly source, the Midlands land-mass (Trewin and Holdsworth, 1973). From Kinderscoutian times onwards, deltas with coarse feldspathic sandstones derived from the north also built out into the Staffordshire Gulf.

The sedimentological studies of Allen (1960), Walker (1966), Collinson (1968, 1969), Morris (1969), Trewin and Holdsworth (1973), Chisholm (1977), Jones (1980), Jones and Chisholm (1997) and Hampson (1997) have distinguished such features as delta-top aggradation, prograding slope sheets, overbank splays, channel-fills, proximal turbidite fans, distal aprons, offshore muds and growth faults (Fig. 11). Most importantly, a change of view has emerged from simple stacking of deltas one on top of the other to a concept of laterally prograding fluvio-deltaic systems. For example, Jones (1980) showed that the Ashover Grit was fed into the South Pennine basin from a southeast direction, by-passing the thick pile of Kinderscout and Chatsworth Grits and reaching far enough westwards to form the Roaches Grit. Recent studies have shown that the Ashover Grit and its correlative Roaches Grit in Staffordshire filled a palaeo-valley up to 80m deep cut across the southern margins of the preceding Kinderscout delta complex (Jones and Chisholm, 1997).

The Tertiary Silica Sand Pocket Deposits. Worked for refractory brick manufacture to a limited extent in the late 18th century, and also tested unsuccessfully for china clay, the silica sand pockets did not attract much attention from geologists until Brown's (1867) and Maw's (1867) descriptions. Their economic importance was investigated by Howe (1897; 1918; 1920) but the deposits in the sixty or so pits (Fig. 12) were not described in any detail until Yorke's private publications (1954-61). Long regarded as Triassic outliers (Kent, 1957), the late Cenozoic age of the Pocket Deposits was not established until much later when Walsh *et al.* (1972) formally named the sands and clays as the Brassington Formation. They showed that there was once a continuous sheet at least 45m thick over much of the southern part of the Peak District, composed of three members:

3. Kenslow Member: grey clays with fossil plants;
2. Bees Nest Member: coloured clays;
1. Kirkham Member: white and yellow sands with pebble bands.

In spite of the former extent of the Brassington Formation, these three members are now preserved only as a result of sagging into subsidence collapse "pockets" (Fig. 13), but a continuous sheet of these fluvial sediments is thought to have once formed a braided river plain across much of the southern Peak District (Walsh *et al.*, (1972).

The fossil plants in the Kenslow Member were listed by Boulter (1971), who deduced a late Miocene to early Pliocene age. Quartzite pebbles in the sands were deduced to have been derived from the Triassic Sherwood Sandstones which now occur as a low, north-facing escarpment around Hulland Water, some 8km south of Brassington. The

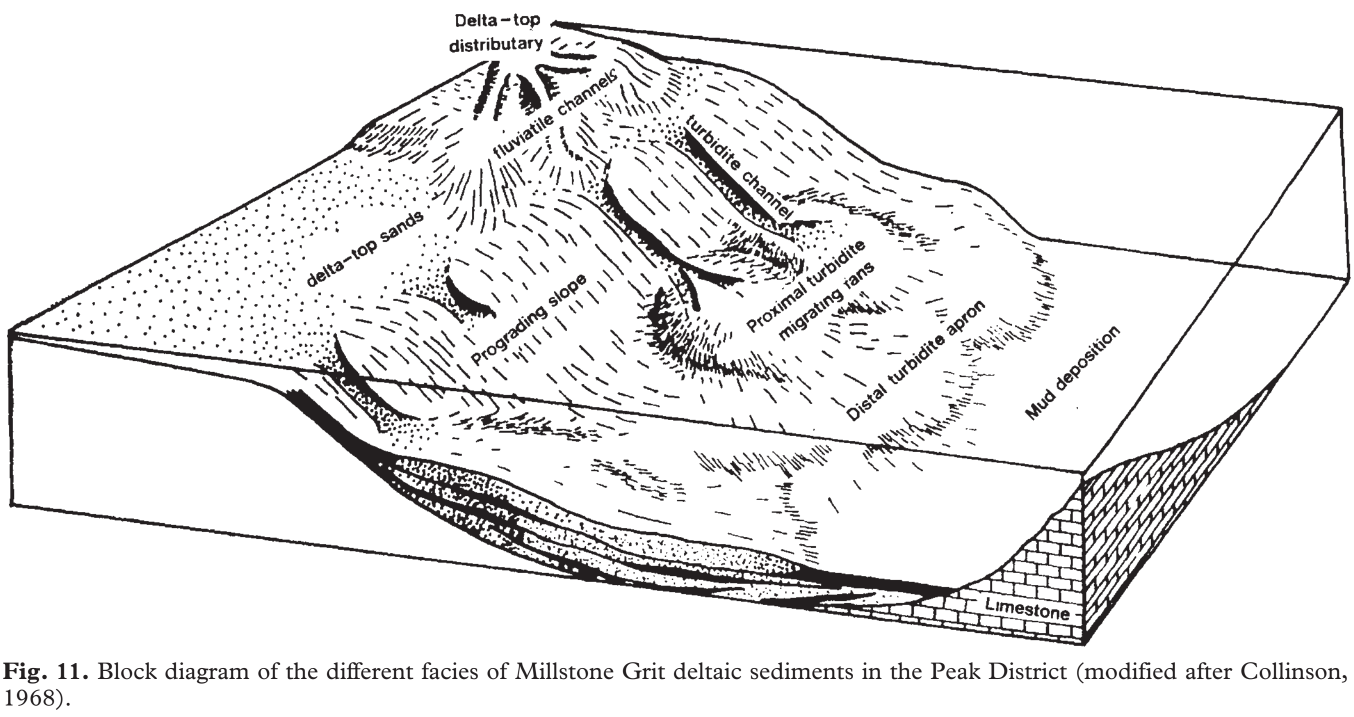

Fig. 11. Block diagram of the different facies of Millstone Grit deltaic sediments in the Peak District (modified after Collinson, 1968).

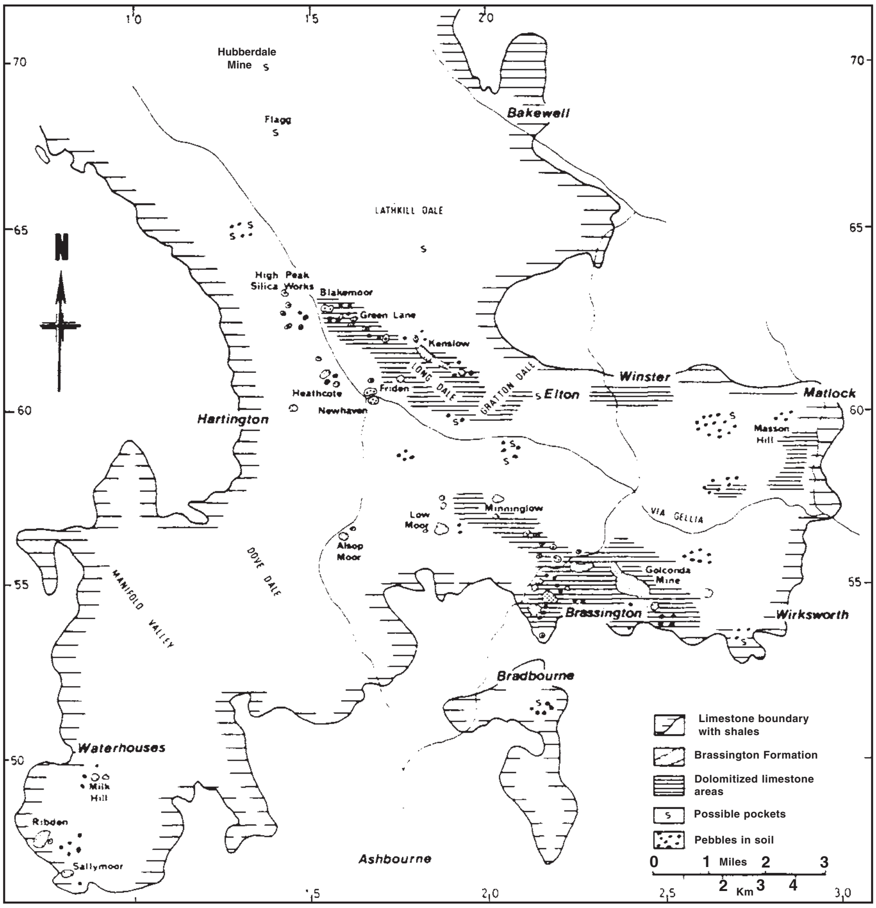

Fig. 12. Sketch-map to show the distribution of the Neogene Brassington Formation in the Peak District (from Ford, 1977).

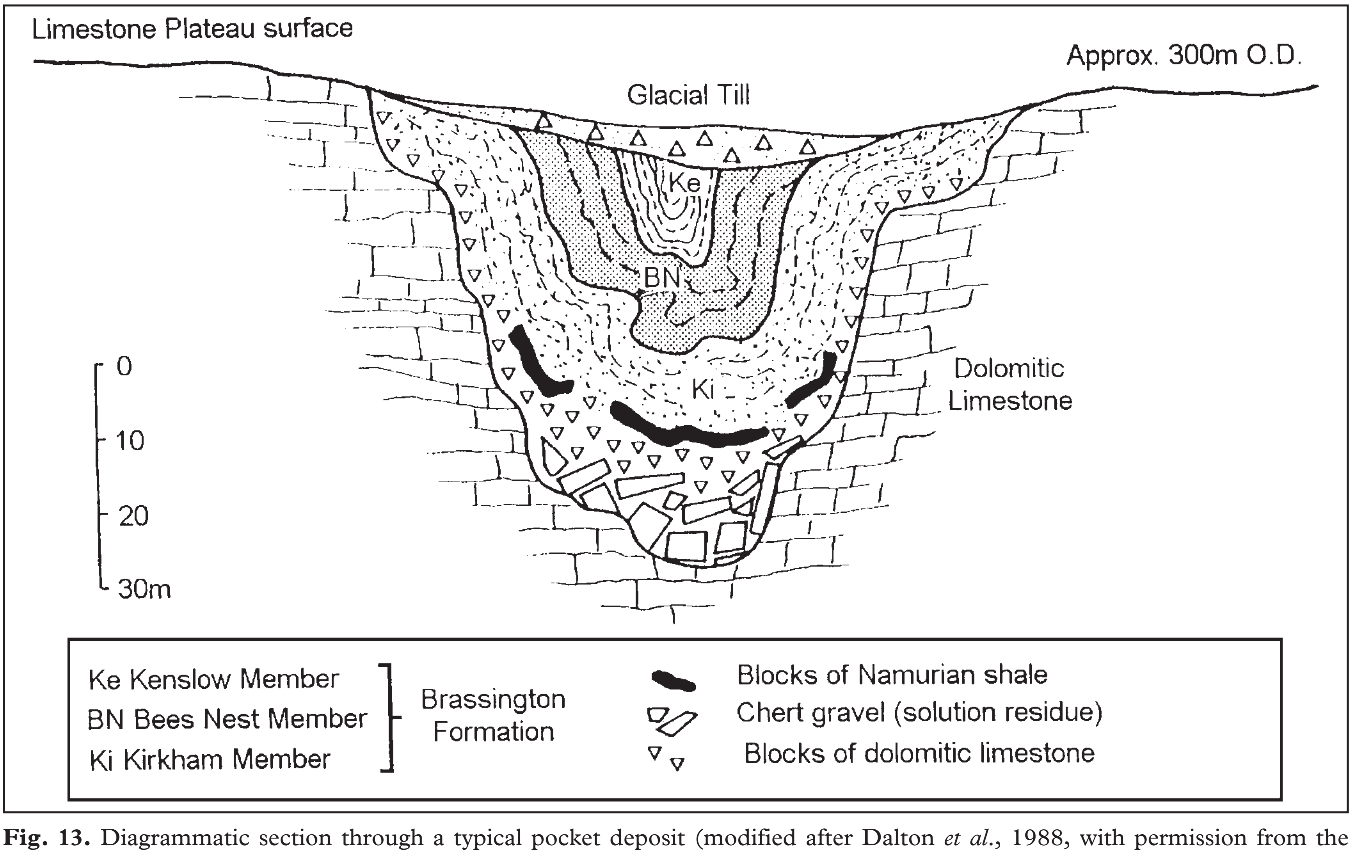

Fig. 13. Diagrammatic section through a typical pocket deposit (modified after Dalton *et al.*, 1988, with permission from the Geographical Association).

escarpment appears to have retreated from a former extent covering the southern part of the limestone massif. The fact that the escarpment is now at a lower altitude than the silica sand pockets suggests that there has been differential uplift of the limestone plateau since the early Pliocene (Walsh *et al.* 1972).

The Quaternary. Often regarded by 19th century geologists as "the muck" on top of the real geology, Quaternary deposits are thin and patchy over most of the Peak District and have received comparatively little attention.

Passing remarks concerning Pleistocene mammal remains in caves were made by White Watson (1811), who recorded an elephant skull alleged to have been found in Ball Eye cave near Bonsall. A rhinoceros skeleton was found in the Dream Cave near Wirksworth (Buckland, 1823). It was not until the 1870s that systematic digging started (Dawkins and Pennington, 1877). A Pliocene fauna found at Doveholes (Dawkins, 1903) was later re-determined as probably Cromerian in age, perhaps one million years younger (Spencer and Melville, 1974). From the 1930s onwards, Elderbush Cave and other caves in the Manifold Valley and Dovedale area yielded important, later Pleistocene sequences and faunas (Bramwell, in Ford, 1977).

The early Geological Survey (Green *et al.*, 1869; 1887) commented on the patchy representation of glacial drift in the Peak District, and little further advance was made until Jowett and Charlesworth (1929) analysed the directions of ice streams across the White Peak and found little evidence of more than a single glaciation. However, an analysis of river terraces along the Derwent valley by Waters and Johnson (1958) showed that there were 'high' and 'low' level deposits which could be related to "Older" and "Newer" Drifts, suggesting at least two episodes of glaciation. Further discussion on the relationship of tills, terraces and drainage diversion and their implications for glacial chronology, was put forward by Straw and Lewis (1962) and by Straw (1968). Drainage patterns and terraces in the Buxton — Chapel-en-le-Frith area were also inferred to support two glacial episodes (Johnson and Rice, 1961; Johnson, 1967; Burek, 1977) (Fig. 14). Burek (1991) has more recently shown that two distinct tills can be distinguished by their clay mineralogy.

Widespread yellowish silty clays on the limestone plateau were interpreted as bioturbated loess by Pigott (1962). Representing wind-blown detritus from the surrounding Millstone Grit areas, they are probably largely Devensian in age, though there may be earlier deposits of unproven age. Material apparently derived from these is intermixed with outwash sands in cave sediments (Noel *et al.*, 1984; Ford, 1986).

A starting point for a chronological sequence of Pleistocene events was provided by the recognition of the Mio-Pliocene age of the Brassington Formation (Walsh *et al.*, 1972). Noting the work of Beck (in Ford, 1977), Burek (1977) was able to build up a tentative history of Pleistocene events as they relate to cave formation. The chronology was developed further by Ford's (1986, 1996) analysis of the evolution of the Castleton cave systems, based partly on morphology and partly on uranium disequilibrium dates on stalagmites (Ford *et al.*, 1983). The caves' relationship to the evolution of such landforms as the Winnats Pass has also been discussed by Ford (1987).

Cave sediments around Matlock have yielded palaeomagnetic evidence of a pre-Anglian glaciation at around 780,000 years BP (Noel *et al.*, 1984). The glacial/interglacial history is critical in the analysis of the evolution of the Derwent Gorge at Matlock (Ford, 1997) and further dating and research are needed. Similar glacial-related sediments in ancient caves intersected by quarrying at Eldon Hill, near Castleton, still await a full description.

The problem concerning whether the high level drifts represent a different glaciation (Anglian?) from the low level drifts on terraces (Wolstonian?) highlights the deficiencies in knowledge. The high level drifts, at least in the southern part of the limestone area, contain a high proportion of material derived from the Trias via the Brassington Formation, whilst the low level till has a high proportion of Carboniferous material with rare Lake District erratics. In short, the details of the Pleistocene glacial history of the Peak District still await full analysis and understanding.

Landforms such as gritstone tors (Palmer and Radley, 1961), dry valleys (Warwick, 1964), landslides (Skempton *et al.*, 1989), dolomite tors (Ford, 1963), caves (Ford, 1977, 1986), outwash sheets (Johnson, 1967) and anomalous gorges (Ford and Burek, 1976) such as the Winnats Pass (Ford, 1987) and Derwent Gorge at Matlock (Ford, 1997), demonstrate the diversity of geomorphology in the Peak District. Useful summaries of the geomorphological history have been provided by Dalton *et al.* (1988; 1990; 1999).

Structure. The general structural pattern of the "Derbyshire Dome" and its subsidiary folds was known early in the 19th century with simple sketch maps produced by Farey (1811) and Watson (1811). The general wrench fault nature of the mineral veins was established later, but the structural history of the Peak District drew little early attention until Fearnsides' (1933) astute observations. From the fault pattern, he deduced the possibility that the Peak District limestones had been deposited on a block of buried Precambrian (Charnian) rocks and that this had been pushed northwestwards so that folds in the Millstone Grit country were bent round it, as around the prow of a ship. Fearnsides' compilation, however, combined different phases and types of folds and faults as though one single episode of tectonic movement was responsible.

The nature of the pre-Carboniferous basement below the limestone massif remained unknown until

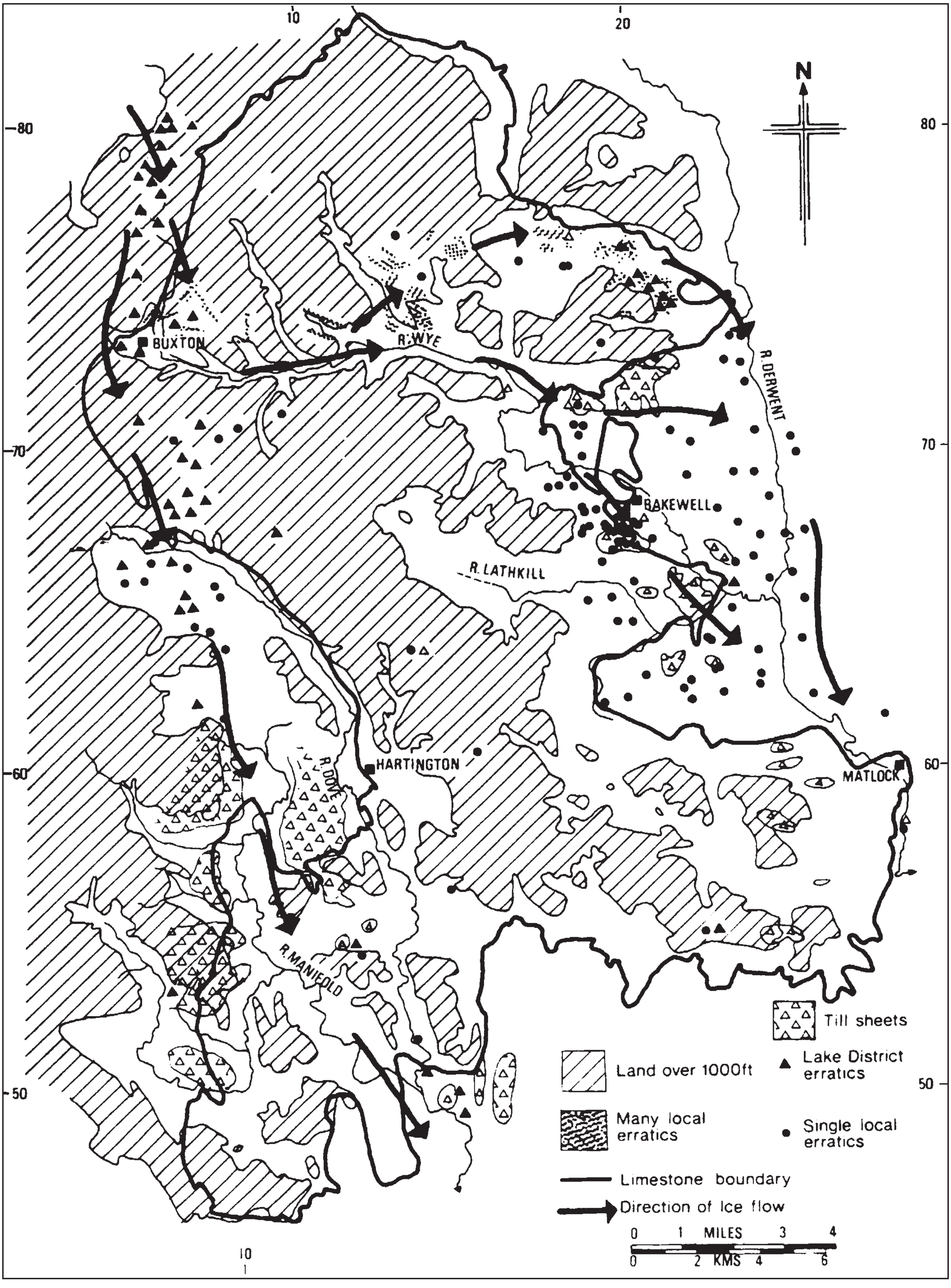

Fig. 14. Sketch-map of the distribution of glacial deposits, erractic boulders and suggested lines of ice flow (from Burek, 1977).

the Woodale borehole demonstrated a volcanic foundation only 273m down (Cope, 1949; 1973). The age of these volcanics is still uncertain. Cope (1979) reported a K/Ar date of 382±6Ma, i.e. Devonian, though this may reflect a Caledonian overprint on Precambrian (Charnian) or Ordovician volcanics (Webb and Brown, 1989). In contrast, the deep borehole at Eyam (Dunham, 1973) proved basement at more than 1600m, composed of Ordovician pelites. This indicated that the basement was not a northerly extension of the Precambrian rocks of Charnwood Forest. The thick sequence of carbonates in this borehole threw some doubt on the buried massif concept. No boreholes in the adjacent deep basins have proved basement. A borehole at Cauldon Low in the Weaver Hills of Staffordshire penetrated 170m of early Dinantian and possibly late Devonian sandstones beneath the carbonates (Aitkenhead and Chisholm, 1982). The borehole terminated at a depth of 535m, probably not far above the basement.

Geophysical studies of the sub-Carboniferous basement (Maroof, 1976; Rogers, 1983; Colman *et al.* in Plant and Jones, 1989) suggested that the basement is faulted and that the carbonates are draped over tilted fault blocks, thereby covering a series of half-grabens. The positions, trends, directions and amounts of throw on these buried faults remain controversial, with the faults downthrowing west according to Miller and Grayson (1982) or northeast according to Smith *et al.* (1985). Gutteridge (1987) agreed with the latter but proposed a rather more complex pattern of largely concealed listric faults (Fig. 15). The pattern of blocks and half-grabens was discussed further by Plant and Jones (1989). Some of the bounding faults appear to have become inactive during Dinantian times so that they have little or no expression in the higher beds. Others were reactivated as wrench faults by later movements and may also have been mineralized. Buried faults around the Derbyshire block comparable with the Craven Faults bounding the Askrigg Block to the north have not yet been demonstrated, though Gutteridge (1991) suggested that such basement faults outlined the northern end of the limestone massif. The results of oil company vibroseis traverses in the 1980s have largely remained confidential though may ultimately yield a solution if they are ever released into the public domain.

The Derbyshire block thus appears to be a local uplift within a much wider South Pennine basin which suffered inversion as a result of the Variscan compression at the end of the Carboniferous.

Within the orefield, the major veins or rakes are characterized by lateral movement and Firman's (1977) intriguingly titled paper on "Wrenches and Ores, the Rake's Progress" suggested how mineralized faults might have been propagated. However, analysis of mineral vein patterns indicates that the stress field changed intermittently through middle and late Carboniferous times, with both compressional and extensional phases operating with varying orientation (Fig. 16). These stress patterns evolved during episodic mineralization mainly in late Carboniferous times (Quirk, 1986; 1993).

The structure of the orefield was related to a much wider study of metallogenesis in Eastern England by Plant and Jones (1989). They extended the concept of the Widmerpool and Edale Gulfs bounding the Derbyshire Block, first proposed by Falcon and Kent (1960), to suggest that there were other blocks and basins beneath the East Midlands. Any or all of these basins could have held the Carboniferous mudstones that yielded the metals, fluorine, barium and sulphur ions necessary for mineralization during diagenesis and could thus represent a buried equivalent of the South Pennine Orefield.

The relationship of the different types of fault patterns in the White Peak, the adjoining Millstone Grit country and the coalfields to a history of changing stress regimes still awaits full analysis.

The burial history of the Peak District has given rise to some debate. Though formerly portrayed on some palaeogeographic maps as a series of islands, the South Pennines are now thought to have been covered by Jurassic and Cretaceous strata (Cope *et al.*, 1992), before being denuded again in Tertiary times.

Mineral Deposits and Mineralisation. The galena in the mineral veins of the Peak District (also known as the South Pennine Orefield) attracted attention from prehistoric times but its origin was considered a matter of divine provenance: indeed tithes were once claimed on the basis that ores regenerated in the same way as crops grew on the surface. The lead miners used elementary principles of geology as early as the 16th century in predicting the strata which would be penetrated in shafts and drainage levels (Rieuwerts, 1984) (Fig. 1). However, little appeared in print until the end of the 18th century when brief ideas on ore genesis were put forward. Whitehurst (1778) and Farey (1811) both argued that the ores had been concentrated from surrounding rocks, i.e. by some form of lateral secretion. White Watson elaborated on this a little in an unpublished lecture sheet, advocating origin of the mineral veins by volcanic effects.

After these early comments there was little written on ore genesis until the early 20th century when a consensus seemed to regard the Peak District mineral veins as being comparable with the Cornish veins and therefore fed from a concealed granite.

Mineral veins were long categorized by lead miners into four types: rakes (major fracture fills), scrins (minor fracture fills), flats (along the bedding), and pipes (cavity linings) (Fig. 17). The mineral veins themselves were catalogued by Farey (1811) with notes on their mineral content and on the stratigraphy of the host rocks, such as 1st lime, 2nd lime etc (Fig. 3). The early Geological Survey Memoirs (Green *et al.*, 1869, 1887) added some

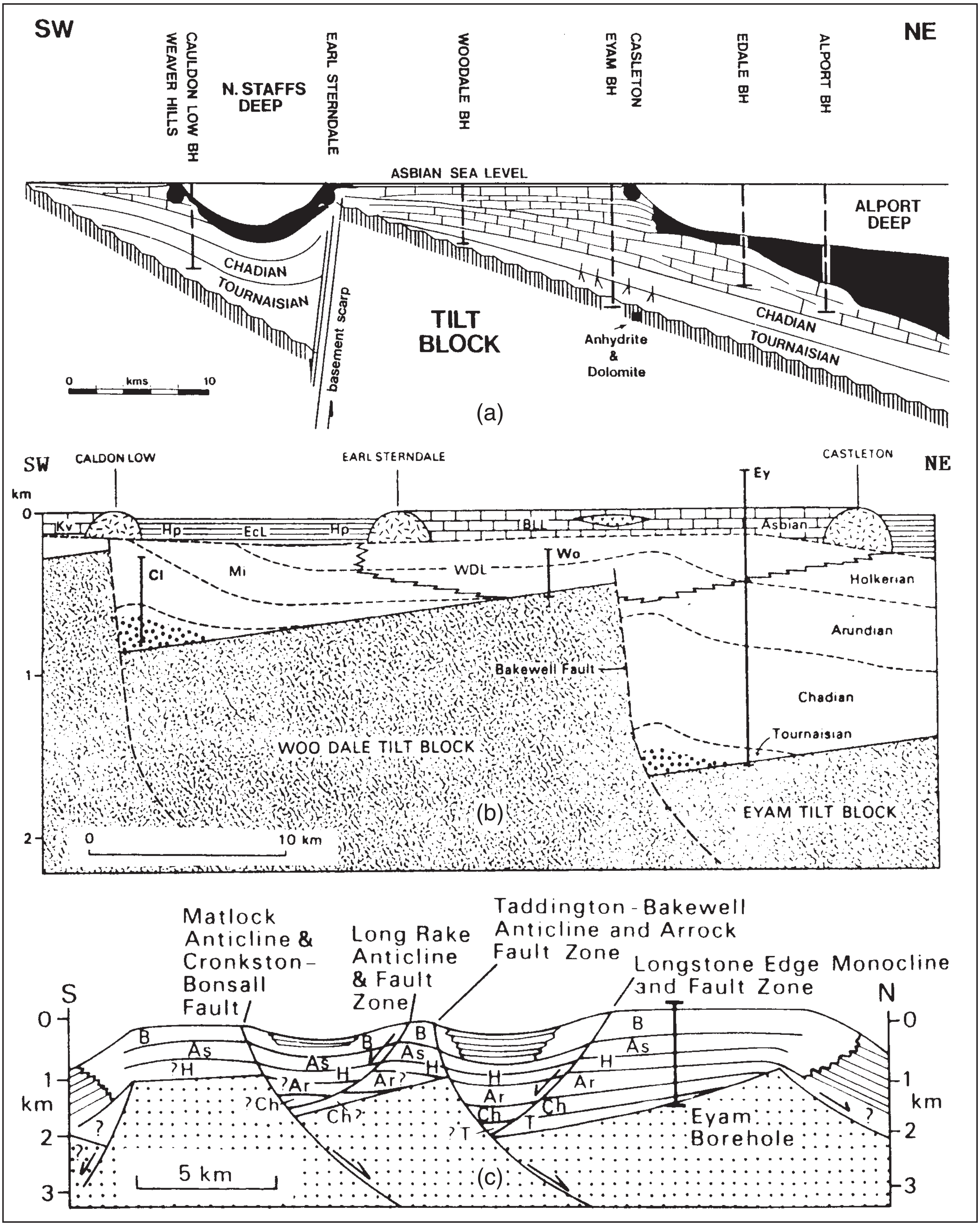

Fig. 15. Different interpretations of the basement structure beneath the Peak District:
a. single tilt-block and half-graben with a major fault system throwing down to the west (after Miller and Grayson, 1982);
b. two tilt-blocks and half-grabens with faults throwing down to the northeast (reproduced with permission from Smith *et al.*, 1985; © John Wiley & Sons Ltd.).
c. three tilt-blocks with half-grabens bounded by listric fault systems (reproduced with permission from Gutteridge 1987; © John Wiley & Sons, Ltd.).

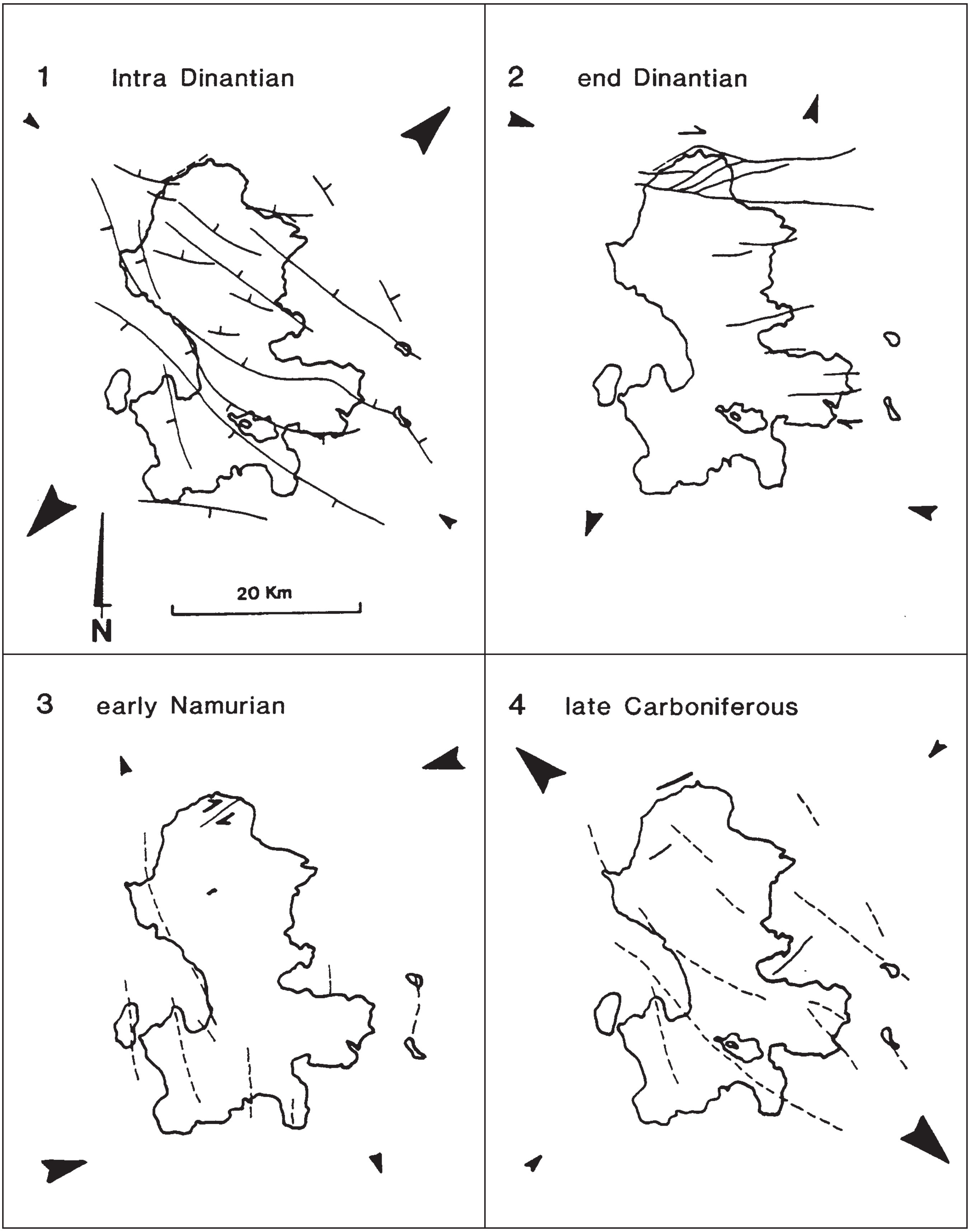

Fig. 16. Outline maps of the changing stress fields affecting the Peak District mineral deposits (after Quirk, 1993):
1. Intra-Dinantian NE-SW extension results in NW-SE faults above basement structures.
2. End-Dinantian: stress field rotates anticlockwise resulting in dextral wrench faults.
3. Early Namurian: stress field continues to rotate with some uplift and erosion, and the development of NNW-SSE faults.
4. Late Carboniferous: thermal subsidence with maximum extension NW-SE resulting in faulting along the same trend.

information on both individual mines and on production but said little on ore genesis. The Inspector of Mines, A. H. Stokes, provided a comprehensive survey of mineral deposits of economic potential (Stokes, 1879) and a map of the veins with an account of the history of mining and of the associated legal system (Stokes, 1880-83). However, he was writing during the declining years of the lead mining industry and it was not until the early 20th century that interest was renewed owing to the rise of the fluorspar industry (Wedd and Drabble, 1908). World War I brought new investigations of resources needed for the war effort and the rebuilding of industry afterwards. The Geological Survey published Special Reports on lead and zinc (Carruthers and Strahan, 1923), copper (Dewey and Eastwood, 1915), fluorspar (Carruthers and Pocock, 1916), barytes (Carruthers *et al.*, 1915), fireclay and other refractories (Howe, 1918; 1920). Though giving useful descriptions of the deposits, it is doubtful if these reports provided much stimulus to home production. None of the reports had much to say on genetic theories. World War II brought a more complete survey of baryte resources (Dunham and Dines, 1945) and, later, of fluorspar resources (Dunham, 1952). The fluorspar mining potential was reviewed again by Ford and Ineson (1971).

While the distribution of the mineral deposits was well-covered, little was written on the economics of exploitation and matters such as stratigraphical and structural relationships were left until later (Varvill, 1937; Traill, 1939; Dunham and Dines, 1945; Dunham, 1952). The Pb-Zn-F-Ba veins occupy a dominantly E-W wrench fault system and its off-shoots in the limestone massif. Local controls of the position of strata-bound orebodies are afforded by toadstone and tuff horizons with their limited permeability (Traill, 1939; Shirley, 1949). In spite of a widely-held belief that there was no ore in the toadstones, Walters and Ineson (1980) were able to list many such occurrences. The dominant minerals were shown to be zoned with fluorspar common in the east, baryte in the centre and calcite in the west (Dunham, 1952; Mueller, 1954a). Subsequent research (Firman, 1977; Quirk, 1986, 1993) has shown the distribution of gangue minerals to be considerably more complex owing to episodic, sometimes overlapping, phases of mineralization.

A summary map of the veins was compiled by Quirk (1993) (Fig. 18) as part of an analysis of the genesis of the orefield (Fig. 19). An accompanying anotated catalogue of nearly a hundred minerals was compiled by Ford *et al.* (1993).

A small, separate orefield dominated by copper minerals occurs at Ecton in the Manifold Valley and was worked as far back as Bronze Age times. Hosted in folded basinal limestones, the ore-pipes are vertical bodies said to be formed at the intersections

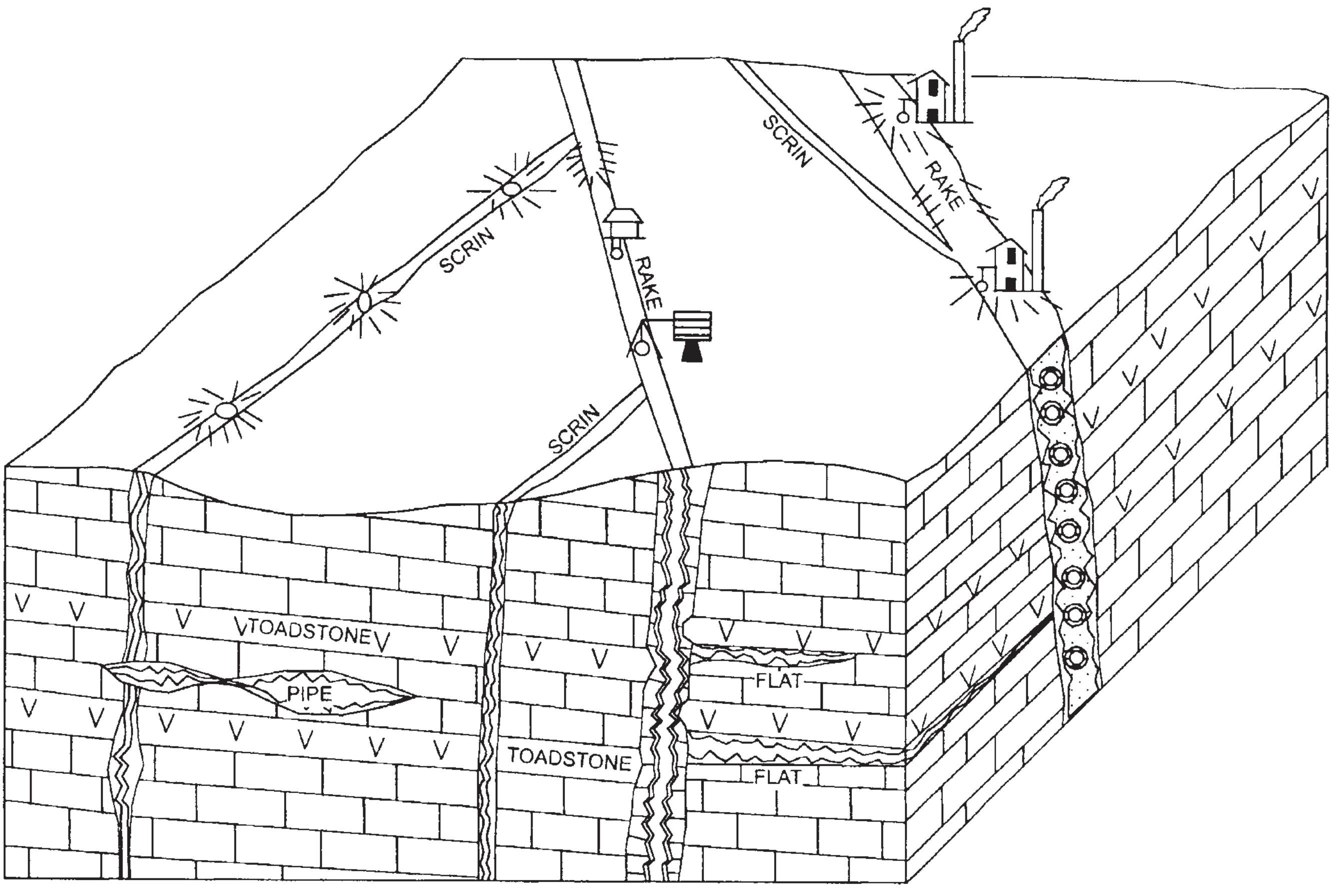

Fig. 17. Block diagram of the types of mineral vein in the Peak District: two rakes (one brecciated) have scrins branching from them: two flats underlie volcanic horizons: a pair of strata-bound pipe veins are cavities lined with minerals.

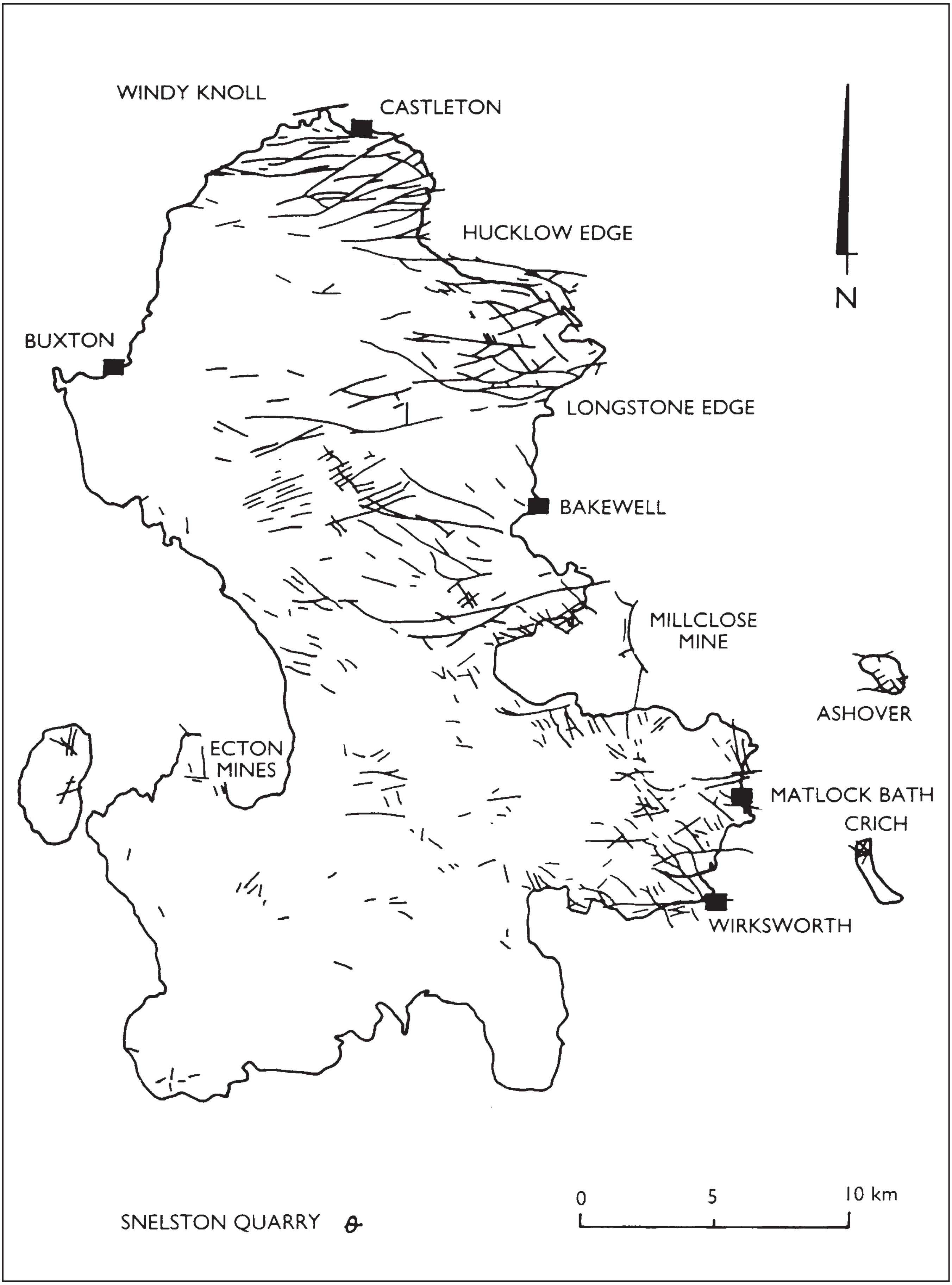

Fig. 18. Sketch-map of the principal mineral veins of the Peak District (from Quirk, 1993).

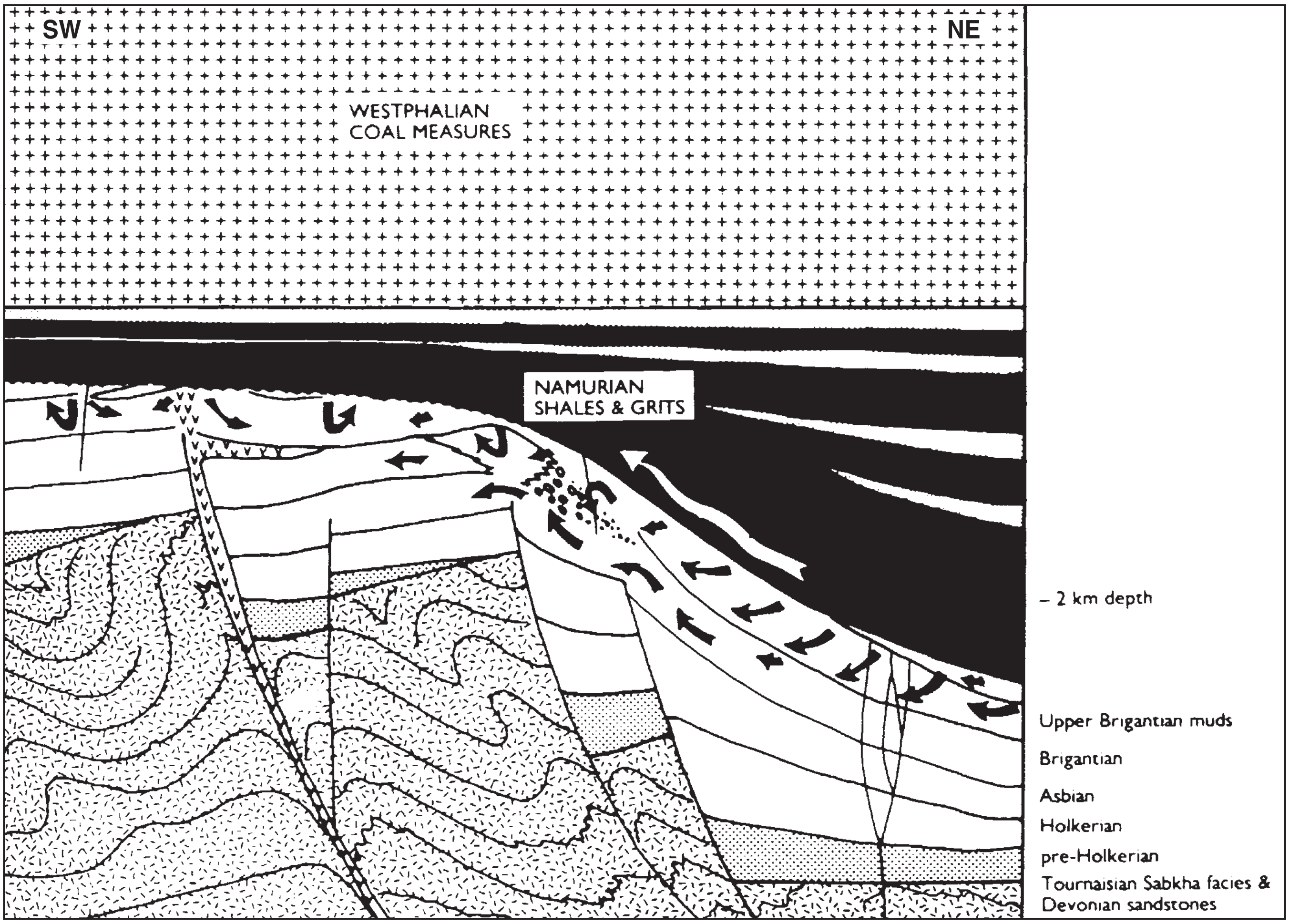

Fig. 19. Diagram of the fluid flow pattern resulting in mineralization (from Quirk, 1993).

of N-S and E-W veins (Critchley, 1979) though these are difficult to delineate. On the basis of fluid inclusion studies, Masheder and Rankin (1988) argued that the ores at Ecton had been derived from fluids expelled from the Cheshire Basin, in contrast with the rest of the South Pennine orefield, which had been sourced from the east.

A unique fluorite-baryte deposit alongside Dirtlow Rake, south of Castleton, was found to be hosted in a pre-Namurian palaeokarstic collapse structure (Butcher and Hedges, 1987).

Unusual pervasive mineralization was found in the only areas where Triassic sediments rested directly on Carboniferous Limestone, at Snelston and at Limestone Hill, near Ashbourne (Cornwell *et al.*, 1995). Although some mining of both lead and copper occurred the deposits were only of limited extent.

Dolomitization has affected the higher parts of the limestone sequence (Asbian-Brigantian) over about a quarter of the limestone outcrop (Parsons, 1922) though it is still uncertain whether it resulted from a phase of the mineralization process or to a former cover of Permian Magnesian Limestone. No evidence has yet been found to prove that the Magnesian Limestone was ever deposited over the limestone plateau (Cope *et al.*, 1992) though it is possible that there could have been a transgression westwards from the main Permian escarpment of east Derbyshire and Nottinghamshire. Projection westwards of the east Derbyshire scarp would take the Magnesian Limestone only a hundred metres or so above the White Peak's limestones. However, the Magnesian Limestone is late Permian in age and much of the mineralization was in place by the late Carboniferous which raises a chronological problem, adding weight to the hypothesis of dolomitization being an early phase of mineralization.

Dolomitization also affected older (Arundian-Holkerian) limestones in the Woodale and Eyam boreholes (Schofield and Adams, 1985; Dunham, 1973). This earlier phase of dolomitization probably resulted from restricted circulation in the lagoon in pre-Asbian times and is perhaps related to the anhydrites at the bottom of the limestone sequence in the Eyam borehole.

The dolomite resources were described during the Geological Survey's survey of limestone resources of the 1980s, summarized by Harrison and Adlam (1985). Once worked for refractory materials, dolomite is no longer exploited today. A commercial attempt to extract magnesium metal near Wirksworth in the 1960s proved uneconomic. Small amounts of manganese pigment materials, umber and wad, were once extracted from the dolomite areas (Stokes, 1879).

In post World War II years there was a marked change from hypotheses concerning a buried granite origin for Pennine orefields to sedimentary sources. Derivation of the ions from the host limestones during diagenesis was considered but did not find favour. Comparison with overseas orefields soon concentrated ideas onto sources in adjoining shale basins (Dunham, 1983; Ford, 1976; Quirk, 1986; 1993; Colman *et al.*, 1989; Plant and Jones, 1989; Ixer and Vaughan, 1993). Dunham (1983) viewed Pennine mineralization as a fluorine-rich variant of the Mississippi-Valley-type of mineralization. Dating of fault gouges by K/Ar methods (Ineson and Mitchell, 1972) showed that phases of mineralization probably ranged from late Carboniferous to late Triassic times, though the validity of the method later raised some doubts. Fluid inclusion studies indicated that the mineralizing fluids were highly saline with palaeo-temperatures indicating an easterly source with the zoning effected by westward fluid migration with falling temperatures (Dunham, 1952; Mueller, 1954a; 1954b). However, more recent work on fluid inclusions (Atkinson *et al.*, 1982; Masheder and Rankin, 1988; Quirk, 1993) has found more uniform palaeotemperatures across the orefield with little evidence of a thermal gradient. Discoveries of metasomatic fluorspar deposits west of the so-called fluorspar zone again indicate that the zoning hypothesis is too simplistic.

The consensus of opinion at present is that the South Pennine Orefield is a local variant of Mississippi-Valley-Type mineralization. The saline mineralizing fluids originated by expulsion from neighbouring Carboniferous shale basins, transported during the changing stress regimes of mid- to late Carboniferous times into the limestone high of the White Peak. Precipitation was effected by mixing with local oxygenated formation waters, by the oxidation of organic catalysts and by cooling. Fluid inclusions bearing hydrocarbons have been described by Moser *et al.* (1992) and their light hydrocarbon gases by Ferguson (1991). Hydrocarbons carrying uraniferous inclusions have been noted by Parnell (1988). Ewbank *et al.* (1995; 1996) have argued that there is evidence of three phases of fluid migration from the adjoining basins into the Peak District high; an early high temperature mineralizing fluid, and two later low temperature hydrocarbon-bearing fluids. The Ecton copper mineralization has been regarded as a slightly lower temperature variant with a different source (Masheder and Rankin, 1988). In the discussion of Ewbank *et al.* (1966), Quirk argued that the mineralizing and hydrocarbon phases may have been pene-contemporaneous. Hollis and Walkden (1996) have related mineralization to calcite cementation in the limestones; the sixth and last phase of cementation appears to have been contemporaneous with the main episode of mineralization and with late Carboniferous extensional tectonics at the onset of the Variscan orogeny.

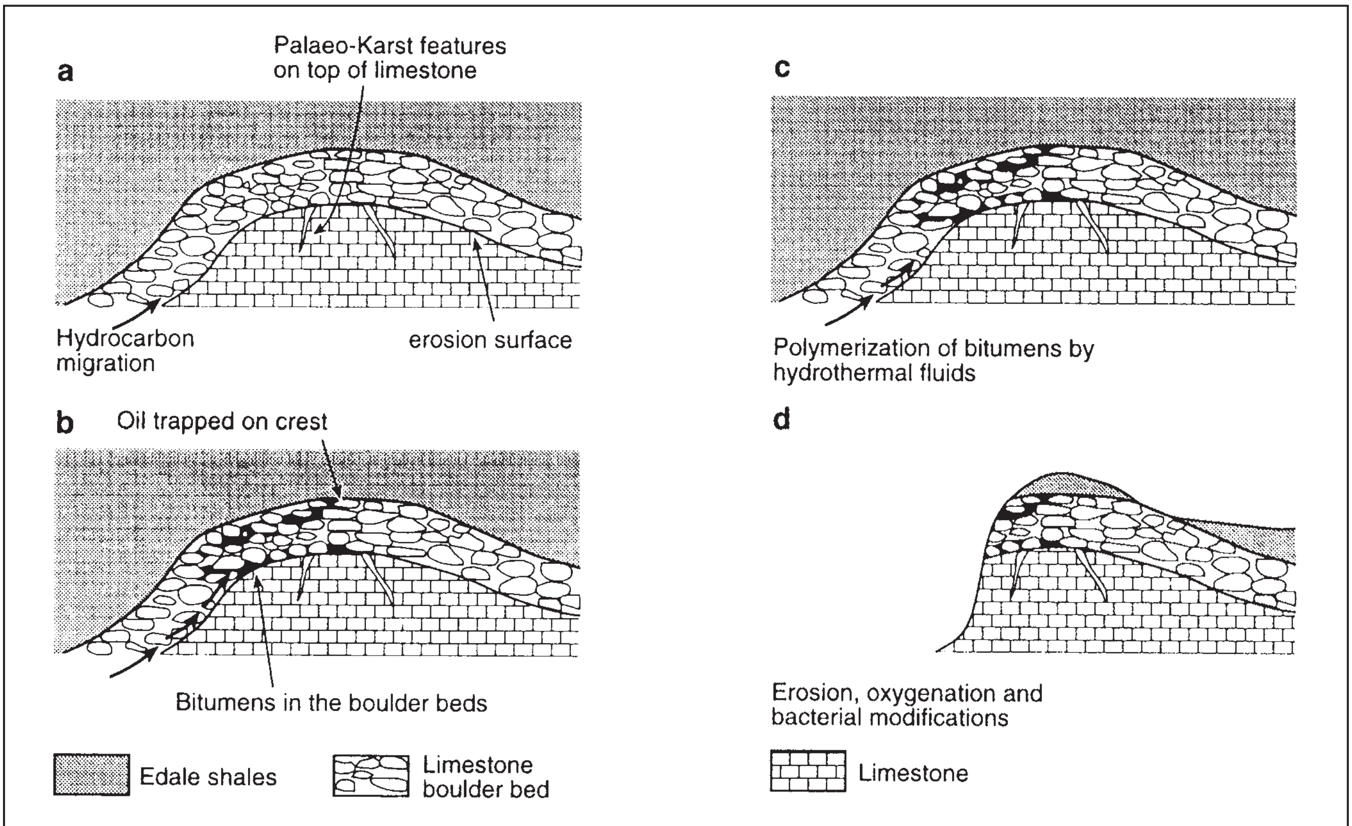

Fig. 20. The sequence of events in the development of the bitumen deposits at Windy Knoll, near Castleton (after Pering, 1973).

The cause of the colouring of the Blue John variety of fluorite found in Treak Cliff, near Castleton, has been the subject of much investigation, summarized in Ford *et al.* (1993). The colour was initially attributed to a small manganese content (Adam, 1843) but analysis failed to confirm this. Blount and Sequira (1919) and Mueller (1954a) argued that hydrocarbon inclusions were the cause, but Braithwaite *et al.* (1973) deduced that the colouring was mainly due to crystal dislocations induced by the radiation from uranium in surrounding rocks. Uranium is present in uraniferous collophane nodules near the limestone/shale contact (Peacock and Taylor, 1966), and has been absorbed within hydrocarbon inclusions in the Blue John fluorite crystals. The blue and white colour banding is thought to be due to the vagaries of changing flow rates and pressures through a complex plumbing system in voids in the pre-Namurian Boulder Bed, leading to a varying supply of uraniferous hydrocarbons (see also Ford, 2000).

The Bitumens of Windy Knoll. Though known since the 17th century, the bitumen (elaterite) deposits of Windy Knoll, near Castleton, were not studied in any detail until the early 1950s (Mueller, 1954b). He distinguished some 30 hydrocarbon "mineraloids" (listed in Ford *et al.*, 1993) and argued that their relationship to the hydrothermal mineral suite demonstrated that the heat of the mineralizing solutions had been enough to polymerize the original hydrocarbons. Subsequent fluid inclusion work (Atkinson *et al.*, 1982) threw doubt on Mueller's arguments. The space race in the 1960s attracted the attention of NASA to the possibility that the bitumens were abiogenic and thus representative of extra-terrestrial processes. However, NASA's investigations showed conclusively that the Windy Knoll bitumens are biogenic (Pering, 1973) (Fig. 20). In spite of more recent investigations by Xuemin *et al.* (1987), Parnell (1988), Moser *et al.* (1992) and Ewbank *et al.* (1995; 1996) the genesis of the Windy Knoll bitumens is still incompletely known and the part played by hydrocarbons in mineralization is still uncertain.

Radio-activity studies. A pre-war advertisement once alleged that the therapeutic properties of the Buxton themal springs was due to their radio-activity! No supporting evidence was presented.

The search for uranium resources in post-war years revealed its presence in trace proportions in Carboniferous sediments in Derbyshire, particularly in shale partings in the reef limestones of the Castleton area (Ponsford, 1955). Uranium was also found in Derbyshire's underground waters, with concentrations in the karstic waters of Russet Well at Castleton being close to those of the thermal springs at Buxton (Peacock, 1961). The source was thought to be uraniferous collophane clasts in Neptunean dykes in the pre-Namurian weathered limestone surface (Peacock and Taylor, 1966).

The gaseous daughter of uranium decay, radon, has been found in sufficient quantities to be a potential health hazard in several mines, caves and houses in the Castleton and Ashover areas (Ball *et al.*, 1992; Hyslop, 1993). In these areas, mineral veins and joints provided conduits for radon emanations originating from the upper limestones, particularly from uraniferous hydrocarbons in stylolites. Sediments washed into caves also yielded radon from uranium in transported material (Gunn *et al.*, 1991; Bottrell, 1993).

Economic Geology. Apart from limestone quarrying and the lead-zinc-fluorspar-baryte deposits noted above, many other materials have been exploited in the Peak District. These include chert, tufa, dolomite, calc-spar, "marble", copper and iron ores, gritstone, refractory clays and sands, brick clays, umber and wad. Site investigations and constructional materials for dams, assessments of underground water resources and the abortive search for oil have also been important. Each has contributed in its own way to geological knowledge in the Peak District but a comprehensive review is beyond the scope of this paper.

Conclusions

Whilst not exhaustive, this review of the state of knowledge of the Peak District's geology should provide future researchers with a background for their studies. It also clarifies where research and/or publication are still deficient. Future research or data acquisition is needed in several areas.

1. Much more needs to be known about the basement beneath the Peak District. It is to be hoped that some unpublished geophysical studies will see the light of day soon.
2. The details of the formation of many of the mud-mounds are still imperfectly understood, particularly the marginal reefs of the Castleton and upper Dovedale areas.
3. An atlas of Carboniferous fossils is desirable at least as a teaching aid.
4. There is as yet no full catalogue of the mineral veins and their minerals comparable with those published for the North Pennines and Cornwall.
5. The structural history in relation to basin inversion and the formation of the mineral veins is still imperfectly known.
6. In spite of research on the bitumens of Windy Knoll, there is still no complete analysis of what hydrocarbons are present or of their genesis.
7. The denudation chronology in relation to one, two or even three glacial advances is far from clear and correlation with other areas is uncertain.
8. Many cave deposits await the application of modern dating techniques, and promising cave sites such as Peak Cavern entrance remain unexcavated.

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References

Adam, W., 1843. *Gem of the Peak*. 5th edition, Mozeley, Derby. reprinted with biographical introduction by T. D. Ford, Moorland, Hartington, 1973, 406pp.

Adams, A. E. and Cossey, P. J., 1978. Geological history and significance of a laminated and slumped unit in the Carboniferous Limestone of the Monsal Dale region, Derbyshire. *Geological Journal*, **13**, 47-60.

Aitkenhead, N. and Chisholm, J. I., 1982. A standard nomenclature for the Dinantian Formations of the Peak District of Derbyshire and Staffordshire. *Report of the Institute of Geological Sciences*, **82/8**, 17pp.

Aitkenhead, N., Chisholm, J. I. and Stevenson, I. P., 1985. Geology of the Country around Buxton, Leek and Bakewell. *Memoir of the British Geological Survey*, Sheet 111, 168pp.

Allen, J. R. L., 1960. The Mam Tor Sandstones — a turbidite facies of the Namurian deltas of Derbyshire. *Journal of Sedimentary Petrology*, **30**, 193-208.

Allport, S., 1874. On the microscopic structure and composition of British Carboniferous dolerites. *Quarterly Journal of the Geological Society*, **30**, 529-567.

Atkinson, P., Moore, J. McM. and Evans, A. M., 1982. The Pennine Orefields of England with special reference to recent structural and fluid inclusion investigations. *Bulletin du Bureau Recherches Geologiques et Minieres*, Section II, no.2, 149-156.

Ball, T. K., Cameron, D. G. and Colman, T. B., 1992. Aspects of radon potential mapping in Britain. *Radiation Protection Dosimetry*, **45** (1/4), 211-214.

Bemrose, H. H. Arnold., 1894. The microscopical structure of the Carboniferous dolerites and tuffs of Derbyshire. *Quarterly Journal of the Geological Society, London*, **50**, 603-644.

Bemrose, H. H. Arnold., 1907. The toadstones of Derbyshire, their field relations and petrography. *Quarterly Journal of the Geological Society, London*, **63**, 241-281.

Bemrose, H. H. Arnold, 1910a. The Lower Carboniferous rocks of Derbyshire. *In: Geology in the Field*, Geologists Association, London, 540-563.

Bemrose, H. H. Arnold, 1910b. On the olivine nodules in the basalt of Calton Hill. *Geological Magazine*, Dec.5, Vol.7, 1-4.

Bisat, W., 1924. The Carboniferous Goniatites of the North of England and their zones. *Proceedings of the Yorkshire Geological Society*, **20**, 40-124.

Blount, B. and Sequira, J. A., 1919. Blue John and other forms of fluorite. *Journal and Transactions of the Chemical Society*, **115**, 705-709.

Bottrell, S. H., 1993. Redistribution of uranium by physical processes during weathering and implications for radon production. *Environmental Geochemistry and Health*, **15**, 21-25.

Boulter, M. C., 1971. A survey of the Neogene flora from two Derbyshire pocket deposits. *Mercian Geologist*, **4**, 45-61.

Bowering, G. and Flindall, R., 1998. A history of the Derbyshire chert industry. *Mining History*, **13**(5) 1-31.

Brady, H. B., 1876. *Carboniferous and Permian Foraminifera*. Palaeontological Society Monograph. 12 plates.

Braithwaite, R. S. W., Flowers, W. T., Haszeldine, R. N. and Russell, M., 1973. The cause of the colour of Blue John and other purple fluorites. *Mineralogical Magazine*, **39**, 401-411.

Bridge, D. McC. and Gozzard, J. R., 1981. The limestone and dolomite resources of the country around Bakewell. *Mineral Assessment Report of the Institute of Geological Sciences*, **79**, 64pp.

Bridge, D. McC. and Kneebone, D. S., 1983. The limestone and dolomite resources of the country north and west of Ashbourne, Derbyshire. *Mineral Assessment Report of the Institute of Geological Sciences*, **129**, 78pp.

Bridges, P. H., 1982. The origin of the cyclothems in the late Dinantian platform carbonates at Crich, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **44**, 159-180.

Bridges, P. H. and Chapman, A. J., 1988. The anatomy of a deep-water mud-mound complex to the southwest of the Dinantian platform in Derbyshire. *Sedimentology*, **35**, 135-162.

Bridges, P. H., Gutteridge, P. and Pickard, N. A. H., 1995. The environmental setting of early Carboniferous mud-mounds. *In* Monty, C. L., Bosence, D. W. J., Bridges, P. H. and Pratt, B. R., Carbonate mud-mounds, their origin and evolution. *International Association of Sedimentologists Special Publication*, **23**, 171-190.

Broadhurst, F. M. and Simpson, I. M., 1973. Bathymetry on a Carboniferous reef. *Lethaia*, **6**, 367-381.

Brown, E., 1867. The Weaver Clays. *Geological Magazine*, **IV**, 381-382.

Buckland, W., 1823. *Reliquae Diluvianae*. Oxford, 278pp. 2nd edition 1824.

Burek, C. V., 1977. The Pleistocene Ice age and after. *In* Ford, T. D., *Limestones and Caves of the Peak District*, Geobooks, Norwich, 87-128.

Burek, C. V., 1991. Quaternary History and Glacial deposits of the Peak District. *In* Ehlers, J., Gibbard, P. L. and Rose, J., *Glacial Deposits in Great Britain and Ireland*, Balkema, Rotterdam, 193-201.

Butcher, N. J. D. and Ford, T. D., 1973. The Carboniferous Limestone of Monsal Dale, Derbyshire. *Mercian Geologist*, **4**, 179-195.

Butcher, N. J. D. and Hedges, J. D., 1987. Exploration and extraction of structurally and lithostratigraphically controlled fluorite deposits in the Castleton-Bradwell area of Southern Pennine Orefield, England. *Transactions of the Institution of Mining and Metallurgy*, **B96**, B149-155.

Carruthers, R. G., Eastwood, T., Wilson, G. V., Pocock, R. W., Wray, D. A. and Robertson, T., 1915. *Barytes and Witherite*. Geological Survey Special Report on Mineral Resources, **2**, 93pp.

Carruthers, R. G. and Pocock, R. W., 1916. Fluorspar. *Geological Survey Special Report on Mineral Resources*, **4**, 42pp.

Carruthers, R. G. and Strahan, A., 1923. Lead and zinc ores of Durham, Yorkshire, Derbyshire and the Isle of Man. *Geological Survey Special Report on Mineral Resources*, **26**, 114pp.

Challinor, J., 1949-1951. North Staffordshire Geology, 1811-1948. *Transactions of the North Staffordshire Field Club*, **83**, A1-A26, A27-A48; **85**, A49-64.

Chisholm, J. I., 1977. Growth faulting and sandstone deposition in the Namurian of the Stanton syncline, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **41**, 305-323.

Chisholm, J. I., Mitchell, M., Strank, A. E., Cox, F. C. and Harrison, D. J., 1983. A revision of the stratigraphy of the Asbian and Brigantian limestones of the area west of Matlock. *Institute of Geological Sciences Report*, **83/10**, 17-24.

Chisholm, J. I., Charsley, T. J. and Aitkenhead, N., 1988. Geology of the Country around Ashbourne and Cheadle. *Memoir of the British Geological Survey*, Sheet 124, 160pp.

Colman, T. B., Ford, T. D. and Laffoley, N. d'A., 1989. Metallogeny of Pennine Orefields. *In* Plant, J. A. and Jones, D. G. q.v., 12-23.

Collinson, J. D., 1968. Deltaic sedimentation units in the Upper Carboniferous of Northern England. *Sedimentology*, **10**, 233-254.

Collinson, J. D., 1969. The sedimentology of the Grindslow Shales and Kinderscout Grit: a deltaic complex in the Namurian of Northern England. *Journal of Sedimentary Petrology*, **39**, 194-221.

Cope, F. W., 1933. A tholeiite dyke near Buxton, Derbyshire. *Geological Magazine*, **70**, 414-422.

Cope, F. W., 1933. The Lower Carboniferous Succession in the Wye Valley region of North Derbyshire. *Journal of the Manchester Geological Association*, **1**, 125-145.

Cope, F. W., 1939. The mid-Visean (S_2-D_1) succession in North Derbyshire and Northwest England. *Proceedings of the Yorkshire Geological Society*, **24**, 60-66.

Cope, F. W., 1949. The Woodale Borehole, near Buxton. *Abstracts and Proceedings of the Geological Society*, no.1446, 24, and *Quarterly Journal of the Geological Society, London*, **105**, iv.

Cope, F. W., 1973. The Woodale Borehole near Buxton, Derbyshire. *Nature*, London, **243**, 29-30.

Cope, F. W., 1979. The age of the volcanic rocks in the Woodale borehole, Derbyshire. *Geological Magazine*, **116**, 319-320.

Cope, F. W., 1997. An igneous dyke complex in the Carboniferous Limestone of North Derbyshire and its significance. *Proceedings of the Yorkshire Geological Society*, **51**, 245-249.

Cope, J. C. W., Ingham, J. K. and Rawson, P. F., 1992. *Atlas of Palaeogeography and Lithofacies*. Geological Society Memoir 13, 106pp.

Cornwell, J. D., Busby, J. P., Colman, T. B. and Norton, G. E., 1995. Exploration for carbonate-hosted base-metal mineralization near Ashbourne, Derbyshire. *British Geological Survey Mineral Reconnaissance Programme Report*, **139**, 57pp.

Cox, F. C. and Bridge, D. McC., 1977. The limestone and dolomite resources of the country around Monyash. *Mineral Assessment Report of the Institute of Geological Sciences*, **26**, 138pp.

Cox, F. C. and Harrison, D. J., 1980. The limestone and dolomite resources of the country around Wirksworth. *Mineral Assessment Report of the Institute of Geological Sciences*, **47**, 137pp.

Craven, M., 1996. *John Whitehurst of Derby: clockmaker and scientist 1713-1788*. Mayfield Books, Ashbourne, 272pp.

Critchley, M. F., 1979. Geological outline of the Ecton copper mine, Staffordshire. *Bulletin of the Peak District Mines Historical Society*, **7**, 177-191.

Dalton, R., Fox, H. and Jones, P., 1988. *Classic Landforms of the White Peak*. Classic Landforms Guide No. 9, Geographical Association, Sheffield, 48pp. (revised edition 1999).

Dalton, R., Fox, H. and Jones, P., 1990. *Classic Landforms of the Dark Peak*. Classic Landforms Guide No. 11, Geographical Association, Sheffield, 48pp. (revised edition 1999).

Davidson, T., 1858-1863. The fossil Brachiopoda — Carboniferous. *Palaeontographical Society Monograph*, **2**, (5), 48pp & 8 pls. (Supplement in 1880).

Dawkins, W. Boyd, 1874. *Cave Hunting*. London, 455pp.

Dawkins, W. Boyd, 1875. The Mammalia found at Windy Knoll. *Quarterly Journal of the Geological Society, London*, **31**, 246.

Dawkins, W. Boyd, 1903. On the discovery of an ossiferous cavern of Pliocene age at Dove Holes, Buxton, Derbyshire. *Quarterly Journal of the Geological Society*, **59**, 105-132.

Dawkins, W. B. and Pennington, R., 1877. The exploration of the ossiferous deposit at Windy Knoll, Castleton, Derbyshire. *Quarterly Journal of the Geological Society, London*, **33**, 724-729.

Dewey, H. and Eastwood, T., 1915. Copper ores of the Midlands, Lake District and the Isle of Man. *Geological Survey Special Reports on Mineral Resources*, **30**, 87pp.

Downing, R. A., 1967. The geochemistry of the groundwaters in the Carboniferous Limestone of Derbyshire and the East Midlands. *Bulletin of the Geological Survey*, **27**, 289-307.

Dunham, K. C., 1952. Fluorspar. *Geological Survey Special Report on Mineral Resources*, **4**, 4th edition, 143pp.

Dunham, K. C., 1973. A recent deep borehole at Eyam, Derbyshire. *Nature, Physical Science*, **241**, 84-85.

Dunham, K. C., 1983. Ore genesis in the English Pennines: A Fluorite sub-type. *In* Kisvarsanji *et al*., (Eds.) *International Conference on Mississippi-Valley-Type Lead-Zinc Deposits*. Rolla, Missouri. 86-112.

Dunham, K. C. and Dines, H. G., 1945. Barium minerals in England and Wales. *Geological Survey Wartime Pamphlet*, **46**, 150pp.

Eden, R. A., Orme, G. R., Mitchell, M. and Shirley, J., 1964. A study of part of the margin of the Carboniferous Limestone massif in the Pindale area of Derbyshire. *Bulletin of the Geological Survey of Great Britain*, **21**, 73-118.

Eden, R. A., Stevenson, I. P. and Edwards, W., 1957. Geology of the Country around Sheffield. *Memoir of the Geological Survey*, Sheet 100, 238pp.

Edmunds, W. M., 1971. Hydrogeochemistry of groundwaters in the Derbyshire Dome with special reference to trace constituents. *Institute of Geological Sciences Report*, **71/7**. 52pp.

Ewbank, G., Manning, D. A. C. and Abbott, G. D., 1995. The relationship between bitumens and mineralization in the South Pennines Orefield, central England. *Journal of the Geological Society, London*, **152**, 751-765. Discussion in vol. 153, 653-656 (1996).

Falcon, N. L. and Kent, P. E., 1960. Geological results of petroleum exploration in Britain 1945-1957. *Geological Society of London*, Memoir 2, 56pp.

Farey, J., 1811. *General View of the Agriculture and Minerals of Derbyshire*. Vol. 1. Board of Agriculture, London, 532pp.

Fearnsides, W. G., 1932. The Geology of the Eastern part of the Peak District. *Proceedings of the Geologists' Association*, **43**, 152-191.

Fearnsides, W. G., 1933. A correlation of structures in the coalfields of the Midland Province. *Report of the British Association (Sheffield)*, 57-80.

Fearnsides, W. G. and Templeman, A., 1932. A boring through Edale Shales to Carboniferous Limestone and pillow lavas at Hope Cement Works near Castleton, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **22**, 100-121.

Ferguson, J. 1991. The organic geochemistry of hydrocarbon gases in fluorites from Northern England. *Journal of Petroleum Geology*, **14**, 221-228.

Firman, R. 1977. Derbyshire Wrenches and Ores — a study of the Rake's Progress by Secondary Faulting. *Mercian Geologist*, **6**, 81-96.

Ford, T. D., 1960. White Watson (1760-1835) and his geological sections. Proceedings of the Geologists' Association, **71**, 349-363. (Reprinted as the Introduction to the 1973 reprint edition of Watson's Delineation, by Moorland, Ashbourne).

Ford, T. D., 1963. The Dolomite Tors of Derbyshire. *East Midlands' Geographer*, **3**, (19), 148-153.

Ford, T. D., 1967. The first detailed geological sections across England, 1806-1808. *Mercian Geologist*, **2**, 41-49.

Ford T. D., 1972. Supplement to the Bibliography of the Peak District of Derbyshire (to 1970). *Mercian Geologist*, **4**, (2) 109-137.

Ford, T. D., 1976. The ores of the South Pennines and Mendip Hills, England — a comparative study. *In* Wolf, K. H. (Ed.) *Handbook of Stratabound and Stratiform Ore Deposits* Vol. 5, Elsevier, Amsterdam, 161-195.

Ford, T. D., 1977. *Limestones and Caves of the Peak District*. Geo-Books, Norwich. 469pp.

Ford, T. D., 1986. The Evolution of the Castleton Cave Systems, Derbyshire. *Cave Science*, **13**, 131-148.

Ford, T. D., 1987. The origin of the Winnats Pass, Castleton, Derbyshire. *Mercian Geologist*, **10**, 241-249.

Ford, T. D., 1995. White Watson (1769-1835) and his Geological Tablets. *Mercian Geologist*, **13**, 157-164.

Ford, T. D., 1996. *The Castleton area*. Geologists' Association Guide 56. 94pp.

Ford, T. D., 1997. The development of the Derwent Gorge and its caves at Matlock, Derbyshire: a review. *Cave and Karst Science*, **24**, 5-19.

Ford, T. D., 2000. *Derbyshire Blue John*. Ashbourne Editions, Ashbourne, 112pp.

Ford, T. D. and Burek, C. V., 1976. Anomalous limestone gorges in Derbyshire. *Mercian Geologist*, **6**, 59-66.

Ford, T. D., Gascoyne, M. and Beck, J. S., 1983. Speleothem dates and Pleistocene chronology in the Peak District. *Cave Science*, **10**, 103-115.

Ford, T. D. and Ineson, P. R., 1971. The fluorspar mining potential of the Derbyshire orefield. *Transactions of the Institution of Mining and Metallurgy*, Section B: **80**, 186-210. Discussion in vol. 81, 103-106.

Ford, T. D. and Mason, M. H., 1967. Bibliography of the Geology of the Peak District of Derbyshire to 1965. *Mercian Geologist*, **2**, (2), 133-244.

Ford, T. D., Sarjeant, W. A. S. and Smith, M. E., 1993. Minerals of the Peak District of Derbyshire. *Bulletin of the Peak District Mines Historical Society*, **12**, (1), 16-55.

Ford, T. D. and Torrens, H. S., 1989. *John Farey (1766-1826): an unrecognized polymath*. 42pp. Biographical Introduction to the reprint edition of Farey's "General View . . ." (q.v.) published by Peak District Mines Historical Society.

Gatliff, R. W., 1982. The limestone and dolomite resources of the country around Tideswell. *Mineral Assessment Report of the Institute of Geological Sciences*, **98**, 84pp.

Gawthorpe, R. L. and Gutteridge, P., 1990. Geometry and evolution of platform margin bioclastic shoals, late Dinantian (Mississippian) Derbyshire. *In* Tucker, M. E., Wilson, J. L., Grevello, P. D., Sarg, J. R. and Read, J. F. (Eds.), Carbonate platforms, facies, sequences and evolution. *International Association of Sedimentologists Special Publication 9*. Blackwell, Oxford, 30-54.

George, T. N., 1972. The classification of Avonian limestones. *Journal of the Geological Society, London*, **128**, 221-256.

George, T. N. *et al*., 1976. A correlation of the Dinantian rocks of the British Isles. *Geological Society Special Report*, **7**, 87pp.

Gilligan, A., 1919. The petrography of the Millstone Grit of Yorkshire. *Quarterly Journal of the Geological Society*, **75**, 251-294.
Green, A. H., Foster, C. le Neve, and Dakyns, J. R., 1869. The Carboniferous Limestone, Yoredale Rocks and Millstone Grit of North Derbyshire. Memoir of the Geological Survey. 212pp. (2nd edition 1887).
Greg, R. P. and Lettsom, W. G., 1858. *Manual of Mineralogy of Great Britain and Ireland*. London, 483pp.
Gunn, J., Fletcher, S. and Prime, D., 1991. Research on radon in British caves and mines, 1970-1990. *Cave Science*, **18**, 63-82.
Gutteridge, P., 1987. Dinantian sedimentation and the basement structure of the Derbyshire Dome. *Geological Journal*, **22**, 25-41.
Gutteridge, P., 1989. Controls on carbonate sedimentation in a Brigantian intrashelf basin, Derbyshire. *In* Arthurton, R. S., Gutteridge, P. and Nolan, S. C. (Eds), *The Role of Tectonics in Devonian and Carboniferous sedimentation in the British Isles*. Yorkshire Geological Society Occasional Publications 6, 171-187.
Gutteridge, P., 1990. The origin and significance of the distribution of shelly macrofauna in late Dinantian carbonate mud-mounds of Derbyshire. *Proceedings of the Yorkshire Geological Society*, **48**, 23-32.
Gutteridge, P., 1991. Aspects of Dinantian sedimentation in the Edale basin, north Derbyshire. *Geological Journal*, **26**, 245-269.
Gutteridge, P., 1995. Late Dinantian (Britantian) carbonate mud-mounds of the Derbyshire carbonate platform. *In* Monty, C. L., Bosence, D. W. J., Bridges, P. H. and Pratt B., Carbonate Mud-mounds; their origin and evolution. *International Association of Sedimentologists Special Publication 23*, 298-307.
Hamad, S. el D., 1963. The chemistry and mineralogy of the olivine nodules of Calton Hill, Derbyshire. *Mineralogical Magazine*, **33**, 483-497.
Hampson, G., 1997. A sequence stratigraphic model for deposition of the Lower Kinderscout Delta, an Upper Carboniferous turbidite-fronted delta. *Proceedings of the Yorkshire Geological Society*, **51**, 273-296.
Harrison, D. J., 1981. The limestone and dolomite resources of the country around Buxton. *Mineral Assessment Report of the Institute of Geological Science*, **77**, 108pp.
Harrison, D. J. and Adlam, K. M. McL., 1985. The limestone and dolomite resources of the Peak District of Derbyshire and Staffordshire. *Mineral Assessment Report of the Institute of Geological Sciences*, **144**, 48pp.
Hind, W., 1897. On the subdivisions of the Carboniferous Series in Great Britain and the true position of the beds mapped as the Yoredale Series. *Geological Magazine*, Decade 4, **4**, 159-169 and 205-213.
Hind, W., 1898. The correlation of the British and European Carboniferous Beds. *Transactions of the Manchester Geological Society*, **26**, 96-118.
Holdsworth, B. K., 1963. Pre-fluvial autogeosynclinal sedimentation in the Namurian of the southern Central Province. *Nature*, **199**, 133-135.
Holdsworth, B. K. and Collinson, J. D., 1988. Millstone Grit cyclicity revisited. 132-152. *In* Besley, B. A. and Kelling, G. (Eds), *Sedimentation in a Synorogenic Basin Complex: the Upper Carboniferous of Western Europe*. Blackie, Glasgow, 132-152.
Hollis, C. and Walkden, G. M., 1996. The use of burial diagenetic calcite cements to determine the controls upon hydrocarbon emplacement and mineralization on a carbonate platform, Derbyshire, England. *In* Stroben, P., Somerville, I. D. and Jones, G. L. (Eds.), *Recent Advances in Lower Carboniferous Geology*. Geological Society of London Special Publication **107**, 35-49.
Hopkins, W., 1834. *On the stratification of the limestone district of Derbyshire*. Private Publication, Cambridge. 47pp.
Howe, J. A., 1897. Notes on the pockets of sand and clay in the limestone of Derbyshire and Staffordshire. *Transactions of the North Staffordshire Field Club*, **31**, 143-149.
Howe, J. A., 1918. Refractory Materials: Ganister and Silica Rock. *Geological Survey Special Reports on Mineral Resources*, **6**, 241pp. (2nd edition in 1920).
Howe, J. A., 1920. Refractory Materials: Fireclays. *Geological Survey Special Reports on Mineral Resources*, **14**, 243pp.
Hudson, R. G. S., 1931. The Pre-Namurian knoll topography of Derbyshire and Yorkshire. *Transactions of the Leeds Geological Association*, **5**, 49-64.
Hudson, R. G. S. and Cotton, G. 1945a. The Carboniferous Rocks of the Edale anticline, Derbyshire. *Quarterly Journal of the Geological Society, London*, **101**, 1-36.
Hudson, R. G. S. and Cotton, G., 1945b. The Lower Carboniferous in a boring at Alport, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **25**, 254-330, (appendix on Gun Hill, Staffs.).
Hyslop, E. K., 1993. Uranium distribution studies of potential radon source rocks from the Ashover area, Derbyshire. *British Geological Survey Technical Report*, WG/93/4, 36pp.
Ineson, P. R. and Mitchell, J. G. 1972. Isotopic age determinations on clay minerals from lavas and tuffs of the Derbyshire orefield. *Geological Magazine*, **109**, 501-512.
Ixer, R. A. and Vaughan, D. J., 1993. Lead-zinc-fluorite-baryte deposits of the Pennines, North Wales and the Mendips. *In* Pattrick, R. A. D. and Polya, D. A. (Eds.), *Mineralization in the British Isles*. Chapman & Hall, London, 355-418.
Jackson, J. W., 1925. The relation of the Edale Shales to the Carboniferous Limestone in North Derbyshire. *Geological Magazine*, **62**, 267-274.
Jackson, J. W., 1926. The goniatite zones below the Kinderscout Grit in North Derbyshire. *Naturalist*, 205-207.
Jackson, J. W., 1927. The succession below the Kinderscout Grit in North Derbyshire. *Journal of the Manchester Geological Association*, **1**, 15-32.
Johnson, R. H., 1967. Some glacial, periglacial and karstic landforms in the Sparrowpit-Doveholes area of north Derbyshire. *East Midland Geographer*, **4**, 224-238.
Johnson, R. H. and Rice, R. J., 1961. Denudation chronology of the Southwest Pennine Upland. *Proceedings of the Geologists' Association*, **72**, 21-31.
Jones, C. M., 1980. Deltaic sedimentation in the Roaches Grit and associated sediments (Namurian R_{2b}) in the Southwest Pennines. *Proceedings of the Yorkshire Geological Society*, **43**, 39-67.
Jones, C. M. and Chisholm, J. I., 1997. The Roaches and Ashover Grits: sequence stratigraphic interpretation of a turbidite-fronted delta system. *Geological Journal*, **32**, 45-62.
Jones, T. R., Kirkby, J. W. and Brady, G. S. 1875. *A monograph of the British Fossil Bivalved Entomostraca from the Carboniferous Formations*. Palaeontographical Society Monograph. 7 plates.
Jowett, A. and Charlesworth, J. K., 1929. The glacial geology of the Derbyshire Dome and the western slopes of the South Pennines. *Quarterly Journal of the Geological Society, London*, **85**, 307-344.
Kent, P. E., 1957. Triassic relics and the 1000ft surface in the Southern Pennines. *East Midland Geographer*, **12**, (8), 3-10.
Ludford, A., 1951. Stratigraphy of the Carboniferous rocks of the Weaver Hills district, North Staffordshire. *Quarterly Journal of the Geological Society, London*, **106**, 211-230.
Macdonald, R., Gass, K. N., Thorpe, R. S. and Gass, I. G., 1984. Geochemistry and petrogenesis of the Derbyshire Carboniferous Basalts. *Journal of the Geological Society of London*, **141**, 147-159.
Maroof, S. I., 1976. The structure of the concealed pre-Carboniferous basement of the Derbyshire Dome from gravity data. *Proceedings of the Yorkshire Geological Society*, **41**, 59-69.
Martin, W., 1810. *Petrificata Derbiensa*. Wigan. 29pp.
Masheder, R. and Rankin, A. H., 1988. Fluid inclusion studies on the Ecton Hill copper deposits, north Staffordshire. *Mineralogical Magazine*, **52**, 473-482.
Maw, G., 1867. On the distribution beyond the Tertiary Districts of white clays and sands subjacent to the Boulder Clay Drifts. *Geological Magazine*, **4**, 240-251 and 299-307.
Mawe, J., 1802. *The Mineralogy and Geology of Derbyshire*. Mawe, London. 211pp.
Mello, Rev. J. Magens, 1876. *Handbook to the Geology of Derbyshire*, London.
Miller, J. and Grayson, R. F., 1982. The regional context of Waulsortian facies in Northern England. *In Symposium on the paleoenvironmental setting and distribution of the Waulsortian facies*. El Paso Geological Society, Texas, 17-33.
Milne-Edwards, H. and Haime, J., 1852-4. British Fossil Corals. Part III — Corals from the Permian Formation and the Mountain Limestone. *Palaeontographical Society Monograph*. pp. 147-210 and Plates xxxi-xlvi.
Morris, P. G., 1969. Dinantian and Namurian stratigraphy, east and southeast of Leek, north Staffordshire. *Proceedings of the Geologists' Association*, **80**, 145-175.

Moser, M. R., Rankin, A. H. and Milledge, H. J., 1992. Hydrocarbon-bearing fluid inclusions in fluorite associated with the Windy Knoll bitumen deposits, U.K. *Geochimica et Cosmoschimica Acta*, **56**, 155-168.

Mueller, G. 1954a. The distribution of the coloured varieties of fluorite within the thermal zones of the Derbyshire mineral deposits. *19th International Geological Congress, Algiers, Comptes Rendus*, Fasc. 15, 523-539.

Mueller, G., 1954b. The theory of the genesis of oil by hydrothermal alteration of coal-type substances within certain Lower Carboniferous stata of the British Isles. *19th International Geological Congress, Algiers, Comptes Rendus*, Fasc. 12, 279-328.

Noel, M., Shaw, R. P. and Ford, T. D., 1984. A palaeomagnetic reversal in early Quaternary sediments in Masson Hill, Matlock, Derbyshire. *Mercian Geologist*, **9**, 235-242.

Oakman, C. D., 1984. *The sedimentology and palaeoenvironmental analysis of the Dinantian limestones of the Wirksworth-Grangemill area, Derbyshire*. Unpublished Ph.D. thesis, University of Aberdeen.

Orme, G. R., 1974. Silica in the Visean limestones of Derbyshire. *Proceedings of the Yorkshire Geological Society*, **40**, 63-104.

Palmer, J. and Radley, J., 1961. Gritstone tors of the English Pennines. *Zeitschrift für Geomorphologie*, Band 5, Heft 1, 37-52.

Parkinson, D., 1947. The Lower Carboniferous of the Castleton district, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **27**, 99-125.

Parkinson, D., 1950. The stratigraphy of the Dovedale area, Derbyshire and Staffordshire. *Quarterly Journal of the Geological Society*, **105**, 265-294.

Parkinson, D., 1953. The Carboniferous Limestone of Treak Cliff, Derbyshire, with notes on the structure of the Castleton reef belt. *Proceedings of the Geologists' Association*, **64**, 251-268.

Parkinson, D., 1954. Quantitative studies of Brachiopoda from the Lower Carboniferous of England (*Schizophoria* & *Pugnax*). *Journal of Paleontology*, **28**, 367-381, 563-574 and 668-676.

Parkinson, D. and Ludford, A., 1964. The Carboniferous Limestone, Blore-with-Swinscoe district, northeast Staffordshire: with revision to the stratigraphy of neighbouring areas. *Geological Journal*, **4**, 167-176.

Parnell, J., 1988. Mineralogy of Uraniferous Hydrocarbons in Carboniferous-hosted mineral deposits, Great Britain. *Uranium*, **4**, 197-218.

Parsons, L. M., 1922. Dolomitization in the Carboniferous Limestone of the Midlands. *Geological Magazine*, **59**, 51-63 and 104-117.

Peacock, J. D., 1961. Uranium in British surface and underground waters. *Nature*, **191**, 1189-1190.

Peacock, J. D. and Taylor, K., 1966. Uraniferous collophane in the Carboniferous Limestone of Derbyshire and Yorkshire. *Bulletin of the Geological Survey*, **25**, 19-32.

Pennington, R., 1874. On the Ossiferous Deposit at Windy Knoll, near Castleton. *Transactions of the Manchester Philosophical and Literary Society*, **14**, 1-7.

Pennington, R., 1875. On the Bone Caves in the Neighbourhood of Castleton, Derbyshire. *Quarterly Journal of the Geological Society*, **31**, 238.

Pennington, R., 1877. *Barrows and Bone Caves of Derbyshire*. London, 124pp.

Pering, K. L., 1973. Bitumens associated with lead, zinc and fluorite minerals in North Derbyshire. *Geochimica et Cosmochimica Acta*, **37**, 401-417.

Pickard, N. A. H., 1996. Evidence for microbial influence on the development of Lower Carboniferous build-ups. *In* Stroben, P., Somerville, I. D. and Jones, G. L. (Eds.). *Recent advances in lower Carboniferous Geology*. Geological Society Special Publication, **107**, 65-82.

Pigott, C. D., 1962. Soil formation and development on the Carboniferous Limestone of Derbyshire: Part 1 Parent materials. *Journal of Ecology*, **50**, 145-156.

Plant, J. A. and Jones, D. G., 1989. *Metallogenic models and exploration criteria for buried carbonate-hosted ore deposits — a multidisciplinary study*. Institution of Mining and Metallurgy and British Geological Survey, Nottingham. 161pp.

Ponsford, D. R. A., 1955. Radioactivity studies of some British sedimentary rocks. *Bulletin of the Geological Survey*, **10**, 24-44.

Prentice, J. E., 1951. The Carboniferous Limestone of the Manifold Valley region. *Quarterly Journal of the Geological Society*, **106**, 171-209 and **107**, 335.

Quirk, D. G., 1986. Mineralization and Stress History in North Derbyshire. *Bulletin of the Peak District Mines Historical Society*, **9**, 333-386.

Quirk, D. G., 1993. Origin of the Peak District Orefield. *Bulletin of the Peak District Mines Historical Society*, **12**, 4-15.

Ramsbottom, W. H. C., 1973. Transgressions and regressions in the Dinantian: a new synthesis of British Dinantian stratigraphy. *Proceedings of the Yorkshire Geological Society*, **39**, 567-607.

Ramsbottom, W. H. C., 1977. Major cycles of transgression and regression (mesothems) in the Namurian. *Proceedings of the Yorkshire Geological Society*, **41**, 261-291.

Ramsbottom, W. H. C. *et al.*, 1978. A Correlation of Silesian rocks in the British Isles. *Geological Society Special Report*, **10**, 81pp.

Ramsbottom, W. H. C., Rhys, G. H. and Smith, E. G., 1962. Boreholes in the Carboniferous rocks of the Ashover district, Derbyshire. *Bulletin of the Geological Survey of Great Britain*, **19**, 75-168.

Read, W. A., 1991. The Millstone Grit (Namurian) of the Southern Pennines viewed in the light of eustatically controlled sequence stratigraphy. *Geological Journal*, **26**, 157-165.

Rieuwerts, J. H., 1984. Derbyshire Lead Mining and Early Geological Concepts. *Bulletin of the Peak District Mines Historical Society*, **9**, 51-100.

Rieuwerts, J. H., 1987. *History and gazetteer of the Lead Mine Soughs of Derbyshire*. Private publication, 143pp.

Rogers, D. E., 1983. *Seismic studies on the Derbyshire Dome*. Unpublished Ph.D. thesis, University of Leeds.

Sadler, H. E., 1966. A detailed study of microfacies in the mid-Visean (S2-D1) limestones near Hartington, Derbyshire, England. *Journal of Sedimentary Petrology*, **36**, 864-897.

Schofield, D. K. and Adams, A. E., 1985. Stratigraphy and depositional environments of the Woodale Limestones Formation (Dinantian), Derbyshire. *Proceedings of the Yorkshire Geological Society*, **45**, 225-233.

Schofield, D. K. and Adams, A. E., 1986. Burial dolomitization of the Woodale Limestones Formation (Lower Carboniferous), Derbyshire, England. *Sedimentology*, **33**, 143-158.

Shirley, J., 1949. The stratigraphical distribution of the lead-zinc ores of Mill Close Mine, Derbyshire, and future prospects for the area. *Proceedings of the 18th International Geological Congress, London*, **7**, 353-361.

Shirley, J. and Horsfield, E. L., 1940. The Carboniferous Limestone of the Castleton-Bradwell area, North Derbyshire. *Quarterly Journal of the Geological Society*, **96**, 271-299 and **97**, 180-181.

Shirley, J. and Horsfield, E. L., 1945. The stratigraphy, structure and ore deposits of the Eyam district, Derbyshire. *Quarterly Journal of the Geological Society*, **100**, 289-310.

Sibly, T. F., 1908. The faunal succession in the Carboniferous Limestone (Avonian) of the Midland area (North Derbyshire and North Staffordshire). *Quarterly Journal of the Geological Society, London*, **64**, 34-82.

Simpson, I. M. and Broadhurst, F. M., 1969. A Boulder Bed at Treak Cliff, north Derbyshire. *Proceedings of the Yorkshire Geological Society*, **37**, 141-151.

Skempton, A. W., Leadbeater, A. D. and Chandler, R. J., 1989. The Mam Tor landslide, Derbyshire. *Philosophical Transactions of the Royal Society*, **A329**, 503-547.

Smith, E. G., Rhys, G. H. and Eden, R. A., 1967. Geology of the Country around Chesterfield, Mansfield and Matlock. *Memoir of the Geological Survey*, Sheet 112, 430pp.

Smith, K. and Smith, N. J. P., 1989. Geology of the East Midlands. *In* Plant, J. A. and Jones. D. G., q.v., 5-12.

Smith, K. and Smith, N. J. P., 1989. Deep Geology. *In* Plant, J. A. and Jones, D. G., q.v., 53-64.

Smith, K., Smith, N. J. P. and Holliday, D., 1985. The deep structure of Derbyshire. *Geological Journal*, **20**, 215-225.

Sorby, H. C., 1859. The structure and origin of the Millstone Grit in South Yorkshire. *Proceedings of the Yorkshire Geological and Polytechnic Society*, **3**, 669-675.

Spencer, H. E. P. and Melville, R. V., 1974. The Pleistocene Mammalian fauna of Doveholes, Derbyshire. *Bulletin of the Geological Survey*, **48**, 43-49.

Stephens, J. V., 1929. Wells and Springs of Derbyshire. *Memoir of the Geological Survey*, 115pp.

Stevenson, I. P. and Gaunt, G. D., 1971. Geology of the Country around Chapel-en-le-Frith. *Memoirs of the Geological Survey of Great Britain*, Sheet 99, 430pp.
Stokes, A. H., 1879. The Economic Geology of Derbyshire. *Transactions of the Chesterfield and Midlands Institute of Mining, Civil and Mechanical Engineers*, **6**, 60-156, 206-218, 233-243, 297-303.
Stokes, A. H., 1880-3. Lead and Lead Mining in Derbyshire. *Transactions of the Chesterfield and Midlands Institute of Mining, Civil and Mechnical Engineers*, **8**, 67-166, 179-191, 268-279, 310-320. Supplementary papers in **9**, 306-319 and **11**, 70-72. (all reprinted as Special Publication No. 2 by Peak District Mines Historical Society, 87pp, 1996).
Strank, A. R. E., 1985. The Dinantian biostratigraphy of a deep borehole near Eyam, Derbyshire. *Geological Journal*, **20**, 227-237.
Straw, A., 1968. A Pleistocene diversion of drainage in North Derbyshire. *East Midland Geographer*, **4**, 275-280.
Straw, A. and Lewis, G. M., 1962. Glacial Drift in the area around Bakewell, Derbyshire. *East Midland Geographer*, **3**, 72-80.
Tilsley, J. W., 1988. New data on Carboniferous trilobites from the Peak District, Derbyshire. *Proceedings of the Yorkshire Geological Society*, **47**, 163-176.
Tomkeieff, S. I., 1928. The volcanic complex of Calton Hill. *Quarterly Journal of the Geological Society, London*, **84**, 703-718.
Torrens, H. S., 1992. The early life and geological work of John Mawe (1766-1829) and a note on his travels in Brazil. *Bulletin of the Peak District Mines Historical Society*, **11**, 267-271.
Torrens, H. S., 1994. Patronage and Problems: Banks and the Earth Sciences. *In* Banks, R. E. R. *et al.* (Eds.), *Sir Joseph Banks: a Global Perspective*. Royal Botanic Gardens, Kew, 49-75.
Traill, J. G., 1939. Notes on the Lower Carboniferous limestones and toadstones at Mill Close Mine, Derbyshire. *Transactions of the Institute of Mining Engineers*, **49**, 191-229.
Traill, J. G., 1939. The Geology and Development of Mill Close Mine, Derbyshire. *Economic Geology*, **34**, 851-889.
Trewin, N. H. and Holdsworth, B. K., 1973. Sedimentation in the lower Namurian rocks of the North Staffordshire Basin. *Proceedings of the Yorkshire Geological Society*, **39**, 371-408.
Varvill, W. W., 1937. A study of the Shapes and Distribution of the Lead Deposits in the Pennines in relation to Mining. *Transactions of the Institution of Mining and Metallurgy*, **46**, 463-559.
Walkden, G. M., 1972. The mineralogy and origin of interbedded clay way-boards in the Lower Carboniferous of the Derbyshire dome. *Geological Journal*, **8**, 143-159.
Walkden, G. M., 1974. Palaeokarstic surfaces in Upper Visean (Carboniferous) limestones of the Derbyshire block, England. *Journal of Sedimentary Petrology*, **44**, 1232-1247.
Walkden, G. M., Oakman, C. D. and Berry, J. R., 1981. Field guide to the Lower Carboniferous rocks of the southeast margin of the Derbyshire block. *Proceedings of the Yorkshire Geological Society*, **43**, 409-410.
Walkden, G. M. and Williams, D. G., 1991. The diagenesis of the late Dinantian Derbyshire-East Midland Shelf, central England. *Sedimentology*, **38**, 643-670.
Walker, R. G., 1966. Shale Grit and Grindslow Shales: transition from turbidite to shallow water sediments in the Upper Carboniferous of Northern England. *Journal of Sedimentary Petrology*, **36**, 90-114.
Walsh, P. T., Boulter, M. C., Ijtaba, M. and Urbani, D. M., 1972. The preservation of the Neogene Brassington Formation of the Southern Pennines and its bearing on the evolution of Upland Britain. *Journal of the Geological Society*, **128**, 519-559.
Walters, S. G. and Ineson, P. R., 1980. Mineralization within the Igneous Rocks of the South Pennine Orefield. *Bulletin of the Peak District Mines Historical Society*, **7**, 315-325.
Walters, S. G. and Ineson, P. R., 1981. A review of the distribution and correlation of igneous rocks in Derbyshire. *Mercian Geologist*, **8**, 81-132.
Warwick, G. T., 1964. Dry valleys of the Southern Pennines, England. *Erdkunde*, **18**, 116-123.
Waters, R. S. and Johnson, R. H., 1958. The terraces of the Derbyshire Derwent. East Midland Geographer, **2**, (9), 3-15.
Watson, White, 1811. *Delineation of the Strata of Derbyshire*. Todd, Sheffield. 76pp. (Reprint edition by Moorland, Ashbourne, 1973).
Watson, White, 1813. *A Section of the Strata forming the Surface in the Vicinity of Matlock Bath in Derbyshire*. Ford, Chesterfield, 19pp.
Webb, P. C. and Brown, G. C., 1989. *Geochemistry of Igneous Rocks*. *In* Plant, J. A. and Jones, D. G., q.v., 95-121.
Wedd, C. B. and Drabble, G. C., 1908. The Fluorspar Deposits of Derbyshire. *Transactions of the Institute of Mining Engineers*, **35**, 501-535.
Whitehurst, J., 1778. An Inquiry into the Original State and Formation of the Earth, London. 2nd edition 1786, 282pp.
Wolfenden, E. B., 1958. Palaeoecology of the Carboniferous reef complex and shelf limestones in northwest Derbyshire. *Bulletin of the Geological Society of America*, **69**, 871-898.
Woodward, H., 1883. *The British Carboniferous Trilobites*. Palaeontographical Society Monograph, 10 Plates.
Xuemin, G., Fowler, M. G., Comet, P. A., Manning, D. A. C., Douglas, A. G., McEvoy, J. and Giger, W., 1987. Investigation of three natural bitumens from Central England by hydrous pyrolysis and gas-chromatography-mass spectrometry. *Chemical Geology*, **64**, 181-195.
Yorke, C., 1954. *The Pocket Deposits of Derbyshire*. Private Publication, Birkenhead, 64pp; supplements in 1955, 1958 & 1960. Revised version in 1961. 86pp.

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A new reconstruction of the skull of the Callovian elasmosaurid plesiosaur *Muraenosaurus leedsii* Seeley

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Abstract: A new reconstruction of the skull of the elasmosaurid plesiosaur *Muraenosaurus leedsii* is presented, based on a partial but well preserved specimen. The bony labyrinth of the inner ear is used to orient the skull in the horizontal plane. In the new reconstruction, the skull is higher, with more anteriorly directed orbits and a more vertical suspensorium. This reconstruction suggests that *Muraenosaurus* had a more powerful jaw action than coeval cryptoclidid plesiosaurs.

Introduction

The skull of plesiosauroid plesiosaurs is generally a delicate structure which is easily damaged or lost in the processes leading to fossilisation and, ultimately, collection. This paper describes a skull from the Callovian (Middle Jurassic) Oxford Clay Formation of Peterborough, England. The specimen (LEICT G18.1996) was presented to Leicester Town Museum in 1902 by Mr. R. Swales of Peterborough. It seems probable that this is the Robert Swales listed in a local directory of the period (Anon, 1906; page 271) as a shopkeeper of Lincoln Road, Peterborough. The specimen, which includes most of the postcranial skeleton, is referable to the elasmosaurid genus *Muraenosaurus* Seeley, 1874 on the basis of the form and number of the cervical vertebrae (Brown, 1981). Taxonomically important skull characters shown in the specimen are: the number and ornament of the dentary teeth; the sagittal crest; and the form of the occipital condyle. Two species are recognised within *Muraenosaurus*, namely *M. leedsii* Seeley, 1874 and the much smaller *M. beloclis* Seeley, 1892. On the specimen described in this paper the right radius lacks the large facet for the intermedium diagnostic of *M. beloclis*. The specimen just falls within the size range of *M. leedsii*, although it is one of the smallest individuals of this species. The fused neural arches in the cervical vertebrae and fused coracoids and left scapula indicate that it was an "old adult" by the criteria of Brown (1981).

Although incomplete, the skull is largely uncrushed, allowing a new reconstruction to be produced. The only previously published skull reconstruction of *Muraenosaurus sp.* is that of Andrews (1910, reproduced here as Fig. 5c). This shows a relatively low skull with dorsally directed orbits and a sloping suspensorium. However, the specimens which Andrews (1910) described had all been subjected to dorsoventral crushing.

As the osteology of the species is well known, only additional points will be dealt with below. Besides Andrews' (1910) description, elements of the braincase and palate were described by v. Koken and Linder (1913). Their material consisted of four partial skulls curated in the Geological Institute in Tübingen. The prootic and exoccipital-opisthotic were accurately re-articulated, but the gross morphology of the skull was not reconstructed. More recently, Maisch (1998) has reviewed this material, providing detailed descriptions of the braincase and skull table. Brown (1981) commented upon Andrews' reconstruction, most notably on the relationship of the maxillae and jugals, but did not produce an updated reconstruction.

Description

Institution abbreviations: BMNH — Palaeontology Department, The Natural History Museum, Cromwell Road, London SW7 5BD, UK; LEICT — Natural Sciences Section, Leicester City Museums, New Walk Museum, Leicester LE1 7EA, UK.

Frontals and parietal. Portions of both frontals and parietals are preserved. There is some slight distortion in the area of the parietal foramen, so that the midline of the skull appears to be kinked. There is no fusion at the midline forward of the parietal foramen. The medial surface of the parietals and frontals can be seen as a result of a break in the right parietal. The frontal-parietal suture passes through the facet for the postfrontal and then traces a triangular path medially (Fig. 1a). On the ventral surface, the suture has an interdigitating structure before returning up the inner wall of the orbit (Fig. 1b). The ventral portions of the frontal-parietal suture were noted by Maisch (1998) as anterior processes of the parietals intruding between the frontals. Just anterior of the postfrontal facet, the right frontal shows a smooth edge which runs anterolaterally before turning more rostrally at a small boss. This edge forms part of the recess described by Maisch (1998), suggesting the possibility of an unpreserved "supraorbital" or prefrontal element. This recess and the anterior processes of the parietals have been highlighted as characters peculiar to one of the Tübingen skulls (Maisch, 1998).

The frontals form a gentle dorsal arch over the orbit, in contrast to the flatter orbital margin seen in crushed specimens such as BMNH R.2421. Each frontal bears a trough running around the orbital margin towards the midline. Separating the troughs is a ridge formed by the anterior extension of the frontals (preserved only on the left side) which

amp	site of ampulla	mt	mature tooth
ang	angular	mx	maxilla
ar	articular	nfo	nutritive foramen
avsc	anterior vertical semicircular canal	p	parietal
bc	braincase	palv	primary alveolus
boc	basioccipital condyle	pmx	premaxilla
c	coronoid	pob	postorbital bar
d	dentary	ppr	paroccipital process
en	external naris	pt	pterygoid
eo-op	exoccipital-opisthotic	pvsc	posterior vertical semicircular canal
fbo	facet for basioccipital	q	quadrate
fc	facet for coronoid	rt	replacement tooth
fenov	position of fenestra ovalis	sa	surangular
fop	facet for opisthotic	salv	secondary alveolus
fpof	facet for postfrontal	so	supraoccipital
fpro	facet for prootic	sq	squamosal
fr	frontal	sut	suture between frontal and parietal
fso	facet for supraoccipital	ut	utricular recess
gl	glenoid fossa	wpfo	wall of parietal foramen
hsc	horizontal semicircular canal	XI	foramen for cranial nerve XI (accessorius)
j	jugal	XII	foramen for cranial nerve XII (hypoglossal)
jfo	jugular foramen	hatching	broken bone
lab	bony labyrinth	stipple	matrix
lag	approximate position of lagena		

Table 1. Key to abbreviations used in figures.

would have been overlapped by the facial processes of the premaxillae. The external nares would have lain in this trough, which may have played a role in the hydrodynamics of underwater olfaction (Cruickshank *et al.*, 1991).

Squamosals. Portions of both squamosals are present, and are free from each other and the parietals. These elements became disarticulated prior to burial. The squamosal facets of the parietals are preserved as dark brown bone, while the parietal facets of the squamosals are preserved as buff-coloured bone, probably demonstrating different burial histories (Martill, 1986). The posterior surfaces of the dorsal rami are roughened, presumably for the attachment of cervical musculature or ligaments. At the level of the anterior rami, the posterior surfaces form a keel, associated with a pair of ridges. Similar ridges in the pliosaur *Rhomaleosaurus megacephalus* (Stutchbury) have been interpreted as sites for the attachment of the skin and, possibly, musculature of the neck (Cruickshank, 1994), as seems to be the case here.

Each squamosal is broken approximately 3cm below the point where the anterior ramus sweeps forward to form the ventral border of the temporal fenestra. The break reveals a cavity containing a nub of bone, identified here as the head of the quadrate. Below this point, as in all specimens of *Muraenosaurus* described to date, the squamosal is crushed and "telescoped" and so remains poorly known. The dorsal edge of the anterior ramus is thicker than the ventral border, which is very thin. It is impossible to reconstruct the ventral extent of the squamosal due to the breakage of this edge. The thin bone in this region suggests that there was little direct transmission of force to the maxilla through the squamosal and jugal. This supports Brown's (1981) observation that the ectopterygoid provided the structural link between the maxilla and the jaw articulation. The thicker dorsal edge of the anterior ramus forms part of the rim of the temporal fenestra, and so would provide attachment for the temporalis musculature.

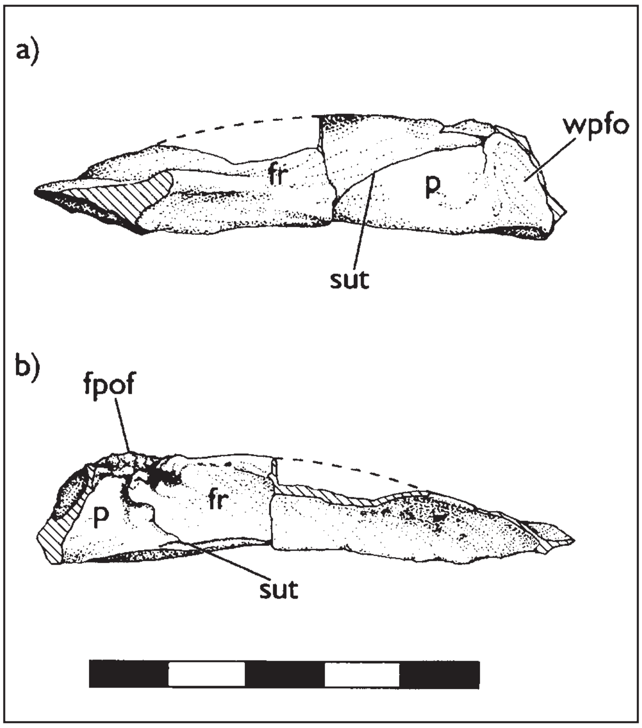

Fig. 1. *Muraenosaurus leedsii* (LEICT G18.1996). Partial right parietal and frontal, showing the suture and the arched dorsal margin, in (a) medial view and (b) lateral view. Scale bar = 50mm. For abbreviations see Table 1.

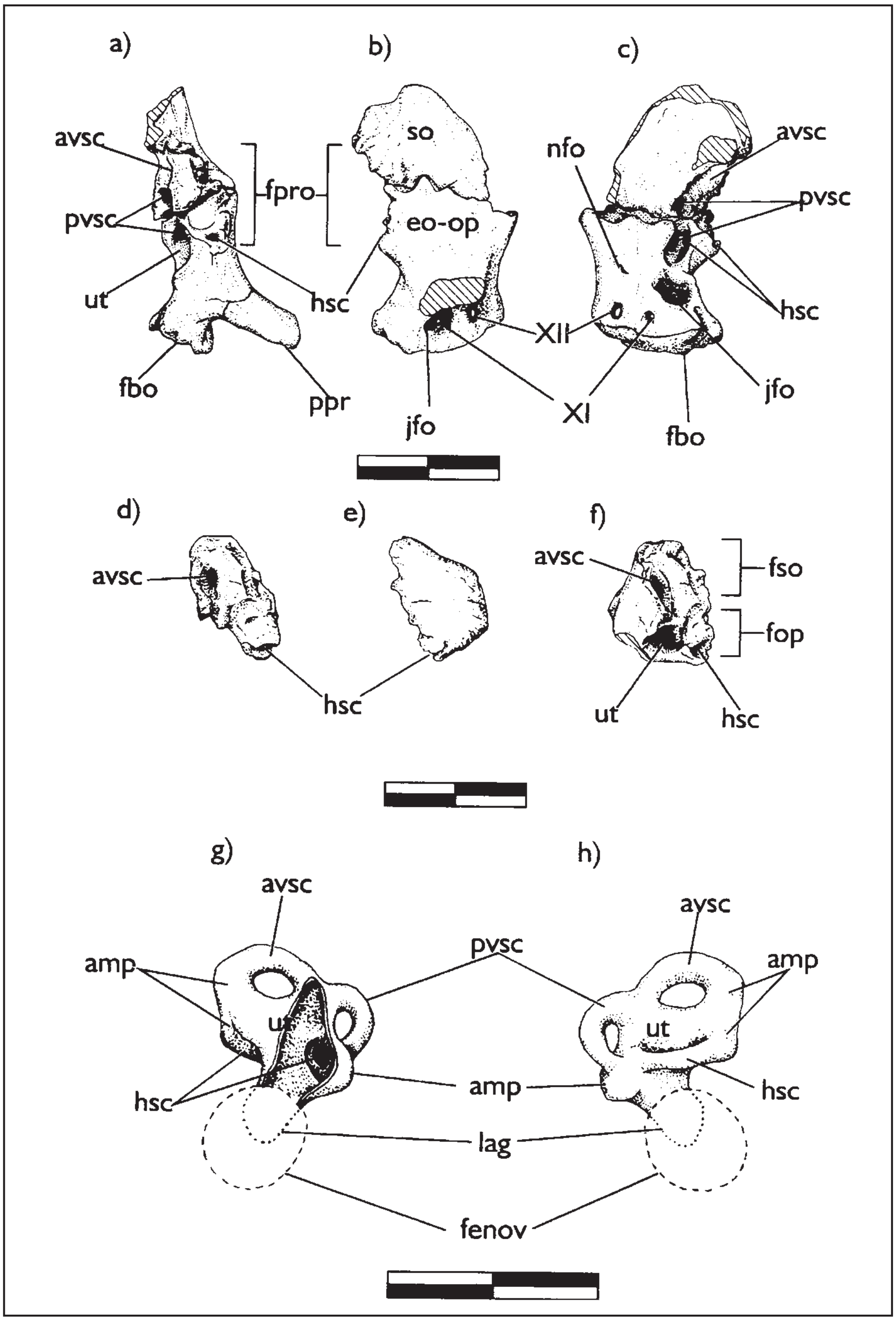

Fig. 2. *Muraenosaurus leedsii* (LEICT G18.1996). Left exoccipital-opisthotic with partial supraoccipital in (a) anterior, (b) lateral, and (c) medial view. Paroccipital process omitted for clarity in (b). Right prootic in (d) posterior, (e) lateral and (f) medial view. Reconstruction of bony labyrinth of right inner ear in (g) medial and (h) lateral view. The medial wall in (g) is rendered transparent. Scale bar = 20mm in all cases. For abbreviations see Table 1.

Braincase. The braincase is represented by the basioccipital, basisphenoid, parasphenoid, partial right prootic, and left exoccipital-opisthotic with attached partial supraoccipital. The occipital condyle is separated from the body of the basioccipital by a groove, and the pedicels of the exoccipitals take no part in its formation. This confirms the identification of this specimen as a small adult. The basicranium agrees with existing descriptions (Andrews, 1910; v. Koken and Linder, 1913; Maisch, 1998).

The medial surface of the exoccipital-opisthotic (Fig. 2a, b and c) bears a relatively large rectangular slit, the jugular foramen (the metotic foramen of Maisch, 1998) and two smaller foramina. At first sight, the lateral surface bears only one smaller foramen. Close inspection shows that the more anterior foramen opens within the jugular foramen. Maisch (1998) suggested that this would be the case, and identified the foramen as that of the accessorius nerve (XI). The lateral wall of the prootic (Fig. 2d, e and f) shows no foramina, unlike those described in BMNH R.2422 by Brown (1981). Inspection of that specimen confirms the presence of at least one foramen, which may have been a nutritive foramen rather than the opening for the facial nerve (VII).

The bony labyrinth of the inner ear can be reconstructed using data from the right prootic, left exoccipital-opisthotic and supraoccipital (Fig. 2g and h). The horizontal and posterior vertical semicircular canals run from a deep excavation for

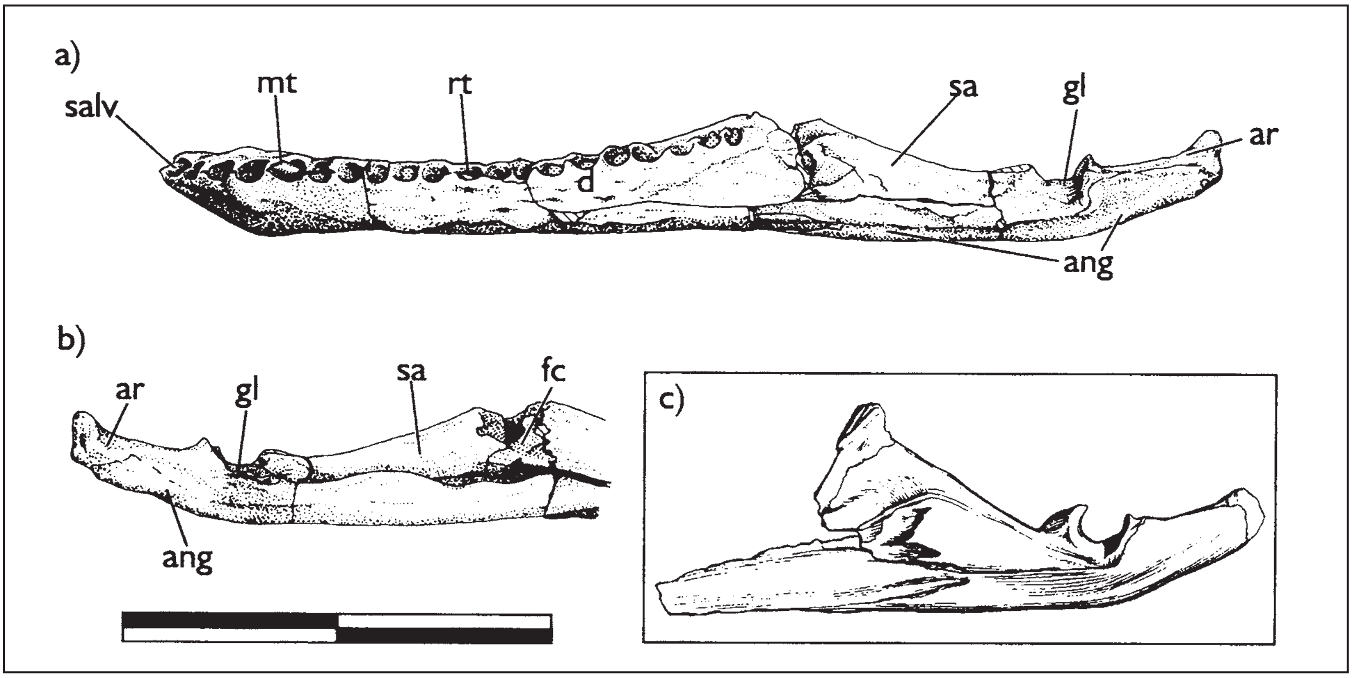

Fig. 3. *Muraenosaurus leedsii* (LEICT G18.1996). Lower jaw in (a) lateral and (b) medial view. Scale bar = 100mm. (c) Articular region of BMNH R.2678, not to scale (from Andrews, 1910). For abbreviations see Table 1.

the utriculus, while the anterior vertical semicircular canal runs up a groove on the sutural surface of the supraoccipital, confirming Maisch's (1998) suggestion. Corresponding passages in the prootic for the anterior vertical and horizontal canals lead to the anterior part of the utricular cavity. The horizontal semicircular canal can be used to reconstruct the horizontal orientation of the skull (Fig. 5).

Jaws and dentition. The lower jaw is complete on the left side (Fig. 3), except for the coronoid. This element in BMNH R.2678 was identified as the splenial by Andrews (1910), and as part of the dentary by Brown (1981), but the distinct concave facet formed by both the dentary and surangular indicates the presence of a separate coronoid. The coronoid eminence does not appear to have been as high and steep as in larger, but ontogenetically younger, specimens such as the "adult" BMNH R.2678 (Fig. 3c) and "juvenile" BMNH R.2863. The proportionally taller coronoid eminence of these larger animals indicates that animals of different sizes were not geometrically similar. In other words, this area of the skeleton displays allometry. A relatively higher coronoid eminence would bring the insertions of the jaw adductor musculature closer to their points of origin around the temporal fenestra, resulting in a smaller muscle mass than otherwise expected. Muscle mass, being dependent on volume, would be expected to increase as the cube of any linear scaling factor. However, the advantages gained by reducing body weight would have been less important in an aquatic animal.

A fragment of upper jaw containing a small replacement tooth is also preserved, and is identified as premaxilla on the basis of the surface ornament and angle of the dental alveoli. The left dentary carries 20 tooth positions. No fully erupted teeth are preserved, apart from broken stubs. The largest complete replacement tooth (Fig. 4) agrees with the description of the dentition of *Muraenosaurus leedsii* given by Brown (1981), although the ridges appear sparser and the tooth blunter. These are size-related differences associated with the small size of both the tooth and the animal. The teeth would have penetrated and held the prey, which would have been mainly soft-bodied (Massare, 1987).

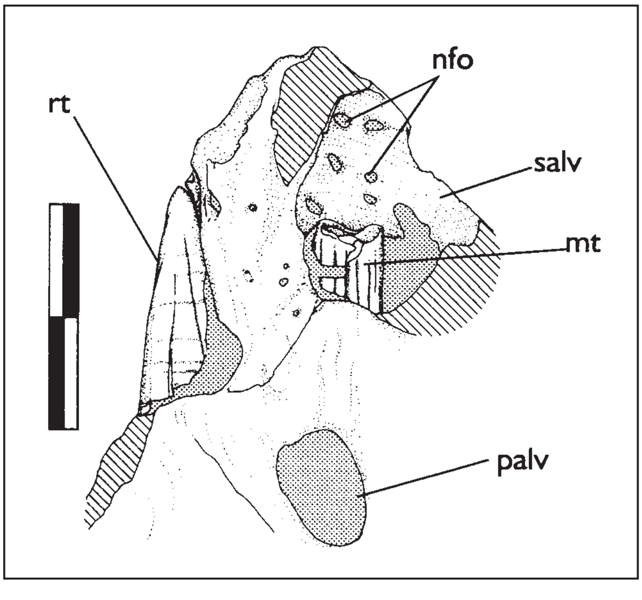

Fig. 4. *Muraenosaurus leedsii* (LEICT G18.1996). Camera lucida drawing of first and second left dentary alveoli, showing tooth ornament. Scale bar = 10mm. For abbreviations see Table 1.

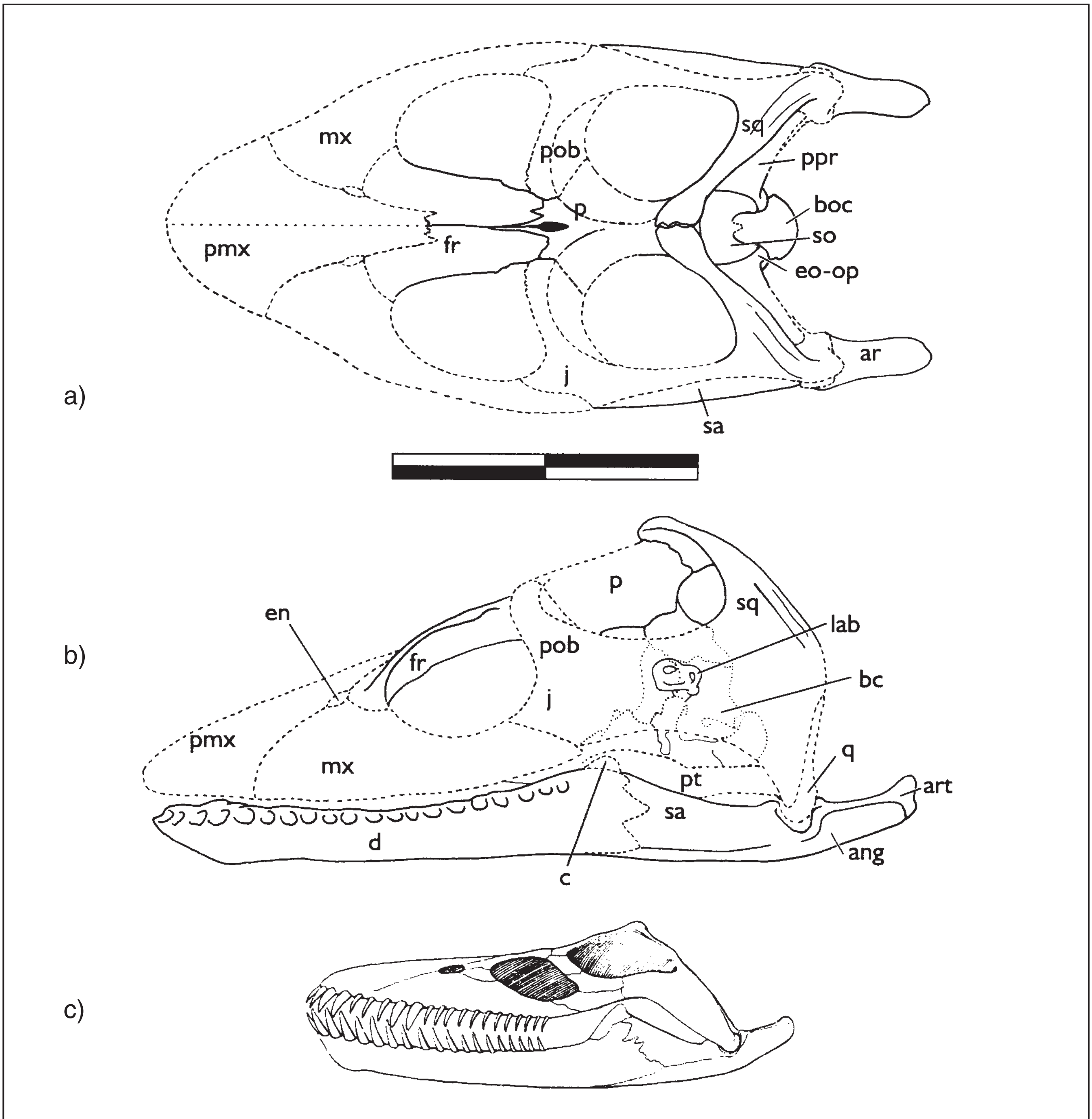

Fig. 5. *Muraenosaurus leedsii*. Reconstruction of skull in (a) dorsal, and (b) lateral view with cheek rendered partially transparent. Based on LEICT G18.1996, with additional data from Andrews (1910) and BMNH R.2861. (c) Andrews' 1910 reconstruction, not to scale. Scale bar = 100mm. For abbreviations see Table 1.

Reconstruction

A new reconstruction of the skull of *Muraenosaurus leedsii* is presented (Fig. 5), based on this specimen. There are three main sections to this skull as preserved, the skull roof, the braincase and occiput, and the lower jaw. The reconstructed skull needs to be high to accommodate the occipital plate, while the lower jaw gives the snout to quadrate length. Comparisons with other specimens indicate that the premaxillae would have extended for approximately 5cm anterior to the end of the frontal.

Unfortunately, the taxonomically important area around the cheek still remains poorly known; here the cheek has been reconstructed as being dorsoventrally deep. The reconstructed horizontal orientation of the skull, as indicated by the semicircular canals, gives the orbits a more anteriorly directed view with the possibility of stereoscopic vision.

The suspensorium is significantly more vertical than has been previously reconstructed (Andrews, 1910; see also Fig. 5). In this respect, it resembles the skulls of the coeval cryptoclidid plesiosaurs (Brown, 1981; Brown and Cruickshank, 1995) more than has been previously thought. However, the temporal fenestra and coronoid eminence are situated more anteriorly. This arrangement results in a longer lever arm for the action of the temporalis musculature, and therefore a more powerful bite. By comparison the shorter coronoid to glenoid distance in the cryptoclidids would result in a faster, snapping bite. This indicates that *Muraenosaurus* could have taken more substantial prey than the cryptoclidids, and supports the niche-partitioning demonstrated by the difference in dentition.

Acknowledgements

Thanks are due to Dr. Arthur Cruickshank, Mr John Martin and Mr. Richard Forrest for bringing me on to the project and for the many discussions on the mechanics of plesiosaurian skills. I would also like to thank the above, along with Dr. Andrew Milner and an anonymous referee, for reading drafts of this manuscript and for their comments. Richard Forrest also kindly provided translations of German references where needed. Sandra Chapman (Natural History Museum, London) provided access to specimens in her care. This paper is based on a poster presented at the 45th Symposium of Vertebrate Palaeontology and Comparative Anatomy (SVPCA) held at the University of Derby in 1997, and I would like to thank SVPCA delegates, especially Dr. Michael Taylor and Dr. David Brown, for their comments. I would also like to acknowledge an award from the Jones-Fenleigh Memorial Fund which allowed me to attend the SVPCA.

References

Andrews, C. W., 1910. *A descriptive catalogue of the marine reptiles of the Oxford Clay. Part 1*. British Museum (Natural History), London.

Anon, 1906. *Kelly's Directory for Bedfordshire, Hunts and Northants*. Kelly's Directories Ltd, 182, 183 & 184 High Holborn, WC. & Middle Hill, Kingston on Thames.

Brown, D. S., 1981. The English Upper Jurassic Plesiosauroidea (Reptilia), and a review of the phylogeny and classification of the Plesiosauria. *Bulletin of the British Museum (Natural History) (Geology)*, **35**, 253-347.

Brown, D. S., and Cruickshank, A. R. I., 1995. The skull of the Callovian plesiosaur *Cryptoclidus eurymerus*, and the sauropterygian cheek. *Palaeontology*, **37**, 937-941.

Cruickshank, A. R. I., 1994. Cranial anatomy of the Lower Jurassic pliosaur *Rhomaleosaurus megacephalus* (Stutchbury) (Reptilia: Plesiosauria). *Philosophical Transactions of the Royal Society of London Series B*. **343**, 247-260.

Cruickshank, A. R. I., Small, P. G. and Taylor, M. A., 1991. Dorsal nostrils and hydrodynamically driven underwater olfaction in plesiosaurs. *Nature*, **352**, 62-64.

Koken, E. v. and Linder, H., 1913. Osteologische Notizen über *Muraenosaurus*. *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie*, **1**, 101-115.

Maisch, M. W., 1998. Notes on the cranial osteology of the elasmosaurid plesiosaur *Muraenosaurus* SEELEY, 1874 (Sauropterygia, Jurassic) with special reference to the neurocranium and its implications for sauropterygian phylogeny. *Neues Jahrbuch für Geologische und Pälaeontologische Abheilung*, **207** pt.2, 207-253.

Martill, D. M., 1986. The stratigraphic distribution and preservation of fossil vertebrates in the Oxford Clay of England. *Mercian Geologist*, **10**, 161-186.

Massare, J. A., 1987. Tooth morphology and prey preference of Mesozoic marine reptiles. *Journal of Vertebrate Paleontology*, **7**, 121-137.

Seeley, H. G., 1874. On *Muraenosaurus leedsii*, a plesiosaurian from the Oxford Clay. Part 1. *Quarterly Journal of the Geological Society of London*, **30**, 197-208.

Seeley, H. G., 1892. The nature of the shoulder girdle and clavicular arch in the Sauropterygia. *Proceedings of the Royal Society of London*, **51**, 119-151.

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New fossils in the Precambrian of Charnwood Forest, Leicestershire, England

Helen E. Boynton

Abstract: New specimens of Precambrian fossils have been found in the Charnian of Leicestershire, at two fossil localities previously described by Boynton and Ford (1995).

Introduction

This short paper reports new fossil finds at two fossil localities previously described by Boynton and Ford (1995) from the Charnian Supergroup (Moseley and Ford, 1985) of Leicestershire, namely Ives Head and Charnwood Golf Club North Quarry. The specimens are preserved as very faint traces on bedding planes and are only visible when illuminated by the sun at certain times of the day and at certain times of the year. At Charnwood Golf Course North Quarry, favourable illumination occurs only around midday in midsummer, and the bedding plane is only accessible by experienced climbers. The bedding plane at Ives Head is usually covered by grass or moss and often needs washing to see the fossils.

The fossils at Ives Head, Shepshed

The finds occur within the Lubcloud Greywacke Member of the Ives Head Formation (Blackbrook Group) and are preserved on the lowest bedding plane, the lowest fossiliferous horizon ever recorded in the Charnian of Charnwood Forest. The fossils are preserved as greyish-white traces with no relief. One specimen is a drooping frond resembling *Shepshedia palmata*. It has a long stem attached to the palmate fingers with an indistinct area of coiled and ring-like structures at the base of the stem; another faint stem appears to arise from these coiled structures (Fig. 1).

About 10cm to the left, also shown in Figure 1, is another new frond. This is similar to *Charnia masoni* but much smaller in size. It does not show the same segmentation and appears to arise from two, slightly coiled disc-like structures at its base (Fig. 2).

The holotype *Shepshedia palmata*, described by Boynton and Ford (1995) from a bedding plane 10m higher at the same locality, does not display comparable coiled or ring structures. The drooping head on the long stem is here placed in the species *Shepshedia* aff. *palmata*, but the small frond to the left is as yet unnamed.

From these two new specimens it is conjectured that *S. palmata* arose as a small frond from a disc-like base with vesicles (Fig. 2), and grew into a long stem with finger-like fronds While some of the other branching structures and groups of vesicles shown in Figures 1 and 2 resemble *Charnia* and *Shepshedia palmata*, they are too ill-defined to be assigned to taxa with confidence.

The fossils at Charnwood Golf Club

The finds at Charnwood Golf Club North Quarry (near Loughborough, Leicestershire) occur within the Hallgate Member of the Bradgate Formation (Maplewell Group). Several new ‘fronds’ have been found on the highest accessible bedding plane, approximately 3m above the horizon where the first *Charnia masoni* was found by Ford (1958). The new ‘fronds’ consist of worm burrow-like marks (compare Boynton and Ford, 1995, p.178, fig. 18) preserved in positive relief. They represent sinuous coils from which, in places, finer ‘branches’ bifurcate and bear knob-like structures on their ends (Fig. 3). These resemble frondose structures with bulbous ends rather than worm burrows.

These specimens lie approximately 15 metres higher up the same steeply dipping bedding plane from the specimens described previously at this locality by Boynton and Ford (1995, fig. 18); they are accessible only by climbers with ropes. On the same bedding plane there is a very large specimen which may extend to over one metre in length, although the exact dimensions are difficult to measure because the extremities are very faint. It consists of a central two-ringed disc from which originates large fronds, similar to *Bradgatia linfordensis* on the Memorial Crags in Bradgate Park (Boynton and Ford, 1995). The specimen described here differs in having a pronounced disc near the centre from which the large masses of fronds arise. It could be a variant of *B. linfordensis*, and is assigned to *Bradgatia* aff. *linfordensis*. The disc may have been a float supporting the large frondose masses, which would sway in the sea as the organism floated.

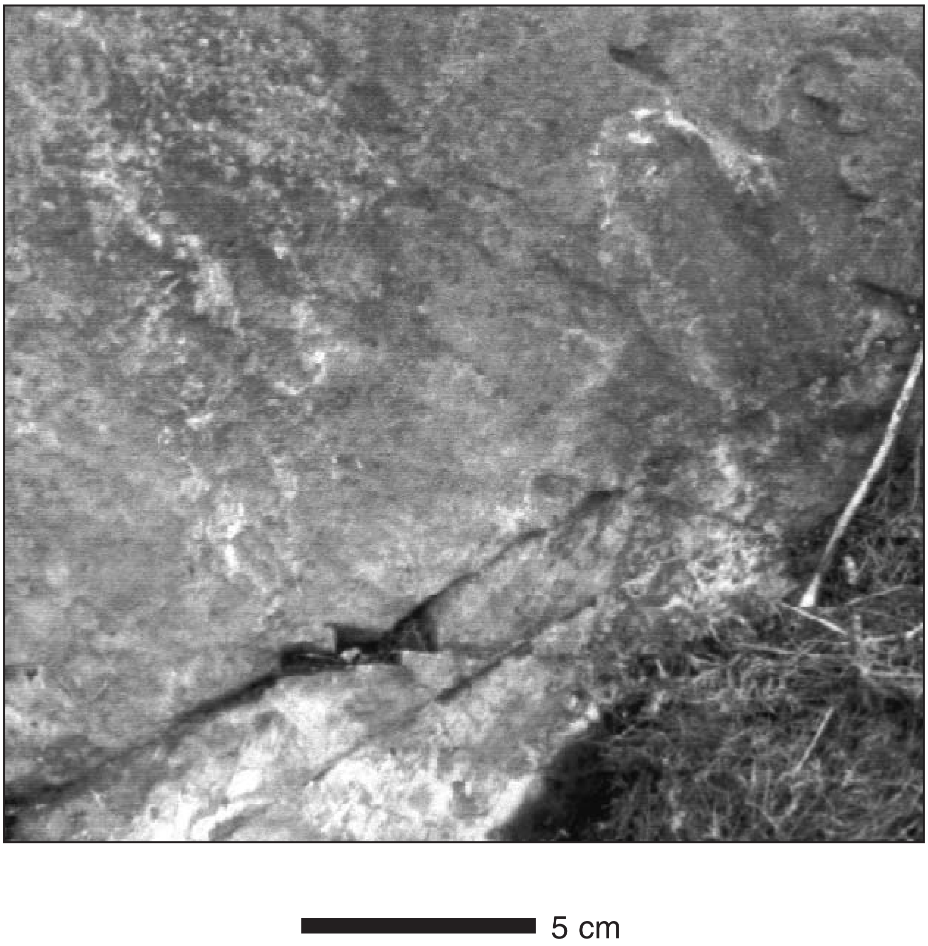
Summary and Conclusions

The new specimens described here do not appear to have parallels at any other Precambrian fossil localities, for example Ediacara in South Australia or Mistaken Point in Newfoundland. They may throw further light on the probable planktonic nature of these organisms.

As more bedding planes are cleaned and examined more fossils are appearing, albeit often faintly defined. This research is ongoing, and with continued further examination in Charnwood Forest, particularly in the Charnwood Golf Club North Quarry, it is certain that other new specimens will be discovered.

Acknowledgements

Thanks go to Dr. T. D. Ford, Dr. J. C. W. Cope and an anonymous reviewer for their helpful comments.



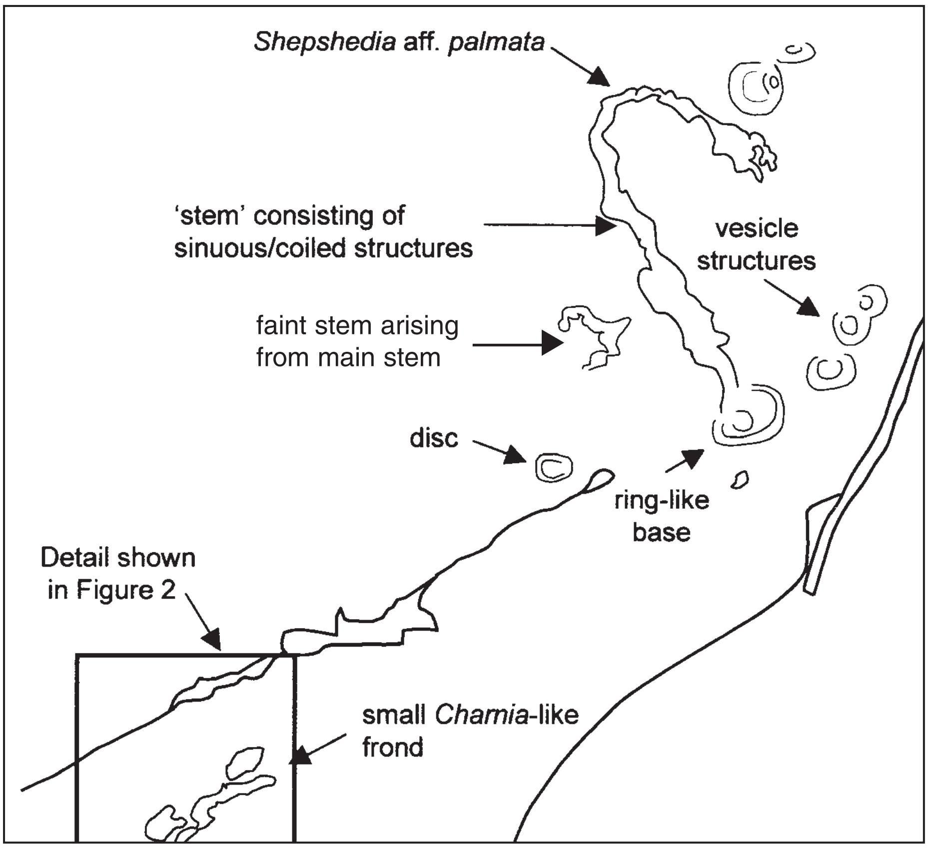


Fig. 1. Bedding plane at Ives Head, displaying *Shepshedia* aff. *palmata* and a small *Charnia*-like frond.

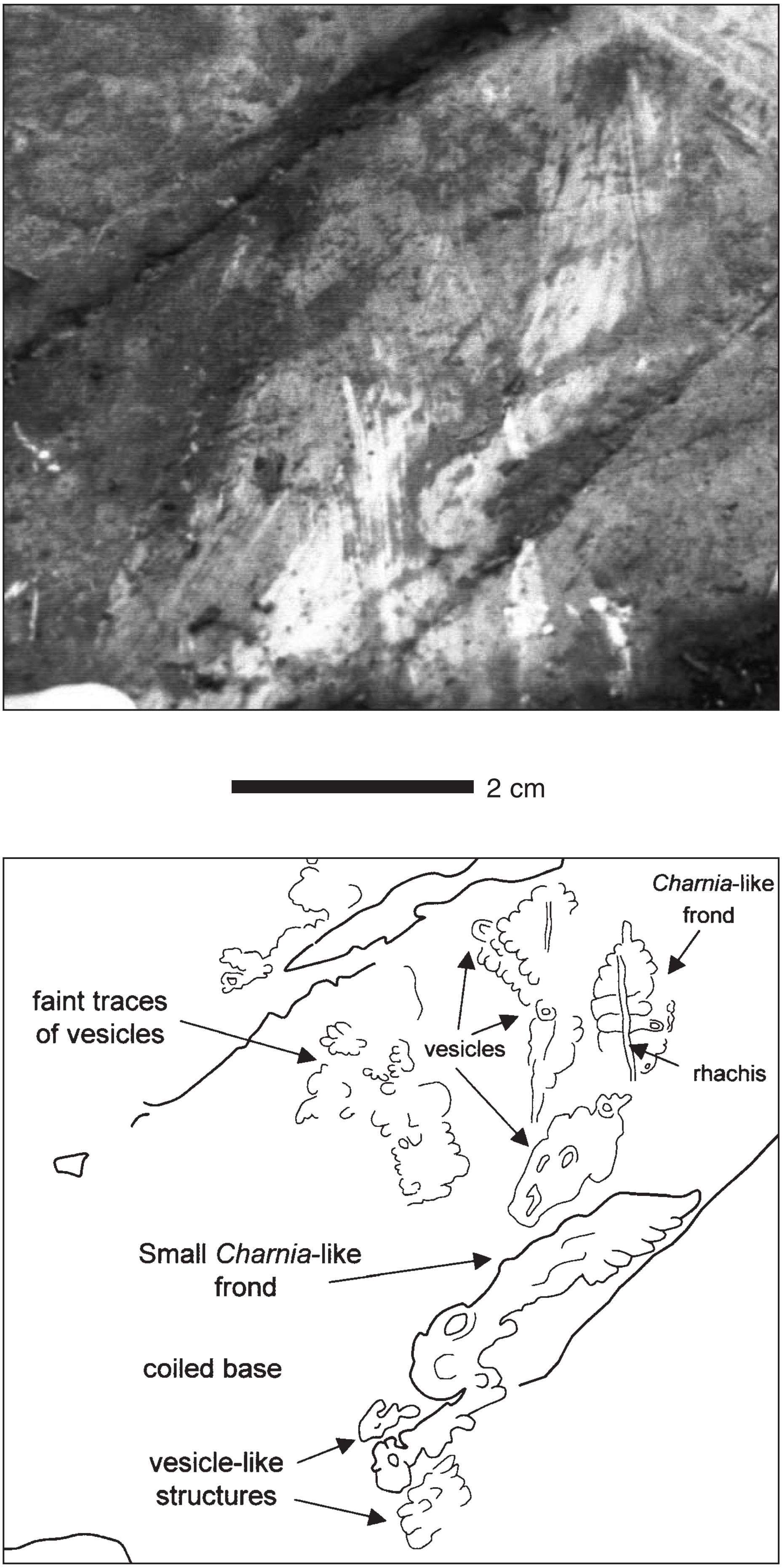
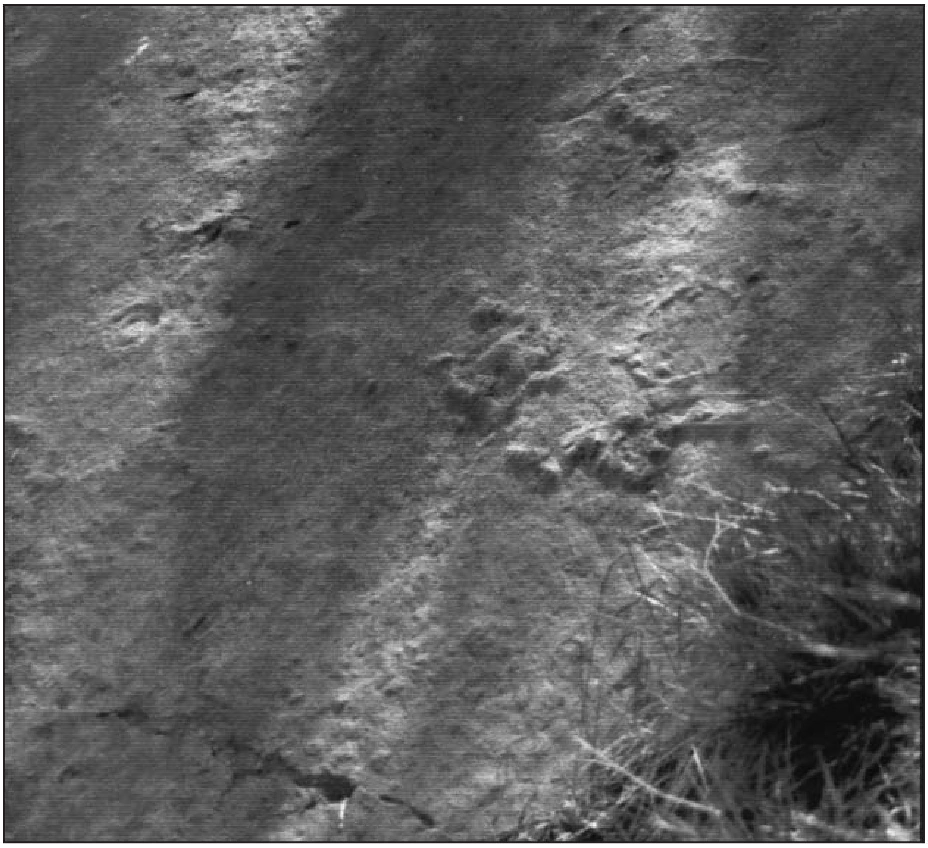


Fig. 2. Close up of small *Charnia*-like frond illustrated in Figure 1, also showing vesicle-like structures.



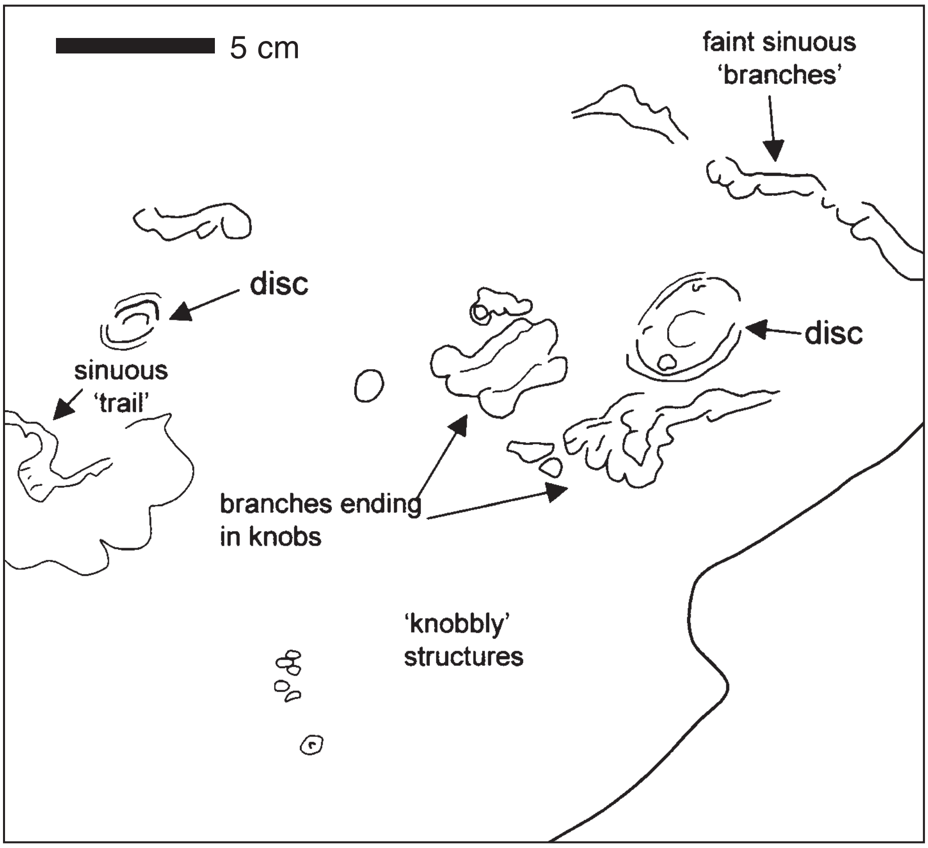


Fig. 3. Coiled fronds and discs, Charnwood Golf Club North Quarry.

References

Boynton, H. E. and Ford, T. D., 1995. Ediacaran Fossils from the Precambrian (Charnian Supergroup) of Charnwood Forest, Leicestershire, England. *Mercian Geologist*, **13**, 165-182.

Ford, T. D., 1958. Precambrian Fossils from Charnwood Forest. *Proceedings of the Yorkshire Geological Society*, **31**, 211-217.

Moseley, J. and Ford, T. D., 1985. A stratigraphic revision of the Precambrian rocks of Charnwood Forest, Leicestershire. *Mercian Geologist*, **10**, 1-18.

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EXCURSION

Asbian and Brigantian evolution of the Central Derbyshire carbonate platform: Wye Valley

Leader: Peter Gutteridge, Cambridge Carbonates Ltd, 11 Newcastle Drive, The Park, Nottingham.

7th June, 1998

The aim of this trip was to demonstrate the sedimentary evolution of the central part of the Derbyshire carbonate platform during the Asbian and Brigantian, with emphasis on:

- The nature of carbonate sedimentation on a flat-topped carbonate shelf during the Asbian.
- The volcanic and sedimentary events associated with the development of an intrashelf basin within the Derbyshire carbonate platform.
- The depositional mechanisms of deep water carbonates in the intrashelf basin.
- The contrasting effects of sea level variations on sedimentation in the intrashelf basin and on carbonate platform sedimentation.

Asbian platform limestones were examined at Hartington Station Quarry. The main features of the evolution of the carbonate platform during the Asbian and Brigantian were illustrated by a traverse from Millers Dale to Monsal Head along the former railway line and the story was completed near Ashford. The general geology of the Derbyshire carbonate platform is described by Gutteridge (1987) and Aitkenhead *et al.* (1985).

1. Hartington Station Quarry (SK 151 613)

Hartington Station Quarry exposes the Bee Low Limestones of Asbian age. These were deposited in the shelf interior before the intrashelf basin was formed. The succession comprises thickly bedded limestones separated by prominent bedding planes. Each limestone bed contains evidence of progressive shallowing. The bases of some beds comprise a thin unit with large brachiopods in an argillaceous matrix deposited in relatively deep water. This passes upward into grainstone and packstone with abundant peloids, crinoids and other open marine bioclasts deposited in shallow water high-energy conditions. The tops of limestone beds often show features indicative of subaerial exposure such as calcrete and desiccation structures including fenestrae. Bedding planes represent a lithified palaeokarstic surface that has undergone dissolution during subaerial exposure. This took place either beneath a soil cover or on an exposed bedding plane. The palaeokarsts are overlain by former volcanic soils.

These limestones were deposited on a flat-topped carbonate platform in water depths ranging from tens of metres to emergent. The succession represents several repeated shallowing events culminating in subaerial exposure followed by flooding. This pattern of sedimentation is a common feature of shelf carbonates of this age in Britain and beyond and was probably caused by a combination of variations in subsidence rate and eustatic sea level variations induced by accretion and melting of polar ice caps (Horbury, 1989; Walkden, 1987).

2. Great Rocks Dale: Overview from lay-by on the A6 (SK 114 725)

The main features of the stratigraphy of the central part of the Derbyshire carbonate platform can be seen from this viewpoint. The Woo Dale Limestones of Holkerian age crop out in the Wye Valley to the west. These are the oldest exposed limestones on the Derbyshire carbonate platform and were deposited in shallow subtidal and peritidal environments (Schofield and Adams, 1985). The lower part of the Woo Dale Limestones has been replaced by dolomite. The dolomitisation was caused by the influx of Mg-rich pore fluids during Upper Carboniferous burial (Schofield and Adams, 1986). The lay-by is close to the boundary of the Woo Dale (Holkerian) and Bee Low Limestones (Asbian). The Bee Low Limestones are exposed in the old Greater Rocks Dale Quarry and in Tunstall Quarry to the north. They are equivalent to those exposed in Hartington Station Quarry and were deposited in similar enviroments. To the east, the former Buxton to Bakewell Railway follows the River Wye. The regional dip of the limestones is, with minor variations, to the east. Progressively younger limestones are therefore exposed to the east, providing an almost continuous record of the sedimentary evolution of the Derbyshire carbonate platform from the Holkerian to its final demise in the mid Brigantian.

3. Millers Dale Station Quarry (SK 137 732)

This locality demonstrates the stratigraphical relationships associated with the development of an intrashelf basin within the Derbyshire carbonate platform. The detailed stratigraphical relationships, sequence of events and sedimentology of the Station Quarry Beds has been described by Walkden (1977) and Gutteridge (1990).

The exposure behind the car park at the old Millers Dale Station comprises thickly bedded, pale limestones of Asbian age deposited in a platform interior setting. These are equivalent to the limestones exposed at Hartington Station Quarry. The top of the Asbian limestones is marked by a palaeokarst. This is overlain by more thinly bedded, darker limestones known as the Station Quarry Beds, which represent the first limestones of Brigantian age to be deposited on the Derbyshire carbonate platform. The sequence of events was:

1. Deposition of Asbian shelf limestones.
2. Subaerial exposure of the carbonate shelf at the Asbian/Brigantian boundary, producing a major palaeokarstic surface at the top of the Asbian

shelf carbonates.

3. Differential subsidence of the central part of the Derbyshire carbonate platform and the development of an intrashelf basin in which the Station Quarry Beds were deposited.

4. Litton Mills disused railway cutting (SK 156 729 to SK 162 728)

The west to east transect along the old railway cutting shows the relationship between basinal sedimentation, volcanism and a facies change from deep water basinal sedimentation to shallow water sedimentation over a structurally-controlled intrabasinal high.

The transect starts at the eastern margin of the Upper Millers Dale lava which was extruded into water. This formed a local area of shallow water over which bioclastic sediment grew. This was shed off the lava to form a wedge of bioclastic limestone containing corals and brachiopods draped over the front of the lava. The overlying Monsal Dale limestones are younger than the Station Quarry Beds. They were deposited in deep-water conditions within the intrashelf basin. The limestones exposed along the rest of the cutting to the east are at approximately the same stratigraphical level as the lava flow and show a progressive eastward change to deposition in more open marine and higher energy conditions. At the tunnel entrance at the eastern end of the cutting, the Asbian carbonate shelf limestones are seen at the base of the face. These are overlain by a palaeokarstic surface with a deep pit infilled by brownish clay. This palaeokarstic surface formed during the local uplift that produced the intrabasinal high. The Station Quarry Beds have been removed by erosion at this locality. The sequence of events recorded here is:

1. Localised uplift resulted in subaerial exposure of the Asbian limestones and removal of the Station Quarry Beds.
2. Extrusion of the Upper Millers Dale lava seen at the western end of the section. The distribution of the lava was controlled by this uplift.
3. Deposition of the Monsal Dale Limestones in an intrashelf basin setting. These show a transition from deep to shallow water deposition across this uplift.

5. Cressbrook Railway Cutting (SK 172 724)

This locality exposes the Monsal Dale limestones that were deposited in deep water in the intrashelf basin. The detailed sedimentology of limestones deposited in the intrashelf basin has been described by Gutteridge (1989).

The main limestone type comprises evenly bedded fine-grained carbonates with common tabular chert. These were deposited in low energy conditions with very low oxygen levels. They represent the background deposition of very fine-grained carbonate sediment reworked from the surrounding carbonate shelf. Several slump sheets are present which are composed of bioclast packstone and wackestone which was deposited in higher, more oxic conditions in shallow water. These are overlain erosively by bioclastic turbidites that probably represent repeated slope failure after slumping.

6. Monsal Dale viaduct cutting (SK 179 718 to SK 183 717)

This section commences at the Hobs House Coral Bed which can be traced throughout the basin. A total of three coral beds are present in the succession and are thought to represent transgressive events when sea level rose after a period of lowstand. The majority of the limestones in the Monsal Dale Viaduct Cutting are fine-grained bioclastic sediments with rare beds of coarse bioclastic sediment. They were deposited as carbonate turbidites derived from the surrounding carbonate shelf. A slump sheet is present part of the way along the section. Both the up dip extensional and down dip compressional parts of the slump sheet can be seen. In one example, a colonial coral appears to have surfed down slope on this slump sheet.

The ‘Rosewood Marble’ is present at the top of the succession. This is a finely laminated dolomitic unit. The laminations consist of alternating mm-scale carbonate mudstone and grainstone. The ‘Rosewood Marble’ is one of four similar units in the basinal succession that were deposited in a peritidal setting during a sea level lowstand when the intrashelf basin was almost completely drained. The ‘Rosewood Marble’ is slumped, showing that it is not in its initial depositional setting.

7. A6 By-Pass: Ashford Village (SK 195 695)

The highest finely laminated dolomitic unit present in the intrashelf basin succession is exposed here. This marks the boundary between the Monsal Dale and overlying Eyam Limestones (both Brigantian in age) in the intrashelf basin (Gutteridge, 1991).

This unit contains evidence of desiccation including fenestrae and desiccation curls. Other features indicative of deposition in shallow to emergent conditions, such as pseudomorphs of early-formed evaporites, plant fragments and calcrete textures are also present. This unit was deposited in a peritidal environment that developed in the intrashelf basin during sea level lowstands. The abundance of soft sediment deformation features in this laminite also shows that it is not in its original depositional setting. The details of the depositional environments of these dolomitised laminated units have been described by Gutteridge (1989). The laminated dolomitic unit is overlain erosively by a thin bed containing reworked spiriferid brachiopods. This was deposited during flooding of the intrashelf basin and is overlain by interbedded fine-grained carbonate turbidites and shale.

References

Aitkenhead, N., Chisholm, J. I. and Stevenson, I. P., 1985. The geology of the country around Buxton, Leek and Bakewell. *Memoir of the Geological Survey of Great Britain*. Sheet 111 (England and Wales).

Gutteridge, P., 1987. Dinantian sedimentation and the basement structure of the Derbyshire Dome. *Geological Journal*, **22**, 25-41.

Gutteridge, P., 1989. Controls on carbonate sedimentation in a Brigantian intrashelf basin, Derbyshire. *In* Arthurton, R. S., Gutteridge, P. and Nolan, S. C. (Eds.), *The role of tectonics in Devonian and Carboniferous sedimentation in the British Isles*. Occasional Publication of the Yorkshire Geological Society, **6**, 171-187.

Gutteridge, P., 1980. Depositional environments and palaeogeography of the Station Quarry Beds (Brigantian), Derbyshire, England. *Proceedings of the Yorkshire Geological Society*, **48**, 189-196.

Gutteridge, P., 1991. Revision of the Monsal Dale/Eyam Limestone boundary (Dinantian) in Derbyshire. *Mercian Geologist*, **12**, 71-78.

Horbury, A. D., 1989. The relative roles of tectonism and eustacy in the deposition of the Urswick Limestone in south Cumbria and north Lancashire. *In* Arthurton, R. S., Gutteridge, P. and Nolan, S. C. (Eds.), *The role of tectonics in Devonian and Carboniferous sedimentation in the British Isles*. Occasional Publication of the Yorkshire Geological Society, **6**, 153-169.

Schofield, K. and Adams, A. E., 1985. Stratigraphy and depositional environments of the Woo Dale Limestone Formation (Dinantian), Derbyshire. *Proceedings of the Yorkshire Geological Society*, **45**, 225-233.

Schofield, K. and Adams, A. E., 1986. Burial dolomitisation of the Woo Dale Limestones Formation (Lower Carboniferous), Derbyshire, England. *Sedimentology*, **33**, 207-219.

Walkden, G. M., 1977. Volcanic and erosive events on the Upper Viséan carbonate platform, north Derbyshire. *Proceedings of the Yorkshire Geological Society*, **41**, 347-366.

Walkden, G. M., 1987. Sedimentary and diagenetic styles in late Dinantian carbonates of Britain. *In* Miller, J., Adams, A. E. and Wright, V. P. (Eds.), *European Dinantian Environments*, John Wiley and Sons. 131-155.

EXCURSION

Cloud Hill Quarry

Leader: Keith Ambrose

Wednesday, 17th June, 1998

Twenty-three members met at this vast working quarry operated by Breedon Quarries plc. Access to the quarry is strictly controlled for safety reasons. These controls required the party to be conveyed between stops by Land Rovers supplied by quarry operators and the BGS. The quarry management also maintained a safety vigil throughout the duration of the trip.

The purpose of this excursion was to examine the Carboniferous Limestone exposed in the quarry. Two main facies are present, separated by an unconformity, the Main Breedon Discontinuity. Virtually the entire sequence is heavily dolomitised and as a result, precise environmental interpretation remains speculative. Undolomitised limestone is restricted to a small part of one face.

Cloud Hill [SK 41 21] is situated about 1km south of Breedon on the Hill and is one of 5 inliers of Carboniferous Limestone aligned NNW-SSE, lying between Shepshed and Melbourne. The quarry has a maximum depth of over 120m, the lowest part lying below sea level. It exploits the dolostone for roadstone and is excavated into the Milldale Limestone Formation (Aitkenhead and Chisholm, 1982) of Early Chadian age and the Cloud Hill Dolostone Formation, of ?Holkerian-Asbian age. The Milldale Limestone crops out in the eastern part of the quarry and in the lower levels in the western part; the Cloud Hill Dolostone crops out in the north and upper western faces. The major unconformity between the two formations is well exposed on these faces. The highest beds seen, in the south-west of the quarry, have been correlated with the Ticknall Limestone Formation. They have not been dated here, but are of Brigantian age at Ticknall. The rocks dip steeply (approximately 60 degrees) to the west, the dip magnitude decreasing westwards.

The inliers of Carboniferous Limestone in South Derbyshire have received little attention over the years. Table 1 shows the lithostratigraphy of the Carboniferous Limestone in Cloud Hill and Breedon quarries (Ambrose and Carney, 1997). The first detailed accounts were by Parsons (1918) and Mitchell and Stubblefield (1941), who both erected a stratigraphy for the beds. The quarries also received brief mention by Ford (1968). Monteleone (1973) produced the first detailed work on the Carboniferous Limestone of Leicestershire and South Derbyshire in an unpublished PhD thesis. King (1968, 1980, 1982, 1983) has published various papers relating to the mineralisation seen in the quarries. In 1993, the British Geological Survey commenced a full resurvey of the 1:50,000 sheet 141 (Loughborough) which includes all of the Carboniferous Limestone outcrops. The results of the mapping and detailed logging of the quarries have enabled stratigraphical revision, age determination and palaeoenvironmental interpretation. A summary of the stratigraphy is given in Table 1.

Throughout the Early Carboniferous, the area south of Breedon was submerged below a shallow shelf sea, the Hathern Shelf. This lapped onto the emergent Charnwood Forest to the south, with a fault-bounded deep-sea trough, the Widmerpool Half-Graben or Gulf, lying to the north. Here, a thick turbidite sequence accumulated as a result of fault-controlled subsidence. The Cloud Hill inlier formed in response to Late Carboniferous deformation. It stood out as an inselberg in the Permo-Triassic desert and gradually became buried by sediment deposited by fluvial and aeolian processes. The inselberg was probably completely buried in Mid to Late Triassic times. It may have remained buried until the Pleistocene, when it was exhumed by erosion associated with glacial advances and accompanying periglacial denudation.

At the **first locality**, on the eastern face of the old floor of the quarry, the oldest part of the sequence was examined. The beds here comprise thinly bedded dolostones with common, undulating, stylolite-enhanced clay or shaly mudstone partings. The beds appear moderately fossiliferous, with brachiopods and crinoids readily visible; the former

<table>
<tr><th colspan="2">LITHOSTRATIGRAPHY</th><th>AGE</th></tr>
<tr><td colspan="2">Mercia Mudstone Group</td><td>Early to Mid-Triassic</td></tr>
<tr><td colspan="3">Major unconformity</td></tr>
<tr><td colspan="2">Ticknall
Limstone
Formation</td><td>Early Carboniferous
(?Late Asbian-Brigantian)</td></tr>
<tr><td rowspan="2">Cloud Hill
Dolostone
Formation</td><td></td><td rowspan="2">Early Carboniferous
(?Holkerian-Asbian)</td></tr>
<tr><td>Cloud Wood Member</td></tr>
<tr><td colspan="3">Main Breedon Discontinuity</td></tr>
<tr><td rowspan="3">Milldale
Limstone
Formation</td><td></td><td rowspan="3">Early Carboniferous
(Early Chadian)</td></tr>
<tr><td>Holly Bush Member</td></tr>
<tr><td></td></tr>
</table>

Table 1. Stratigraphy of the rocks exposed in Cloud Hill Quarry

includes *Levitusia (Productus) humerosus*, an Early Chadian form for which this quarry is the type area. Casts of this fossil were seen in fallen blocks on the quarry floor and coquinas (shell pavements) of these and other brachiopods are visible in the face. Other fossils noted in this part of the sequence include solitary and colonial corals, gastropods and the echinoid *Archaeocidaris*. Chert nodules occur in discrete layers or within beds of dolostone. They were formed prior to dolomitisation and have therefore preserved the original structure of the rock; they have yielded a microfauna that supports an Early Chadian age. Evidence of Lead mineralisation was seen in the form of small cubic crystals of galena lining a small cavity.

Moving westwards along the face, beds of sandy dolostone and dolomitic sandstone are interbedded with the dolostone. These beds have been grouped into the 61m thick Holly Bush Member. Its occurrence is extremely localised as it dies out rapidly to the north and is only about 6m thick on the uppermost level of the quarry. Some sandy beds contain well-rounded pebbles, though these were noted only in fallen blocks. The pebbles consist mostly of vein quartz, with some quartzite, intraformational clasts and a few other lithologies, including a porphyritic, glassy volcanic rock of probable dacitic composition which may be derived from the Charnian. Some of the dolostone beds show a fine, commonly undulating lamination defined by darker, muddy laminae, reminiscent of hummocky cross stratification. Impersistent, non-sutured stylolites can also be seen in some beds.

The **second locality**, on the next face up at the south end of the quarry, allowed examination of the Milldale Limestone in its original, undolomitised state. A sequence of about 25m of partially or undolomitised limestone can be seen, occurring above the Holly Bush Member. It is a grey, fine- to coarse-grained, thin to thickly bedded, oolitic and pelloidal, bioclastic grainstone. Normal and inverse graded cycles up to 0.2m thick can be seen. Some internal bedding is visible, including wavy laminae and draping. Undulating clay, silt or shaly mudstone partings are common.

The Milldale Limestones of Cloud Hill are thought to represent accumulations of carbonate sand (shell detritus, ooids, peloids) in a shelf sea. The absence of any emergent features suggests an outer shelf rather than an inner shelf environment. These can nevertheless be high-energy zones with depositional processes affected by storm events, oceanic waves and possibly tidal currents. The shell pavements are typical storm event features and the bedding undulations may, in part, reflect hummocky cross stratification, also formed during storm events. The interbedded mudstones and siltstones settled out from suspension in quieter periods between the storms. The beds are in a shallower, more proximal setting than their equivalents at Breedon Hill, indicated by the more abundant fauna and the local clastic component seen in the Holly Bush Member.

Between localities 2 and 3, fallen blocks of dolostone were examined, showing a variety of features. They included colonial corals; burrows which are visible on several dark grey mudstone-lined bedding planes; very irregular, rubbly weathering dolostones, interpreted as palaeosols; yellowish blocks of the Late Asbian ‘reef’ facies showing in-filled cavities and bright green malachite mineralisation; blocks of Triassic breccia, composed of angular dolostone clasts set in a red or green muddy sand matrix. The palaeosols occur in the youngest beds (Ticknall Limestone Formation) and represent emergence. The primary sedimentary fabric of these rocks has been destroyed by pedogenesis and their original depositional environment is not known. Where the formation is exposed around Ticknall, and in the Ticknall Borehole, the rocks are typical shallow water carbonates. The malachite mineralisation is associated with the Triassic unconformity and precipitated from mineral-charged water percolating down during the Triassic period.

A little to the north of the undolomitised sequence, the unconformity (Main Breedon Discontinuity) between the Milldale Limestone and the Cloud Hill Dolostone was examined at **locality 3**. Strata of Late Chadian and Arundian age are missing and Holkerian age strata, though tentatively inferred, have not been proved. Current geo-chronological time scales indicate the time gap represented by the Discontinuity is between 7 and 10 million years. The beds above the unconformity dip less steeply than those below. This indicates there was uplift and slight tilting of the rocks in the intervening period. No evidence has been observed for any karstic development along the unconformity.

Farther to the north on the same face, **locality 4** showed the contact of the Asbian 'reef' and bedded carbonate sequences. Here, the contact is interpreted as a fault, but earlier exposures on the higher level showed a passage from the reef into bedded carbonates, with inter-digitation of the two. The bedded dolostones are particularly crinoid-rich hereabouts, with a high porosity resulting from dissolution of the original organisms. The 'reef' itself is a massive, finely crystalline, fossiliferous dolostone, although many potential fossils were destroyed during dolomitisation. Fossils noted in the 'reef' include brachiopods, crinoids, corals including *Amplexus*, gastropods, nautiloids and ammonoids, including the genus *Goniatites*. The fauna indicates a Late Asbian age.

These rocks represent a mud-mound 'reef' ('Cracoean buildup' of Mundy, 1994), deposited on the margin of the Hathern Shelf, probably in water depths up to 100m. The Cloud Hill 'reef' is at least 80m thick. Other Asbian 'reefs' on the northern flanks of the Widmerpool Gulf are composed of carbonate mud produced by various organisms (microbialite). They contain a diverse fauna that includes sponges, bryozoans and corals as secondary constituents, together with brachiopods, molluscs and other taxa. Crinoids can be a very common component. The Cloud Hill Dolostone 'reefs' are assumed to be of similar composition, although coral debris is not commonly preserved.

The **fifth locality**, on a higher level at the north end of the quarry, showed exposures of the Cloud Wood Member of the Cloud Hill Dolostone Formation. At the time of the visit, exposures were rather poor. In the past the formation has been well exposed, showing a thinly bedded sequence of mudstones, dolomitic siltstones and dolostones. The unit overlies the Main Breedon Discontinuity and the basal mudstone was seen near the top of the face. This bed is highly sheared and tight folding has also been observed, suggesting penecontemporaneous slumping. The underlying Early Chadian rocks are also folded here. The 'reef' can also be seen in this face, apparently overlying the Cloud Wood Member conformably. No dateable macro- or micro fossils have been recovered from these beds, but spores indicate a ?Late Holkerian to Early Asbian age.

The **final locality** allowed examination of Triassic rocks, which can be seen on the topmost face in several places throughout the quarry. The exposed face showed over 2m of greyish green and grey, interbedded mudstone and sandstone, a typical 'skerry' of older terminology. These strata occupy a hollow in the original land surface. The Triassic 'skerries' generally formed in response to short-lived sheet floods and associated periods of standing water (playa lakes) on a continental playa mudflat or sabkha. The exposed bed here has yielded a diverse assemblage of miospores, acritarchs and algae, which indicate a Mid-Triassic age. The acritarchs and algae both indicate deposition in waters of marine origin, suggesting a connection with the sea at this time. Detailed mapping of the Triassic in the surrounding area suggests that a number of the component formations (Sneinton, Radcliffe and Gunthorpe) should crop out around the quarry rim, but access problems and complex faulting make identification of the individual formations very difficult. At locality 5, the Triassic rocks are overlain mostly by red-brown till with quartzite and other pebbles derived from the Triassic. This is correlated with the Thrussington Till of the Midlands, the earliest deposit of the Anglian glaciation. On the high ground to the south of Cloud Hill, the Thrussington Till is overlain by the chalk-rich Oadby Till.

On completion of the itinerary, the President thanked Keith Ambrose for a fascinating and expertly-led trip, and also Tim Colman of BGS for his contributions to the mineralisation 'story'. Keith, Tim and Breedon Quarries were also thanked for supplying and driving the Land Rovers, which proved to be invaluable on the day.

Acknowledgements

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References

Aitkenhead, N. and Chisholm, J. I., 1982. A standard nomenclature for the Dinantian formations of the Peak Area of Derbyshire and Staffordshire. *Report of the Institute of Geological Sciences*, No. 82/8.

Ambrose, K. and Carney, J. N., 1997. The geology of the Breedon on the Hill area. *British Geological Survey Technical Report* WA/97/42.

Ford, T. D., 1968. The Carboniferous Limestone. *In* Sylvester-Bradley, P. C. and Ford, T. D. (eds). *The Geology of the East Midlands*. (Leicester: Leicester University Press), 59-81.

King, R. J., 1968. Mineralization. *In* Sylvester-Bradley, P. C. and Ford, T. D. (eds). *The Geology of the East Midlands*. (Leicester: Leicester University Press), 112-137.

King, R. J., 1980. Wulfenite in Leicestershire. *Transactions of the Leicester Literary and Philosophical Society*, **72**, 51-58.

King R. J., 1982. The occurrence of cinnabar in Leicestershire. *Journal of the Leicester Literary and Philosophical Society*, **76**, 51-53.

King, R. J., 1983. The occurrence of galena in Leicestershire. *Journal of the Russell Society*, **1**, 27-47.

Mitchell, G. H., and Stubblefield, C. J., 1941. The Carboniferous Limestone of Breedon Cloud, Leicestershire, and the associated inliers. *Geological Magazine*, **78**, 201-219.
Monteleone, P. H., 1973. *The Carboniferous Limestone of Leicestershire and South Derbyshire*. Unpublished PhD Thesis, University of Leicester.
Mundy, D. J. C., 1994. Microbialite-sponge-bryozoan-coral framestones in Lower Carboniferous (Late Visean) buildups of Northern England. *Canadian Society of Petroleum Geologists*, Memoir 17, 713-729.
Parsons, L. M., 1918. The Carboniferous Limestone bordering the Leicestershire Coalfield. *Quarterly Journal of the Geological Society of London*, **73**, 84-110.

Compiled by the Editor from contributions by Keith Ambrose and Alan Filmer

EXCURSION

Field excursion to Skipton Moor

Leader: Neil Aitkenhead

12th July, 1998

On a grey, wet and windy day, 23 members enjoyed a very interesting trip mainly to study the rocks of the Millstone Grit Group (Upper Carboniferous) south-east of Skipton. On the way the coach detoured to the top of Otley Chevin, where the Leeds Geological Association had been involved in producing a display panel, giving an excellent explanation of “The Geological Evolution of Otley Chevin and Lower Wharfdale”. The rock underfoot here is a fluvial sandstone of equivalent age (Kinderscoutian Stage) to the Kinderscout Grit. Almscliff Crag, which could just be seen through the drizzle to the north-east at the other side of Wharfedale, is of equivalent age (Pendleian) to the much older Warley Wise Grit, which we would see later. On a clear day you can apparently see the White Horse on Sutton Bank, across the Vale of York at the western end of the North Yorkshire Moors!

Before we left the coach, Neil described the geological background to the day’s excursion. Skipton Moor lies to the south-east of Skipton and is flanked by a steep escarpment overlooking the town, formed by the Pendle Grit Formation of Pendleian (E_1) age. This comprises the lowest sandstones of the Upper Carboniferous Millstone Grit Group, overlying the Bowland Shales, which in turn overlie the Lower Carboniferous limestones and shales of the largely drift-covered Craven lowlands to the north-west. The Millstone Grit Group is characterised by a succession of coarse feldspathic sandstones, deposited in the Central Pennine Basin from a large river system that drained a rising mountain range probably far to the north, near Greenland. At times, particularly during the Pendleian (E_1), Kinderscoutian (R_1) and Marsdenian (R_2) stages, huge influxes of sand and silt were carried to deeper water beyond the river delta to be deposited in suspension from turbidity currents. The Pendle Grit Formation represents the first such influx, reaching a thickness of about 400m in the Skipton Moor area. The delta prograded intermittently farther and farther south with time but it wasn’t until Marsdenian times that it eventually reached the Derby and Stoke districts, where it deposited the Ashover/Roaches grit succession.

During the last (Devensian) glaciation to affect the area, a large ice stream flowed across the Craven lowlands from the north-west. The orientation of the long axes of drumlins around Skipton indicate that this ice stream was diverted and divided by the escarpment, so that one flow went east towards Wharfedale and the other south-east down Airedale towards Keighley.

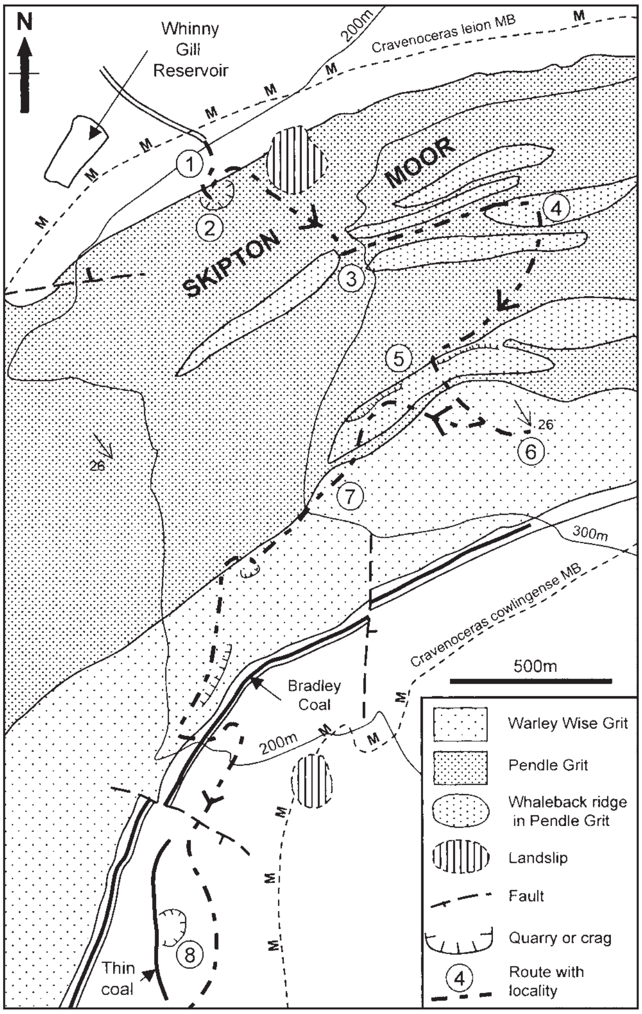
The planned itinerary included a visit to see an exposure of the *Cravenoceras leion* Marine Band in the southern corner of Whinney Gill Reservoir. This marks the base of both the Namurian and the Upper Bowland Shales. It was unfortunately under water, so had to be omitted. A section and list of fossils is given in the Bradford Memoir (Stephens *et al.*, 1953, pp.11-12).

Locality 1. Shale Plantation (SE 004 511)

The coach dropped us at the top of Short Bank Road on the south-east edge of Skipton. The track onto Skipton Moor took us up the scarp slope through Shale Plantation. The shaly mudstones here are in the upper part of the Upper Bowland Shales of Pendleian age. The *Cravenoceras malhamense* Marine Band should be present here but has not so far been detected. A few pale, thin sideritic ironstone bands are visible within the mudstone. The beds dip at 25-27 degrees to the SSE, into the hillside.

Locality 2. Jenny Gill Quarry (SE 0035 5097)

We followed the track up through the wood to Jenny Gill Quarry. This disused stone quarry exposes the lowest leaf of the Pendle Grit Formation, here comprising about 22m of medium- to coarse-grained sandstone. Proximal turbidites form individual massive beds 0.5-2.0m thick, each with a sharp base and shaly intercalations. Some show parallel laminations in their upper parts and are pebble free except for a few beds with mudstone flakes. The shallow dip of the beds into the hillside is displayed in the north wall of the quarry. Higher up the sequence in the back wall there is evidence of erosion surfaces at the base of a channel, filled with much thicker beds. There may have been an active growth fault at the time of deposition of the lowest beds; A. P. Simms (1988), who did his PhD in the area, suggested that these sandstones may be downfaulted to the same level as the previously seen Upper Bowland Shales. Thick vegetation precluded our fully checking the theory. At the base of the south face of the quarry, a thick lens-shaped sandstone bed probably represents a submarine channel fill. The sole of this bed shows well-displayed prod marks and flute casts revealed by the



Sketch map of the geology of the route.

partial removal of the underlying shaly mudstones. The prod marks give a good indication of turbidite flow, typically to the south. They are thought to be produced by woody plant stems being carried along in the current, abruptly digging into the muddy substrate, and then being slowly pulled out again as the current moved on.

Goniatites (or ammonoids in the latest parlance) had previously been collected from small exposures of mudstone in the steep grassy slope above the channel sandstone. These proved to be of late Dinantian (P_1) age, totally at variance with the Pendleian (E_1) age inferred for the quarry succession. Neil suggested that the mudstones were actually fragments in a localised cover of till or boulder clay, moved and deposited by ice from the Dinantian shale outcrop in the valley below to this elevated position high on the Pendle Grit escarpment.

Lunch was taken quickly in the rain before we continued our upwards climb following a path around the north side of the quarry. A planned stop at Cawder Gill (SE 0003 5020) was omitted due to the inclement weather. As we made our way up the hill there was evidence of post glacial landslips adjacent to the path.

Locality 3. (SE 0075 5073)

Here there was a small disused and largely grassed-over pit exposing about 1.8m of thinly interbedded siltstones and fine-grained sandstones showing well developed sole structures, which include some of those illustrated in Eager *et al.* (1985). These fine-grained turbidite beds constitute the 'background facies' into which the series of channels filled with coarse sandstone, to be seen later on, were emplaced.

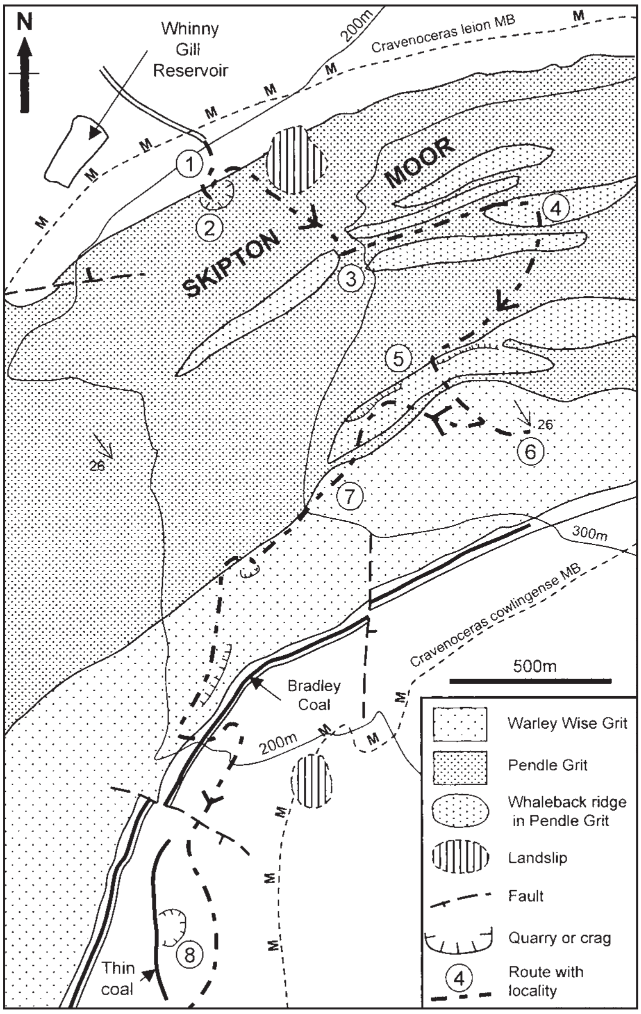
We were now high enough to appreciate the view to the north-west. Neil explained that we were looking at the deeply eroded Skipton Anticline, with the Pendle Grit of Skipton Moor dipping to the south-east forming the south-east limb and another escarpment of Pendle Grit, dipping to the north, forming the other limb. In the middle distance, the sharply featured and extensively quarried ridge in the core of the anticline consists of Lower Carboniferous limestone. The shales separating us from the limestones are mostly covered by Devensian glacial till, largely moulded into the form of drumlins.

Locality 4. (SE 0140 5093)

From here the group walked across the top of the moor towards the Trig Point at 373m on the summit of the highest whaleback ridge. Here we had a good view of the special feature of Skipton Moor, the en-echelon whaleback ridge topography. This is thought to represent high density mass flows eroding and infilling submarine channels. These have been cut into broad turbidite fans (the 'background facies') which underlies the slacks between the sandstone ridges. Alternative but rejected explanations are that the ridges may be fault controlled or even shaped by glacial erosion. The crags below the summit are the most elevated exposure of Pendle Grit. The rocks here are coarse-grained, unsorted pebbly sandstone, indicating very rapid deposition and showing ropey weathering.

Locality 5. Standard Crag and 'Standard' (SE 0110 5050 to 0081 5031)

From here the group cut back across a slack to a line of crags known as 'Standard Crag' and 'Standard'. Here the highest leaves of coarse pebbly sandstone in the Pendle Grit were exposed. This is a feldspathic sandstone with no cross bedding, showing ropey weathering. The uppermost thicker turbidite bed had scoured out the thinner bed beneath. The causes of faint laminations in these otherwise unlaminated (or massive) sandstones, and of 'ropey weathering', were discussed without any firm conclusions being reached. Grain flow was tentatively suggested to explain the former and post-glacial stress release, plus wind abrasion, the latter.



Sketch map of the geology of the route.

Locality 6. Millstone Hill (SE 0132 5022)

By now the rain had stopped and we were beginning to dry out. As we walked south to Millstone Hill, we were leaving the Pendle Grit and moving up the sequence onto the coarse-grained, cross-bedded sandstones of the Warley Wise Grit, which formed this outcrop.

Locality 7. (SE 0078 5017)

From here we turned west to reach an excellent exposure of weathered trough cross-bedded coarse-grained sandstones which are thought to be river or river mouth deposits. These comprise the lower part of the lowest leaf of the Warley Wise Grit. The change from massive turbidite to cross-bedded sandstones indicated a fundamental change in the palaeoenvironment from pro-delta slope to river-dominated delta top.

Leaving the moor on our way down to the coach at High Bradley we made a stop at a small flooded disused quarry (SE 004 499), where the rocks exposed are low in the sequence of Warley Wise Grit, with siderite and quartz pebbles, mica and also mud pellets. The low angle of cross bedding suggested probable fluvial or river mouth deposits.

The track now ran alongside a long line of crags trending NE-SW (SE 003 496). These consisted of coarse-grained, cross bedded sandstones from the upper leaf of the Warley Wise Grit. When viewed more closely they show cross-bedding, ropey weathering and sporadic quartz pebbles.

The field to the right of the road down to the village has the remains of bell pits where the Bradley Coal had been worked in the past.

Locality 8. Bradley Quarry (SE 0020 4885)

The final locality of the day enabled an examination of the Bradley Flags. About 14m of mainly fine-grained micaceous sandstone with a variety of bedforms are exposed, and are probably river mouth bar deposits. The quarry had been worked for curb stones, flagstones and building stones (Stephens, *et al.*, 1953).

By the time we returned to the coach we had dried out and our boots were well washed! We had followed the changes in deposition that had occurred in this area as the large river system from the north had prograded southwards across the Central Pennine Basin during early Namurian (Pendleian) times, from deep water marine shales to turbidites and then deltaic and fluvial sandstones. None of us will ever forget the difference between Pendle Grit and Warley Wise Grit! Many thanks to Neil for a splendid day.

Acknowledgements

I am grateful to Neil Aitkenhead for his help with this report and for providing the following references. Sketch map based on 1:10,560 geological maps SD94NE, SD95SE, SE04NW, SE05SW. Reproduced by permission of the Director, British Geological Survey.

References

Eager, R. M. C., Baines, J. G., Collinson, J. D., Hardy, P. G., Okolo, S. A. and Pollard, J. E., 1985. Trace fossil assemblages and their occurrence in Silesian (mid-Carboniferous) deltaic sediments of the Central Pennine Basin, England. *In* Curran, H. A. (Ed.), *Biogenic structures; their use in interpreting depositional environments*. Special publication of the Society of Economic Palaeontologists and Mineralogists, 99-149.

Sims, A. P., 1988. The evolution of a sand-rich basin fill sequence in the Pendleian of North-west England. Unpublished PhD Thesis, Leeds University.

Stephens, J. V., Mitchell, and Edwards, W., 1953. *Geology of the country between Bradford and Skipton*. Memoir of the Geological Survey of Great Britain.

Judy Small

EXCURSION

Ticknall and Ibstock Brick Pit

Leaders: Keith Ambrose and Albert Horton

Sunday, 6th September, 1998

This excursion visited two sites of contrasting geology. The first stop, at Ticknall, examined two facies seen in exposures in the stratigraphically highest beds of the Carboniferous Limestone cropping out in South Derbyshire. The beds here dip gently, contrasting with the deformed, steeply dipping, older rocks of the Carboniferous Limestone seen at Breedon and Cloud Hill quarries. The afternoon stop, at Ibstock, allowed detailed examination of a range of depositional environments in the Mercia Mudstone Group, commencing in the Sneinton Formation and continuing up into the Gunthorpe Formation.

Locality 1. Ticknall Lime Quarries

The village of Ticknall, in South Derbyshire, is sited in an area of varied geology. The excursion visited some former lime quarries that worked the uppermost beds of the Carboniferous Limestone, the Ticknall Limestone Formation, of Brigantian age. These rocks, which dip gently to the north-east, are overlain by the Millstone Grit. The limited evidence available suggests the contact is unconformable, with probable Arnsbergian age strata resting on the Carboniferous Limestone; all of the Pendleian age strata are thought to be absent. Locally, the Carboniferous Limestone is unconformably overlain by the Permo-Triassic Moira Formation and the Early Triassic Polesworth Formation. The former is a predominantly mudstone sequence around Ticknall and has been worked for brick clay. Elsewhere in the area, it is mainly composed of breccia, formerly known as the Moira Breccia. The Polesworth Formation (formerly Bunter Pebble Beds) consists of conglomerates and sandstones and forms the basal unit of the Sherwood Sandstone Group. It is equivalent to the Nottingham Castle Sandstone Formation of south Nottinghamshire. The Thringstone Fault, one of the major syn-Carboniferous structures of this region, runs NW-SE through the village. Coal Measures crop out to the south-west of the fault in the North-west Leicestershire Coalfield. Glacial deposits (Till; Sand and Gravel) cap some of the hills around the village.

The lime quarries in the village have long since been abandoned. They probably closed around the middle of the 19th century; Hull (1860) referred to operations in the present tense suggesting they were still working at the time of his visit. Fox-Strangways (1905) describes the workings as long abandoned. Both of these writers give only brief mention of the Carboniferous Limestone at Ticknall and adjacent inliers. Parsons (1918) was the first to describe detailed sections from this locality, dividing the exposed sequence, then about 15m thick, into 5 units (Table 1). Mitchell and Stubblefield (1941) agreed with Parsons' findings. The only recent work in the area was an unpublished PhD thesis by Monteleone (1973). He examined the Ticknall sections in detail and proposed a two-fold subdivision, combining Parsons' units. He proposed the name Ticknall Limestone Formation for these strata.

Past workers have published faunal lists from the Ticknall quarries (Hull, 1860; Fox-Strangways, 1905, 1907; Parsons, 1918; Monteleone, 1973). The fauna is dominated by brachiopods, in particular *Gigantoproductus*. Other fossils noted include corals, foraminifera, ostracods, conodonts, gastropods, crinoids, echinoids and a trilobite. In addition, Wilson (1880) found 30 species of fish, mainly identified by teeth, in the mudstone beds of these quarries, and he lists several other species found by other workers at the same locality. In 1993, the British Gological Survey commenced a full resurvey of the 1:50,000 scale sheet 141 (Loughborough) which includes all of the Carboniferous Limestone outcrops. The results of the mapping and detailed logging of the quarries have enabled the stratigraphy to be revised, a more accurate assessment of the age of the rocks to be determined and environmental interpretations to be made. The strata are now all referred to the Ticknall Limestone Formation (Ambrose and Carney, 1997), following Monteleone (1973)

The **first stop** [SK3626 2370] showed the unconformity between the Millstone Grit and the Carboniferous Limestone. A 0.3m thick fine- to coarse-grained pebbly sandstone of the Millstone Grit can be seen at the top of the section. The 'pebbles', ranging from very coarse sand to small pebble in size, comprise mainly quartz and quartzite, together with minor red claystone and some intraformational sandstone clasts. The lowermost few centimetres are dolomitic and the contact is undulating and erosive. The underlying Ticknall

Parsons (1918)		Monteleone (1973)	
Grey and yellow dolostone Thinly bedded limestones	3.4m 3.4m	Thick bedded limestone and Dolostone member	7m
Sandy stratum Foraminiferal limestones and shales Crinoidal limestones	0.7m 4.1m 3.4m	Limestone and shale member	8m

Table 1. Comparison of the lithostratigraphy of the Ticknall Limestone of past workers, giving thicknesses.

Limestone consists of grey-buff, variably red and ochreous stained, finely crystalline dolostone with a few thin clayey partings. Some fossils are visible, mainly *Gigantoproductus*. The dolostones appear to be generally massive, with some lamination visible towards the base of the exposed section.

The massive dolostone occurs throughout the quarry complex and is 4-6m thick. Locally it is sandy, grading to a dolomitic sandstone.

The **second stop** [SK361 236] includes several exposures, with the massive dolostone seen at the first stop visible in the upper part of all sections. The underlying beds are also well exposed and accessible. They consist of grey, finely crystalline, muddy and coarser bioclastic limestones which are locally dolomitised, with common interbeds of fissile mudstone up to 0.2m thick. The limestone beds have undulating boundaries and are nodular where thin, due to the secondary (diagenetic) migration of lime. They commonly have sharp, irregular contacts with the mudstones. Fossils are common locally with shell beds of *Gigantoproductus*, together with crinoids, solitary and colonial corals. Two prominent limestone beds are visible in many of the exposures and were the main beds targeted for lime production. Only about 6m of section is now exposed, compared to over 9m noted by Parsons (1918). Also seen at this stop are a number of large, disturbed and steeply dipping blocks of limestone and dolostone isolated from the main faces. Examination of the nearby faces shows no sign of any tectonic disturbance, the blocks having assumed their present aspect as a result of roof falls from former underground workings of the limestone.

The Ticknall Limestone has been mineralised and was worked for lead at Dimminsdale, a little to the south of Ticknall. Minerals noted from the Ticknall inlier include galena, chalcopyrite, baryte and aurichalcite (King, 1968).

The generally massive uppermost beds of the Ticknall succession are almost completely dolomitised and their original composition is uncertain. They are interpreted as a proximal shallow water marine facies, based on the presence of the clastic (sand) component. The second facies, comprising the fine-grained muddy limestones and coarser bioclastic limestones interbedded with fossiliferous mudstone, is interpreted as distal, shallow water marine.

Locality 2. Ibstock Brick Pit [SK 412 110]

The Ibstock Brick Pit provides some excellent exposures in the lower part of the Triassic Mercia Mudstone Group and overlying Oadby Till. Three formations are present, the Sneinton, Radcliffe and Gunthorpe formations, which were defined and mapped in the Nottingham area (Elliott, 1961; Charsley *et al.*, 1989). No recent work has been carried out by BGS in the Ibstock area since the British Geological Survey revised the Coalville Sheet (Worssam and Old, 1988) and no detailed logs of the quarry are available. Boreholes in the area indicate a thickness of around 40m for the Mercia Mudstone Group, possibly with a thin development of the Moira Formation at the base. The Sherwood Sandstone Group is absent, the Triassic rocks resting unconformably on Coal Measures.

The **first stops** were at the bottom of the quarry where exposures of the Sneinton Formation were examined. This formation, formerly known as the 'Waterstones', is the lowermost unit of the Mercia Mudstone Group. Here, it consists predominantly of structureless red-brown, micaceous siltstones and silty mudstones, with local aeolian sand grains. These are interbedded with beds of sandstone and laminated mudstones, siltstones and sandstones. The presence of mica and fine- to medium-grained sandstone beds are the main distinguishing features of the formation. The structureless argillaceous rocks also tend to be darker in colour than those seen in the higher Gunthorpe Formation. The sandstones are generally cross-bedded or cross-laminated and ripple marks are common features. One sandstone bed seen near the bottom of the quarry is lenticular in form, with well-developed cross bedding indicating deposition in a minor fluvial channel, with currents flowing approximately to the north. The base of this bed contains numerous small cavities, which probably resulted from the dissolution of calcite. The top of the bed is noticeably coarse-grained, with small pebbles visible. They include intraformational clasts, quartzite and possible Charnian lithologies. One feature of note is the well-developed spheroidal weathering, seen on some exposed faces of the structureless siltstones and mudstones. Higher in the formation, several other sandstone beds could be seen in the quarry faces, some of which were continuous and others lenticular. The sequence here contains a greater proportion of structureless mudstone and much less sandstone and laminated mudstone/siltstone/sandstone compared to the type area around Nottingham.

The **second stops** allowed examination of the overlying Radcliffe Formation. This formation is marked by the incoming of very finely laminated red-brown mudstone and paler siltstone and sandstone. It includes some thicker beds of structureless mudstone and sandstone. One of the stops showed a number of sedimentary structures, which included soft sediment deformation features (loading, convolution, pillows), mud cracks, salt pseudomorphs and ripple marks. Horizontal burrows were also noted. Of particular note were the presence of a number of layers in the middle part of the formation which contained scattered pink gypsum nodules.

The **third stops** in the upper part of the quarry showed the Gunthorpe Formation. It consists mostly of brick-red, structureless silty mudstone with some thin beds of sandstone and siltstone. The base is marked by a c.2m bed of green siltstone and sandstone, overlying the well-laminated beds of the Radcliffe Formation.

The Mercia Mudstone Group sequence exposed in this quarry shows a progressive change in depositional environments within the generally arid climate of the Triassic. The Sneinton Formation was deposited on a broad alluvial plain, with sedimentation reflecting a complex association of environments and processes including ephemeral streams, bodies of standing water, periodic sheet floods and accumulation of wind-blown mud particles. The overlying strata of the Radcliffe Formation were deposited mainly in a lacustrine environment, with frequent drying out and desiccation, and the periodic accretion of wind-blown sediment. The overlying red mudstones and silty mudstones of the Gunthorpe Formation are accumulations of wind-blown sediments in an arid playa mudflat or sabkha environment. Short-lived sheet flood episodes associated with periods of standing water (playa lakes) led to the deposition of the intercalated beds of siltstone and fine-grained sandstone.

The **final stops** were made on the uppermost level at the northern end of the quarry. Here Oadby Till ('chalky boulder clay') is exposed, overlying the Gunthorpe Formation. The till consists of a dark grey, pebbly clay with a diverse suite of erratics including numerous flints and chalk pebbles, Jurassic mudstones, ironstone, various limestones (some Middle Jurassic oolite limestones were noted), fossils including belemnites and *Gryphaea*, and quartzites derived from the basal Triassic pebble beds ('Bunter pebbles'). A number of unidentified hard rock lithologies were also noted, which probably include rocks derived from the nearby Charnian outcrops. The Oadby Till was deposited during the Quaternary Anglian ice advance between 500,000 and 400,000 years ago.

Acknowledgements

The organisers of this excursion gratefully acknowledge the co-operation and assistance of the management and staff of Ibstock PLC. This account is published with the permission of the Director, British Geological Survey.

References

Ambrose, K. and Carney, J. N., 1997. Geology of the Ticknall area. *British Geological Survey Technical Report* WA/97/17.

Charsley, T. J., Rathbone, P. A. and Lowe, D. J., 1990. Nottingham: A geological background for planning and development. *British Geological Survey Technical Report* WA/90/1.

Elliott, R. E., 1961. The stratigraphy of the Keuper Series in southern Nottinghamshire. *Proceedings of the Yorkshire Geological Society*, **33**, 197-231.

Fox-Strangways, C., 1905. The geology of the country between Derby, Burton-on-Trent, Ashby-de-la-Zouch and Loughborough. *Memoir of the Geological Survey of Great Britain*, Sheet 141 (England and Wales).

Fox-Strangways, C., 1907. The geology of the Leicestershire and South Derbyshire Coalfields. *Memoir of the Geological Survey of Great Britain* (England and Wales).

Hull, E., 1860. The geology of the Leicestershire Coalfield and of the country around Ashby-de-la-Zouch. *Memoir of the Geological Survey of Great Britain* (England and Wales).

King, R. J., 1968. Mineralization. *In* Sylvester-Bradley, P. C. and Ford, T. D. (Eds.). *The Geology of the East Midlands*. (Leicester: Leicester University Press), 112-137.

Mitchell, G. H. and Stubblefield, C. J., 1941. The Carboniferous Limestone of Breedon Cloud, Leicestershire, and the associated inliers. *Geological Magazine*, **78**, 201-219.

Monteleone, P. H., 1973. *The Carboniferous Limestone of Leicestershire and South Derbyshire*. Unpublished PhD Thesis, University of Leicester.

Parsons, L. M., 1918. The Carboniferous Limestone bordering the Leicestershire Coalfield. *Quarterly Journal of the Geological Society of London*, **73**, 84-110.

Wilson, E., 1880. Fossil fish remains from the Carboniferous Limestone of South Derbyshire. *Midland Naturalist*, **111**, 172-174.

Worssam, B. C. and Old, R. A., 1988. Geology of the country around Coalville. *Memoir of the British Geological Survey*, Sheet 155 (England and Wales).

Keith Ambrose

EXCURSION

Field visit to the Malverns Area

Leaders: Allan Brandon and Brian Moorlock, British Geological Survey

27th September, 1998

Over 50 members travelled down to the Malverns on a grey and wet day. The hired bus was full and a small number of other members, who travelled by car, joined the main group at Gullet Quarry (SO 762 381) — the first stop of the day. As we approached the Quarry good views of the solifluction terraces on the east side of the Malvern Hills could be seen. Underlain by two metres of stony clay head, these features were formed during successive periglacial episodes when warming caused slight melting and consequential sliding over the frozen sub-surface.

Upon arrival at Gullet Quarry, itself at the southern end of Swinyard Hill, the exposed junction between the Pre-Cambrian Malverns Complex and the overlying Silurian Wyche Formation of the May Hill Sandstone Group was seen. Debate as to whether this junction is an unconformity or a fault is now resolved in favour of the former. Brian Moorlock explained that some 680 million years ago, a south-east trending subduction zone resulted in the emplacement of igneous granite rocks ranging from basic to acidic in composition, which were then subject to regional metamorphism to garnet grade, followed by upthrust and shearing. The very high degree of shearing increases to the south end of the Malverns, and the once igneous gabbro has been weakened and weathered. Small pegmatite intrusions were seen to cut the Malverns Complex. Alternating sandstones, mudstones and silt bands of the overlying May Hill Sandstone Group are well exposed above the unconformity.

Returning to the bus for our waterproofs (the rain becoming increasingly heavy), the group then set out to climb up to the ridge to British Camp in the hope of getting good views of the landforms formed by the Quaternary deposits and processes, and the Lower

Palaeozoic and Mesozoic rocks. On the way, we stopped at Clutter's Cave (SO 7628 3953) which is formed in a range of metamorphosed oceanic basin volcanics. Allan Brandon pointed out the rather poorly defined pillow structures in these sodic basalts (Warren House Formation), indicative of extruded sub-aqueous activity some 566 million years ago.

Unfortunately, the weather was so bad that the anticipated views were not available to us, but Allan Brandon, with the help of a handout chart, explained that the Quaternary stratigraphy had to be set in the context of the relationship between deep sea isotope ratios and the British Quaternary stages. Prior to the Anglian glaciation of around 450,000 years ago, the major river of the area lay to the west of the Malvern Hills, not to the east as it is today. This so-called Mathon River laid down fluvial sands and gravels whose provenance lay to the north. Tributaries brought in Longmyndian rocks from the north-west and *Gryphaea arcuata* eroded from Jurassic rocks to the north-east. Interglacial deposits found beneath the river deposits near Colwall have yielded abundant beetle and macroplant remains and pollen. Some 5-600,000 years ago, the area was a boreal forest in which spruce, pine and larch flourished. This is the first and only record of larch in Britain — it was reintroduced by man in historical times. Allan produced a number of examples of amazingly well preserved Norwegian spruce cones and seeds, along with some pieces of partly burned wood that he had found in the interglacial deposits (Cromerian) indicating that forest fires occurred from time to time. The Mathon River drainage was entirely destroyed during the Anglian glaciation of the area, firstly by the valley being impounded at the south end of the Malverns by a glacier. The subsequent glaciolacustrine infill deposits were then over-ridden by the advancing glacier and till was deposited. The present day drainage was initiated at the end of the Anglian glaciation. A further interglacial deposit discovered at Colwall above the glacigenic deposits and below the Late Wolstonian (186 to 128 thousand years ago) head, has yielded late Anglian to early Hoxnian (339 to 303 thousand years ago) pollen. These discoveries have greatly helped to delimit the glaciation. During the stadials of the Middle and Upper Pliestocene, periglacial conditions gave rise to widespread gelifluction or head deposits on both flanks of the Malverns. These are manifest as dissected terraces which steepen up slope. They grade into the River Severn terrace deposits on the east side of the Malverns.

The walk continued over the well-preserved British Camp down to Wynd's Point and lunch at, or adjacent to (depending on preference), the Malvern Hills Hotel, just north of the Herefordshire Beacon.

The afternoon took the group to Eastnor Deer Park (SO 740 380) to view the landforms associated with the alternating limestone and shale sequences of the Silurian sediments. The Coalbrookdale Formation (Wenlock Shale) was seen very poorly exposed in the bottom of the valley where a number of fossils including brachiopods were found. Faulting in the Much Wenlock Limestone was also pointed out by Allan and Brian. We then moved on to see the Much Wenlock Limestone exposed at the very muddy Eastnor Castle Quarry (SO 7322 3629). Brachiopods, crinoids, and coral were found and collected along with trilobite fragments.

Continuing up the Silurian time column and into the Lower Old Red Sandstone, the group then visited a small roadside exposure at Stanley Hill, Bosbury (SO 6758 4394) to see the Bishop's Frome Limestone (previously known as the Psammosteus Limestone). This mature rubbly calcrete up to 8 metres thick is underlain by the Raglan Mudstone Formation, about 800 metres thick. This formation is comprised of silty mudstones, siltstones and interbedded sandstones representing cyclical deposition in a coastal alluvial flood plain environment. The hard calcrete at the top of the formation, Allan Brandon explained, represented the subaerial exposure of a stable surface for perhaps several thousand years. The calcrete has been quarried for the production of agricultural lime for many hundreds of years.

Finally, the group visited the old Linton Tile Works, near Bromyard (SO 668 538) to examine the early Devonian St. Maughan's Formation, which comprises around 750 metres of mudstones, siltstones with fluvial channelled sandstones, and intra-formational conglomerates. The flooded, disused quarry exposes about 24 metres of overbank floodplain mudstones with several immature calcrete profiles and channelled sandstones. The clearly defined basal sandstone has a bedding plane bearing the burrow trace fossil *Beaconites antarcticus*, first described from the Antarctic. They occur in non-marine Devonian and Carboniferous sediments and have been attributed to back-filled burrowing by a large arthropod. Fish fossils had also been found in the sandstone. After a search at the far end of the quarry, examples of *Beaconites antarcticus* were found. A good exposure of the 'cornstone conglomerate' was also seen along with evidence of pseudoanticlines.

After a long and rather wet but very enjoyable day, the coach arrived back in Nottingham just before 8.00pm. It must be added that our two leaders, Allan and Brian, handed out a very comprehensive set of excursion notes, diagrams and maps, from which much of this report has been culled!

Tony Morris

SECRETARY'S REPORT FOR 1998/ 99

The Secretary reported that, since the last AGM, 28 new members had joined and membership now stood at 338 ordinary/joint/student, 68 Institutional. Regrettably the Society had learnt of the death of a longstanding member of the Society, Miss M. Palmer who joined in 1964. The Society has had a very successful year and once again I will use my review to thank the various individuals that have made that possible.

The Secretary's job is in fact shared among a number of people. The field meetings are organised by Dr Ian Sutton and the Society is very fortunate to have someone who has such a wide knowledge of locations and leaders. I understand that very few other societies can turn out enough members to make coach hire viable. This is greatly preferable to the marshalling of large numbers of cars, so please keep coming on the field trips. If you haven't this year you missed some excellent trips:

- In June, Peter Gutteridge led 43 members on a day trip to the Wye Valley.
- Also in June, Keith Ambrose led an evening visit to Breedon Cloud Hill Quarry attended by 23 members.
- In July, Albert Horton led a trip to the Holwell area, which included a contribution from the Leicester and Rutland Wildlife Trust warden.
- Also in July, Neil Aitkenhead led a day trip to Skipton Moor attended by 26 members.
- In September, Albert Horton led a second trip, this time to Ticknall and Ibstock.
- Also in September, Allan Brandon and Brian Moorlock took 54 members on a day trip to the Malvern area.

All the above trips are reported in *Mercian Geologist* Volume 14, parts 3 or 4. We welcome guests of members on field trips where numbers are not limited. For insurance purposes we will make such people members for the day at a cost of £2.00. Members are reminded that the Society has only public liability insurance and that it is members' individual responsibility to ensure that they have adequate personal insurance and to wear a suitable hard hat. A list of field trips for each year is published in the Society's Newsletter.

The indoor meetings are occasions when most of the membership can get together. The meetings for the 1998/99 season were, for the sixth and last year, organised by Dr Neil Aitkenhead. The Society has indeed been fortunate to benefit from Neil's tremendous knowledge of potential speakers, and he is sincerely thanked for his hard work as Meetings Secretary. Jennifer Anderson will take over for the 1999/2000 season. This year once again we have enjoyed a varied and fascinating programme.

The lecture following the 1998 AGM was by Gill Norton of BGS, who had just returned from Montserrat. A huge audience saw some spectacular videos and slides along with a very interesting account of the life of a geologist at the volcano observatory. In April, the meeting was held at Loughborough University and was successful in attracting about 60 people. Tony Buck described the complete history of the Asfordby Mine from conception to demolition and explained the unique geological conditions and processes that contributed to the closure. Colin Bagshaw presented the EMGS lecture at Derby Environmental Week on the subject of Derbyshire Mines and mineralisation. A large audience of about 70 people, many of whom were non-members, all enjoyed a clear and humorous account.

The 1998/99 season of lectures got underway in October with a joint meeting with the Yorkshire Geological Society held at BGS Keyworth. A large audience (150) heard eight speakers on the theme of Recent Advances in Understanding of the Geology of the East Midlands. We are grateful to the organisers, speakers and BGS for this most successful meeting.

In November David Cantrill described the reaction of the Cretaceous flora of the Antarctic to the polar day length. The December meeting heard Russell Coope give his now famous talk on a Beetle's view of the Ice Age, which contained both humour and good science. In January, Andy Russell described the spectacular 1996 Jokulhaup. The Foundation Lecture was given by the President, who described the techniques and results of the BGS survey of the North Sea and English Channel. This was followed by an excellent meal in the comfortable surroundings of the University Staff Club.

There have been six circulars published this year. In producing this I have been greatly helped by Tony Morris and Ian Sutton's staff. Dr Sutton also saves the Society a lot of work by maintaining the address list and receiving and collating postal bookings for the trips. All members of Council have done their bit, including making tea, providing B&B and transport for speakers, moving and staffing the display, etc.

Your Council has met formally six times this year, and has been conscious of its responsibilities in accordance with Society's objectives of promoting interest in Geology by encouraging research, education and conservation. This year we continued with, or supported, several projects.

1. The Society was represented at the National Environmental Week, the Derby Show, Wollaton Hall and at three Minerals 98 quarry open days. Many thanks go to the volunteers who have taken, erected or staffed the stand. Les Hall and Philip Small have recently refurbished the display using photographs supplied by Judy Small, Peter Green and myself. We continue to welcome any other photos to help us keep the displays up to date.
2. The second initiative is the EMGS field guide

which is progressing steadily. A lot of work has been done on this by Albert Horton, Les Hall, Andy Howard and Ian Sutton.

3. The revised Nottingham Sandstone Caves book has sold well. Thanks to the generosity of the author Tony Waltham and the energetic distribution team of Andrew and Judy Rigby, Judy Small and Tony Waltham, 1200 copies of the second edition have been sold so far.

I have one final thank you to make on the Society's behalf and that is to Nottingham University for providing us with excellent accommodation for our meetings and lectures. We are very fortunate indeed to have access to these excellent facilities.

In conclusion I feel that the Society has had a very successful year and with the continuing and hopefully increased support of members, 1999/2000 should be even better.

Alan Filmer

BOOK REVIEWS

Peak District guides

DALTON, R., FOX H. and JONES, P., 1999. *Classical Landforms of the White Peak* and *Classical Landforms of the Dark Peak*. Geographical Association, Sheffield. £8.95 each, 52 pp each. ISBNs 1 899085 60 2 and 1 899085 61 0.

COPE, F. W., 1999. *The Peak District*. Geologist's Association, London, Guide 26. £12. 78 pp. ISBN 0 900717 11 4.

These three rather expensive booklets complement each other in providing a geological and geomorphological overview of the Peak District's geological environment. All three booklets are in fact updated versions of older guides by the same authors improved with the addition of colour photographs.

Dalton, Fox and Jones are lecturers at the University of Derby, with the Peak District conveniently situated for local field work. Their booklet on the White Peak is not a guide in the sense of laying out itineraries, but it does suggest appropriate vantage points. It looks at the character of the limestone plateau, the superimposed drainage pattern with the incised meanders of many of the dales, the dry valley network, the Brassington sand pocket deposits and their former extent, the limited extent of the glacial deposits and the periglacial loessic soils, and it makes a few comments on the cave systems and the underground drainage. Mineral deposits and mines are not discussed. While recognising the probability of a long pre-glacial history of denudation, followed by the multiple Pleistocene glaciations, the authors have, perhaps wisely, made little attempt to correlate the features with the standard series of glacial and interglacial episodes of the Pleistocene period elsewhere. There is a short bibilography but, surprisingly, the authors have made no reference to Tony Waltham *et al*'s "Karst and Caves of Great Britain" (published in the Geological Conservation Review series by Chapman & Hall in 1997) or to your reviewer's "Evolution of the Derwent Gorge at Matlock" (published in *Cave and Karst Science* in the same year). Some diagrams have been "borrowed" from your reviewer's own publications.

Dalton *et al*'s "Dark Peak" describes the Millstone Grit moorlands and dales that frame the White Peak. It covers the Staffordshire moorlands including the Roaches, the High Peak including Edale and Kinderscout, the eastern moors and the Ashover inlier. The evolution of the Derwent Valley is discussed, with special reference to the drainage diversion away from Bakewell to the area around Chatsworth. There is a separate chapter on the gritstone tors which cap so many hills. While the Millstone Grit country has little significance in connection with mineral mining, there was widespread small-scale mining west of Buxton and on the Ringinglow moors near Sheffield for coal seams in the Millstone Grit Series, but these sites are not mentioned. Both the booklets on the White and Dark Peaks have good coloured maps and diagrams but some of the colour photographs are rather dark.

Professor Cope's "Peak District" reflects the author's long-standing interest in the stratigraphy of the limestone beds and their correlation from dale to dale (he was Professor of Geology at Keele University for 26 years). The various groups of limestone beds and the intervening lavas (toadstones) are noted in the itineraries, but he has used local stratigraphic names for the limestone formations, in contrast to the "official" British Geological Survey's maps and memoirs. No correlation chart is offered, so the reader may sometimes get a little lost. Professor Cope only makes passing reference to the mineral deposits and the only diagram relevant to mines is a sketch of the Magpie Mine buildings. The main Millstone Grit features are described in more detail. Itineraries are given for the Wye Valley, Castleton (partly duplicating your reviewer's Geologists' Association guide to Castleton published in 1996), Dovedale, the Manifold Valley, Eyam and Stony Middleton, Matlock, Edale, the Roaches and the Goyt Valley. However, some of the directions for finding specific localities are difficult to follow. Some of the black and white maps are simple geological maps, but others are merely line sketches of roads with localities marked. Dovedale's gorge did not merit either! Thor's Cave is marked on the wrong side of the Manifold Valley. Surprisingly, there is no itinerary for the Wirksworth area where the limestone "reef knolls" are so well displayed in the old quarries around the National Stone Centre. Nor is there an itinerary for the Brassington area with its dolomite crags and tors and its silica sand pocket deposits. The guide includes a bibliography. The only photographs are on the cover, and that on the front is rather dark and gloomy; illustrations inside are entirely line drawings. *Trevor Ford*

NOTES TO CONTRIBUTORS AND AUTHORS

Scientific papers. These are accepted on the understanding that they have not been published (or submitted) elsewhere. Shorter reports, news items, reviews and comments are all welcome, especially where they have a local interest.

Submissions. All material should be prepared and submitted in a format as close as possible to that of the *Mercian Geologist* since 1992. Please submit two copies of the full text and diagrams of scientific papers; only single copies are required of photographs and of the texts of shorter items. All texts should be machine-written on A4 paper, single-sided, double-spaced and with ample margins. The text should be followed by a complete list of the captions of all the diagrams, maps and photographs, numbered in a single sequence. It is helpful if text is also sent by e-mail, and is safer when cut and pasted into a message; please avoid attached files in the first instance. Illustrations and tables are required in hard copy only.

Abstract. Scientific papers should start with an abstract that states the essential themes and results of the paper.

Maps and diagrams. These are essential to almost any paper, and are of prime importance because they are conspicious and so tend to be studied more frequently than their parent text. Please take care over their preparation, and follow the guidance notes in the adjacent panel.

Photographs. Black and white prints with good contrast are preferred. Any other format of photograph may be acceptable, but only after discussion with the editor.

References. Text references should be in the style of (Smith, 1992) or related to work by Smith (1992); use (Smith *et al.*, 1992) for more than two authors. All references are cited in an alphabetical list at the end of the text; please copy the style already used in *Mercian Geologist*, and cite journal titles in full.

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Offprints. 25 complimentary copies of scientific papers are provided.

Correspondence and submissions. All items should be addressed to the editor, Dr Tony Waltham, Civ. Eng. Dept., Trent University, Nottingham NG1 4BU. The editor welcomes queries and discussion concerning any intended submissions; phone 0115 848 2133 or e-mail: <tony.waltham@ntu.ac.uk>.

PREPARATION OF MAPS AND DIAGRAMS

Size and shape. Each illustration should be of a shape that reduces sensibly to one or two columns width in the *Mercian Geologist* format and then has a size that reflects its importance and its amount of detail. Avoid large blank spaces within any diagram; place the key to create a good shape; north should preferably be at the top of maps — but this is not essential if rotation improves the shape.

Drawing. Figures drawn by hand should be about 140% of final print size. Draw them in black ink on good tracing paper. Pay attention to line weight; using Rotring pens, lines should be in the range 0.2 to 0.8. Each drawing must be enclosed in a frame drawn with heavy lines (0.5 thick); roads, contours and boundaries should normally reach to the frame.

Lettering. All lettering must be machine produced, on adhesive lettering tape, or by computer on a scanned image. Lettering should be in sizes that will reduce to 6-12pt on the printed copy; use size and/or bold face to indicate importance; there should be minimal or nil use of upper case lettering.

Ornament. Carefully hand drawn ornament can be very effective. Alternatively add Letratone or by computer. Lithologies should keep to conventional ornaments. Sandstone = dots; limestone = brickwork; shale/clay/mudstone = dashes; igneous = x, + or v; dot size or dash length etc. allows variations for multiple stratigraphic units of comparable lithology. On cross sections, dashes or bricks must follow the bedding; therefore they may best be drawn by hand unless morphing software is available. Fine screen tones must never be used as ornament or as fill on tables (except on a compatible digitised figure) as they cannot be scanned for printing.

Digital preparation. Figures may be scanned into a computer file to then add annotation. Please confirm with the editor before starting work to ensure software compatability. Figures should then be prepared at close to final size; lettering should be in the range 6-12pt; tones of 20-50% may be used as ornament.

Help. Figure drawing is the responsibility of the author. Where facilities are unavailable, the editor may be prepared to offer assistance. In such a case, the author must still prepare the line drawing, and he must submit a clean drawing of all the lines, preferably with hand-drawn ornament, in ink on tracing or white paper, together with a photocopy of the line drawing with lettering added by hand (at approx size and in position), and with any additional ornament clearly indicated.

INDEX

Index to Volume 14 Parts 1 to 4
July 1996 to December 1999

Compiled by J. M. Small

Author Index

General Index

Chronostratigraphical Index

Lithostratigraphical Index

Localities

Palaeontological Index

NOTES

Contents