MERCIAN

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Front cover: Vein cavities on vertical fractures above small caves exposed in the open pit fluorspar mine in Carboniferous Limestone adjacent to Dirtlow Rake, above Castleton. See report on page 290. Photo: Tony Waltham.

Contents

MERCIAN NEWS

Southwell Minster

Some mysteries posed on the Society's visit to Southwell Minster (*Mercian Geologist*, 2006, 220-222) have been resolved through further enquiries by Ian Thomas, with assistance from Malcolm Rose, Mary Skinner, Rory Young and Tony Morris.

The apparently 'red sandstone with occasional green veining' on the west facade of the pulpitum was scorched in a fierce fire caused by a lightning strike 1711, which also brought down the bells, engulfed the timber of the tower and destroyed much of the roof. The redness is ascribed to oxidation, in the fire, of the iron content in the originally paler sandy limestone. The poor state of the stone in parts of the Chapter House is largely due to weathering in the 17th Century, when that part of the Minster had no windows after their lead seatings had decayed.

Of the two main types of stone used in the Minster, resolution of the sources (Mansfield or Mansfield Woodhouse) awaits sampling and chemical testing, to determine whether the blue-grey stone was worked from a deeper, less weathered horizon, or from a site away from the source of the rust-stained stone.

The stone used in the plaque commemorating the Polish army officers murdered in the Katyn Forest was cut by Beaufort Linely, to a design by Ronald Sims (then cathedral architect) using Westmorland slate, and the wall memorial to Bishop Barry is of Cumberland green slate, carved by Simon Verity. The source of the alabaster memorial to Bishop Ridding remains unverified. High in the North Transept, the pilgrim sculpture was carved by Rory Young in Ancaster 'blue heart' stone, from the un-oxidised cores of blocks of the shelly Jurassic limestone from Lincolnshire, most of which is a honey colour due to weathering inward from joint surfaces.

Grand Canyon Skywalk

The many members of the Society who have visited the Grand Canyon in Arizona may rest happier to know that the newly-opened and much-publicised Skywalk does not intrude into the well known vistas of the Canyon. It is actually 240 km downstream of the National Park sites that lie astride the Bright Angel trails, far beyond even Havasupai and Toroweep. It has been built on Eagle Point, in the Hualapai native reservation. Significantly this is less than 150 km from Las Vegas, so it targets the day-trippers for whom the Park's South Rim is a bit too far away. It stands on the Permian Kaibab Limestone (same rim rock as at the Park), which is marked by a good vertical cliff. Publicity has amusingly distorted the facts, by rounding its height above the river to the nearest 1000 feet, making it 4000 feet up. In fact it is about 3580 feet (1100 m) above the river; still respectable, even if the river is just over 2 km away, and it has a steeper profile to the river than anywhere else except the less-visited Toroweep Overlook.

Hamps and Manifold Geotrail

A new geotrail has been established by the Staffordshire RIGS Group, to explore the geology and scenery of a fascinating part of the Peak District. The 13 km trail mainly follows the resurfaced track-bed of the old Leek and Manifold Valley Light Railway between Hulme End and Waterhouses, with access at Ecton Bridge, Wetton Mill and Weag's Bridge.

A new guide describing the trail has a full-colour map, which includes a depiction of the geology, bordered by images and text of numbered features along the route, together with a geological column and cross section through the Ecton Anticline. Short notes explain the background geology of Lower Carboniefereous reefs and muddy limestone turbidites, with later Earth movements and mineralization. Geomorphological features include spectacular gorges and numerous caves. Modern dry river beds, swallets and resurgences are explained, together with periglacial dry valleys, screes and fans. Caves in the area have yielded human and animal remains from the last 10,000 years. The view from inside Thor's Cave provides the distinctive cover illustration. Mining of the copper ore, chalcopyrite, from Ecton Hill goes back to Bronze Age times and there is plenty of evidence remaining of late-18th Century endeavours. Limestone has long been quarried at Apes Tor and Brown End, while aggregates and cement are currently produced at Cauldon and Waterhouses.

The guide is aimed to provide walkers with information that will increase their awareness, understanding and enjoyment of the area. It was written by Patrick Cossey, John Reynolds and Richard Waller, with design by Rosie Duncan. It can be downloaded from the Staffordshire RIGS website, www.esci.keele.ac.uk/srigs . The project was funded by Staffordshire Aggregates Levy Grant Scheme 2006.

Editorial

The editor is happy to be able to thank John Mather, Peter Gutteridge, Mike Murphy, Tim Colman, Richard Hamblin, Keith Ambrose, Eric Robinson, the late Ron Firman, and the members of the Editorial Board for their assistance in refereeing papers that have been submitted to the *Mercian Geologist*, and also Alan Filmer for compiling the index for this volume.

Skywalk out over the rim of the Grand Canyon.

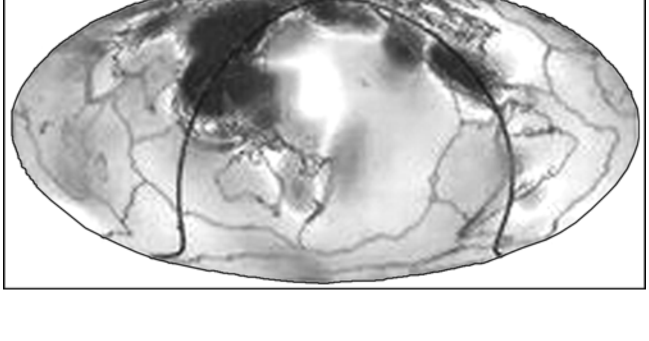
GEOBROWSER

Is science fiction now a reality?

Two recent articles provide more evidence that science fiction stories sometimes predict future discoveries.

Take kryptonite, the glowing green mineral that sapped Superman's powers whenever he was exposed to it. We all thought it only occurred on the planet Krypton, but recently researchers from the mining group Rio Tinto have found a new mineral – sodium lithium boron silicate hydroxide – which has virtually the same scientific name as that written on the box labelled 'kryptonite' that was stolen from a museum in the *Superman Returns* film. But there is a down-side to this, which BBC Television's *Have I Got News For You* programme exposed with their customary ribaldry. The new mineral does not contain fluorine (which Superman's kryptonite did), it is white, does not glow green in the dark, and is quite harmless even to super-beings. Also, it can't be called kryptonite because it does not contain the element krypton. To cap it all it has been called, disappointingly, 'Jadarite', after the place in Serbia where it was discovered (from *Science Daily* website).

The second story takes us on a *Journey to the Centre of the Earth.* Verne wrote this classic novel partly to air his theories about the internal workings of the Earth. The story culminates when the explorers stumble across a vast underground world, lit by electrically charged gas and filled with a very deep subterranean ocean surrounded by a rocky coastline covered in petrified trees and giant mushrooms. Of course there are various prehistoric creatures including an ichthyosaur, which fights and kills a plesiosaur. Most of Verne's ideas could not be proven and were ridiculed at the time, but geophysicists are constantly probing deep Earth and have recently come up with the idea that a body of water, with a volume at least as large as the Arctic Ocean, may be present within the mantle. The technique they used is based on analysis of areas within the mantle where seismic shock waves become incredibly highly attenuated ('dampened') as a result of passing through a medium that does not readily transmit them. Such areas have been found beneath Asia, along the toe of the western Pacific subduction system (dark on the world map below), and the attenuation is attributed to vast amounts of water.



This water was taken down by the subduction zone, whereas Verne used an underground river to fill his subterranean sea. Unfortunately, terms such as 'deep ocean' for this water mass cannot be accurate since voids could not be present at mantle depths. Instead, the water is taken down within the subducting slab and when finally released, it is injected into the fabric of the mantle rocks, perhaps acting as a lubricant for mantle flow and also facilitating deep-seated igneous processes such as partial melting (Source: *University of Washington in St Louis)*.

Plate tectonics theory back in time

Since the theories of Plate tectonics first evolved in the late nineteen sixties a constant research theme has been to find out how far back in time the process operated. To answer this question it is necessary to find *bona fide* fragments of ophiolite, which consists of a layered sequence of highly distinctive lithologies representing a former slice of oceanic crust. Such a sequence has recently been discovered in the Isua basement complex of Greenland, and is believed to be the Word's oldest ophiolite (*Science: 23 March, 2007)*. The sequence was mapped between outcrops covering 4-5km (2.5-3 miles) and it has all the ingredients of a typical ophiolite, except that the lowest mantle portion is missing. Crucially, these rocks show well preserved sheeted dykes and pillow lavas, clear evidence to many that these are the ancient remains of sea floor created by the types of ocean spreading processes seen today. The fact that these rocks have been radiometrically dated to 3.8 billion years ago is regarded by the researchers as a 'significant milestone' for many reasons. The discovery pushes back the oldest known evidence of plate tectonics by at least 1.3 billion years. Not only does it give clues to the processes that formed the surface of the Earth today, but it is also relevant to theories of when the Earth's crust and mantle formed. It now seems that all the essential elements for Plate tectonics must have been in place immediately after the last major meteorite bombardment, between 4 and 3.8 billion years ago (*Geobrowser, 2004)*.

…so are microbes

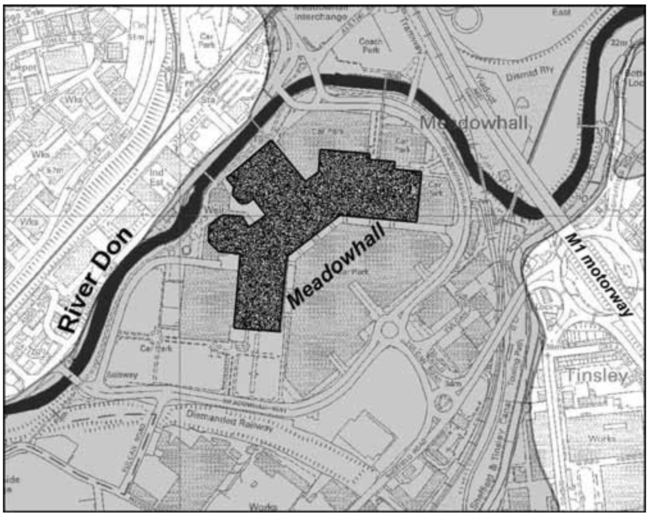
The Isua belt of Greenland could be noteworthy for another 'first'. It contains rocks with thin layers of black sediment that is carbon-rich and may therefore represent the World's oldest microbial accumulations. No microfossils have yet been found to confirm this, but in Pilbara, Australia, there are unusual laminated rocks, 3.4 billion years old, that are believed to be fossil stromatolites (*Geological Survey of Western Australia, 2002*). This, too, has not yet been convincingly demonstrated, but all the signs now point to some sort of microbial life commencing very soon after the first oceans were formed.

FLOOD REPORT

Summer rainstorms bring more geology lessons for planners

In June of this year, a succession of slowly-rotating depressions brought torrential rain to many parts of southern Britain. The East Midlands and South Yorkshire were badly affected, with several centimetres of rain measured over a 24 hour period. Some of the heaviest rain fell over the Pennines ranges, ensuring that stream courses were full and peat bogs saturated. Massive runoff was inevitable, and it was equally obvious that the water would ultimately flow into the tributaries and trunk streams of the River Don. This is unfortunate, because in the Sheffield and Rotherham areas virtually the whole of the Don Valley is a classic example of burgeoning over-development on a floodplain, with industries, residential housing, roads and railways concentrated along it. Urbanisation of this type dates back to the start of the Industrial Revolution but, due to an emphasis on 'brownfield regeneration', development continues apace today, fuelled by planning policies that seemingly do not fully understand the fact that in valleys, space also needs to be made for water (see photos on back cover).

Geological maps show the distribution of deposits such as alluvium, indicating the extent of the floodplains along which excess water is conveyed during extreme rainfall events (see *Mercian Geologist*, 2001, p126). This relationship was highlighted by the flooding that occurred at the Meadowhall Centre, on the River Don floodplain in Sheffield, first on the weekend of June 15-18 and then, with far more devastation, on June 24-25. During the culmination of



The Meadowhall Centre, outside Sheffield, sited on the flood-prone alluvium (shaded) of the River Don floodplain (from DigMap, the BGS digital geological map of Great Britain, with topography by Ordnance Survey).

this flooding, many industries and houses were also inundated, people were stranded overnight and some even had to be rescued by helicopter. Although there is some degree of flood protection along the River Don, either in the form of defences or ground raised by building construction, this has been at the cost of confining and concentrating streamflow. When the Don eventually overtopped its banks, it did so with predictable consequences for those areas that were slightly lower than the artificially elevated 'safer' parts of the modified floodplain. Meadowhall did not re-open until July 2nd, and then only 120 of the 273 stores were back in business.

Active floodplain of the River Rother, with backflooding into Catcliffe village (top left), beneath junction 33 on the M1.

Floodwater in the Meadowhall Centre.

The Magna Charta public house in Lowdham, flooded on June 25th (photo: James Brunton).

Apart from Sheffield, many small East Midlands villages with stream courses running through them were at least partially inundated by muddy ‘flash floods’ (though not comparable to the flash floods that can advance down desert wadis as walls of water, this term is now used to describe floods that rise very rapidly, generally within small catchments): and Southwell. Though relatively localised and of short duration, flooding of the villages of Lowdham, Woodborough and Oxton had much in common with

Sandbags against rising water to protect a bungalow on the main road through Woodborough (photo: Pam Footitt).

the Sheffield devastation. Typically it was caused by inappropriate development on floodplains, exacerbated by inadequate provision, or poor maintenance, of channels or drainage systems designed to convey water from extreme rainfall events.

In Lowdham, the specially designed flood-prevention basin (which doubles as a cricket pitch) overflowed, and the Cocker Beck was in many places constricted by badly designed bridges or culverts. These form ‘pinch-points’ that obstruct flood flows (ie, they encroach on the floodway), and so cause backing up of the flood waters - which then spilled over along roads and into houses built on or close to the floodplain. Houses in Woodborough were again flooded where the culvert that lies partly beneath the main street could not carry the storm flow; this was at least in part due to silting in the tunnel section, but is probably now exacerbated by a small reduction in its gradient induced by mining subsidence in 1990.

John Carney and Tony Waltham

(The aerial photographs opposite and on the back cover are by courtesy of British Geological Survey).

The main street in Woodborough, which was flooded four times by the series of heavy rainstorms this summer (photo: John Hoyland, www.woodborough-heritage.org.uk).

THE RECORD

The level of membership of the Society is being maintained and we extend a warm welcome to any members who have joined the Society this year.

Indoor Meetings 2006-7

This year's indoor meetings have once again satisfied the breadth of interest within the membership

March saw two meetings one concerned with the Jurassic Coast presented by Professor Vincent May and the other, the annual joint meeting with the Yorkshire Geological Society taking a look at recent work on the Quaternary in Eastern England.

April's lecture, given by Dr. David Shilston, told of the impact of landslides on life and property and how they might be predicted.

The beginning of the winter programme began with the work of the recently formed National Ice Age Network explained by its local project officer Dr. Mark Stephens. This was followed in November with a tour of the geology of the Sacramento and Guadalupe Mountains, in Texas and New Mexico given by Dr. Tony Dickson

The annual buffet was preceded in December by David Bate talking about Henry de la Beche's contribution to the early years of the Geological Survey. It was overseas again in January, this time to the United Arab Emirates with Richard Ellison who uncovered some of the geological treasures that have come to light during recent geological mapping there.

The President's Lecture was very well supported and was given by Professor Richard Fortey who spoke about the evolution and environment of trilobites. This meeting was followed by the Annual Dinner.

Once again we are grateful to Beris Cox for organizing such an interesting programme of speakers.

Field Meetings 2006

The season of field meetings began in May with Geo-botany and Lower Jurassic Geology at Launde and Tilton. led by Clive Jones.

In June, led by Eric Robinson, members enjoyed an evening tour of the ever changing face of Derby as seen through its building stones.

Also in June, Gerry Shaw led a visit to Dale Abbey to examine the remains of this historic site, the nearby Triassic sandstone exposures, and remains of iron and coal extraction in the area.

On into July, a day visit to Castleton led by Gerry Slavin took in Cavedale and Dirtlow Rake with an unexpected diversion to visit the site of excavations at the Titan Shaft, together with an explanation given by one of the people involved.

In September a group visited Melton Ross Quarry to see the chalk quarry, its fossils and processing plant.

A very popular visit to Chatsworth House was made in September. This was an opportunity to view the large mineral collection not on public display. It was hosted by members of the Russell Society who have been involved in collating the collection. On the same occasion Ian Thomas took groups around the house to view how stone and minerals had been used both in the construction of the house itself and in some of its fine contents.

The programme of Field Trips was as usual organised by Ian Sutton to whom we give our thanks. We are also grateful to all the field trip leaders for the hard work they put into both the preparation and on the day.

Council

Council met formally on six occasions during the year.

This year has finally seen the publication of a *Guide to the Building Stones of Leicester*. The *East Midlands Field Guide* has continued to sell well and is currently being re-printed. The Society's book *Sandstone Caves of Nottingham* will soon go out of print, and a third edition is in preparation.

A donation was given to Derby Kids Camp, an organization that arranges holidays for underprivileged children, so that they could visit the Stone Centre.

Recent changes in planning regulations have placed a duty on planning authorities to take Geodiversity into account. With this in mind Council has begun to make contact with appropriate bodies with the view to making a contribution to this process.

Some sample Rock Boxes are being trialled in schools at the moment. We thank those members who have passed on specimens for this project and ask that all members continue to bear the project in mind when they visit appropriate localities.

We are grateful to Mrs Sue Miles for keeping members up to date with the Society's activities together with information about other relevant events and organisations. Unsurprisingly as most of our new members come via the website the membership is increasingly taking the circular via e-mail.

The web site has been updated and extended and now has links to other useful sites. It continues to bring us new members and inform the public about the Society's work. We are grateful for the work Rob Townsend puts into maintaining and developing it.

In conclusion I would like to thank all those not especially named in my report without whose hard work there would be no Society.

Janet Slatter
Secretary

Geological Evolution of Central England with reference to the Trent Basin and its Landscapes

John Carney

Abstract A fundamental geological control over development of the Trent catchment system is indicated by the preference for its trunk streams to follow the Triassic outcrop, with the older rocks mainly restricted to the interfluves. This relationship between geology and drainage is partly due to differences in the relative erodibility of the rock sequences, but also to a more subtle role played by tectonics. The most important structural elements were established during the early Palaeozoic (end-Caledonian) earth movements, but their influence persisted long afterwards.

The landscapes and drainage systems of southern Britain are widely considered to have developed during the Cenozoic Period, following the destruction of the shelf sea in which Jurassic and, ultimately, Cretaceous strata were deposited (see review in Gibbard & Lewin, 2003). When this region is studied in greater detail, however, it can be argued that its modern physiography is the culmination of a more fundamental geological inheritance, over hundreds of millions of years. The trunk streams of the Trent catchment system (Fig. 1) demonstrate this, in that they are spatially related to outcrops of Triassic strata (Fig. 2). What are not so obvious are the tectonic factors that have exerted an underlying control over drainage and landscape development. This article briefly assesses the structural framework of the Trent Basin, emphasizing the role that plate tectonics has played in controlling geological and geomorphological evolution through time.

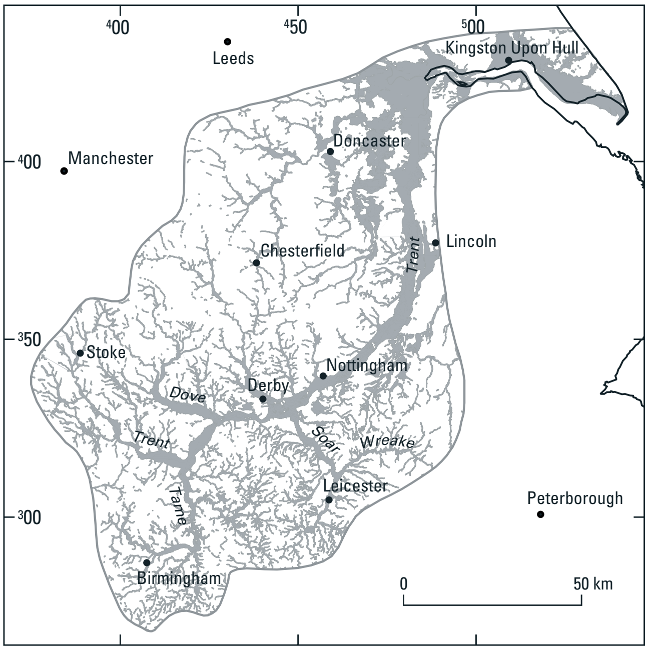


Figure 1. *Distribution of Trent floodplains defined by their deposits (alluvium and 'floodplain terrace'). Extracted from BGS digital databases (DiGMapGB)*

The rocks that frame the Trent Basin (Fig. 2) and its varied landscapes are the products of a complex geological history spanning at least 600 million years. They record periods of volcanic activity, igneous intrusion and sedimentation separated by episodes of deformation, metamorphism, uplift and erosion. The structural events are of particular importance because they have determined patterns of major faults that have been periodically reactivated, thereby controlling sedimentation and uplift within the region and, ultimately, in Cenozoic times, the emergence of the modern Trent catchment system. Such structures are the response of the Midlands' crust to fundamental changes in prevailing plate tectonic regimes, as England 'drifted' progressively northwards across the Equator and into the present temperate latitudes where, in the Quaternary, combinations of fluvial erosion, periglaciation and ice action have completed the Trent landscape evolution.

Precambrian to early Devonian: establishing the basement

The basement (i.e. pre-Carboniferous) rocks are the fundamental crustal 'building blocks' of England. In the Trent Basin, clues to their composition are to be found only in deep boreholes and in the series of small, structurally controlled inliers at Charnwood Forest, Nuneaton and around Birmingham (Fig. 2). The former two areas reveal Precambrian rocks, which mainly consist of volcaniclastic sedimentary strata together with massive andesites and dacites of probable subvolcanic origin, and intrusions. Chemical analyses of the more primary igneous components show that the parental magmas were similar to those of modern volcanic arcs generated above a subduction zone (Pharaoh *et al.*, 1987a). They further indicate that the Nuneaton and Charnwood Precambrian sequences belong to a single, geochemically uniform basement entity, known as the Charnwood Terrane. This formed one segment of the complex Avalonian volcanic arc system situated in the southern hemisphere, off the margin of the Gondwana supercontinent, between about 700 and 560 Ma (Pharaoh & Carney, 2000).

Structural considerations suggest that by end-Precambrian times the Charnwood Terrane had become tectonically merged with chemically different volcanic arc rocks (Wrekin Terrane) seen at the Wrekin and Long Mynd. This juxtaposition occurred along a major northerly trending structure, named as the 'Malvern lineament' by Lee *et al*. (1991), which in this region broadly coincides with the faults defining the Knowle and Needwood Triassic basins (Fig. 4). This 'Malvernian' tectonic influence persisted long afterwards, and will be discussed later.

In Charnwood Forest, the Precambrian rocks form a distinctive landscape of rolling hills crowned by craggy knolls, with intervening valleys excavated in the much softer, unconformable Triassic strata. They are divided (Moseley & Ford, 1985) into two lower groups of volcaniclastic rocks, of which the younger Maplewell Group contains primary volcanic components in the form of tuffs and extremely coarse, bouldery fragmental rocks (Fig. 3). The latter are interpreted as the products of pyroclastic block flows, similar to the recent eruptions on Montserrat in the Caribbean island arc (Carney, 1999; 2000). Their presence is due to the close proximity of local Precambrian volcanic centres, which were situated in the Bardon Hill and Whitwick-Sharpley areas (Carney, 2000). The Caldecote Volcanic Formation of Nuneaton differs in containing tuffaceous beds, up to 60 m thick, characterised by abundant whole or fragmentary quartz and plagioclase crystals (Bridge *et al*., 1998). As in Charnwood Forest, these rocks are cut by two sets of quartz diorite intrusions. The youngest of these has a distinctive granophyric texture and at Nuneaton it has yielded zircons giving a Late Neoproterozoic U/Pb age of 603 ± 2 Ma (Tucker & Pharaoh, 1991). The stratigraphically higher volcaniclastic strata of the Maplewell Group in Charnwood Forest have, however, given younger U/Pb zircon ages of around 566-560 Ma (Compston *et al*., 2002). That part of the succession is famous for its fossil fauna (Boynton & Ford, 1995), which includes *Charnia*, a major index fossil of the newly-established Ediacaran Stage – the final division of Precambrian time, which is considered to have ended at c 543 Ma.

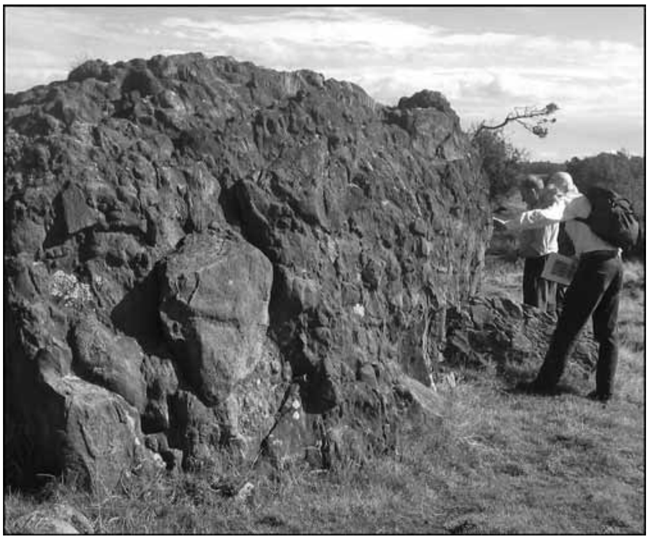


Figure 3. Precambrian volcanic breccia at the 'Bomb Rocks', in the Charnwood Lodge Nature Reserve.

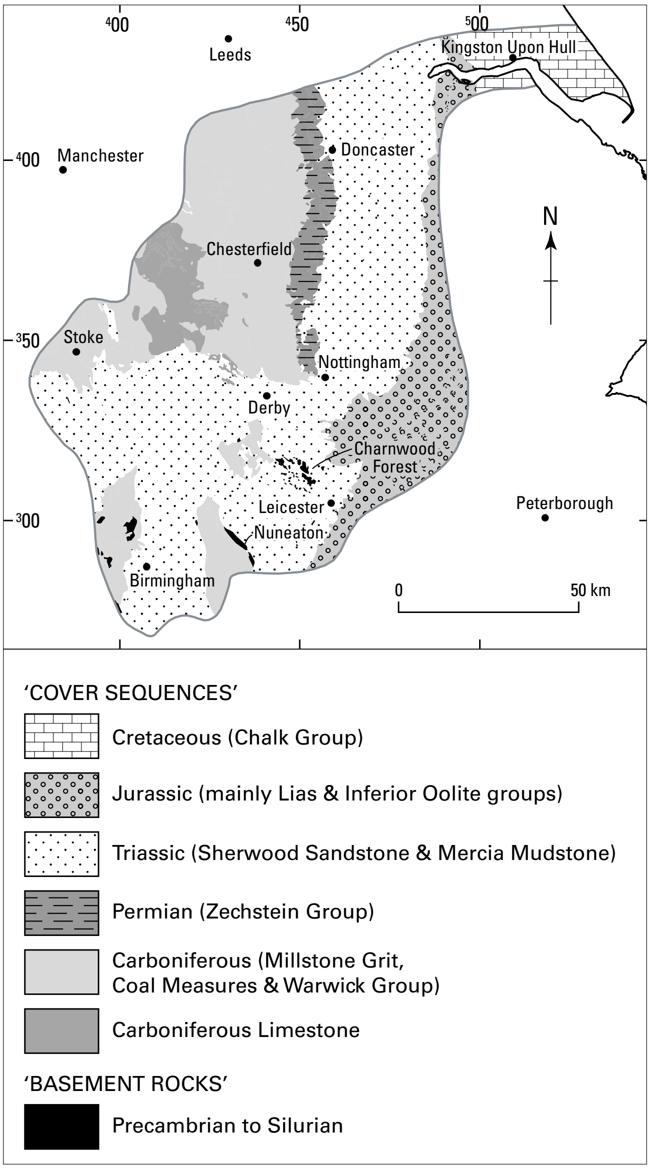


***Figure 2.** Simplified geology of the Trent catchment basin*

By the close of the Precambrian, the various volcanic arc terranes had been tectonically amalgamated to form the elongate microcontinent of Eastern Avalonia (Gibbons & Horák, 1996; Pharaoh & Carney, 2000). The sea then invaded this eroded landmass, depositing a transgressive sedimentary sequence, the fullest development of which is exposed within the Nuneaton inlier (Fig. 2). It commences with the Hartshill Sandstone Formation, deposited in nearshore, tidally influenced environments (Brasier *et al*., 1978; Bridge *et al*., 1998), which rests with erosional unconformity on deeply weathered Precambrian rocks (Carney, 1995). Near the top, this formation contains a minor depositional hiatus represented by the Home Farm Member ('*Hyolithes* Limestone'), a condensed sequence of Lower Cambrian age (Tommotian-Atdabanian) hosting the earliest shelly fossils to be found in Britain (Brasier, 1984). Trilobite-bearing mudrocks of the overlying Stockingford Shale Group are at least 700 m thick at Nuneaton where the topmost unit, the Merevale Shale Formation, has fossils indicative of a lowermost Ordovician (Tremadoc) age (Taylor & Rushton, 1971). Remarkably, Tremadocian mudrocks are also encountered in deep boreholes beneath Leicester (Molyneux, 1991), 33 km farther east. As borehole cores indicate that these rocks commonly dip steeply, the most likely explanation for their regional extent, without invoking extraordinary thicknesses, is that the Stockingford Shale Group has been tectonically repeated across faults and folds in a structurally complex basement.

In Charnwood Forest the suggestion of a Lower Cambrian age for the youngest, Brand Group rocks is a recent major development that has followed from the discovery of *Teichichnus*, a Phanerozoic trace fossil, on local headstones carved from quarries in the Swithland Formation (Bland & Goldring, 1995). The Brand Group may thus be a close contemporary of the Stockingford Shale Group, although there is no other faunal evidence to corroborate this.

Further rock sequences of probable early Ordovician (Tremadoc) age to the west and north of the Birmingham conurbation (Fig. 2) are represented by the Barnt Green Volcanic Formation, which includes water-laid tuffs, and the overlying Lickey Quartzite Formation, the latter probably deposited in nearshore, tidally influenced environments (Molyneux in Old *et al*., 1991; Powell *et al*., 2000). There are possible links between these isolated exposures and the more complete successions of the Welsh Basin, which includes igneous rocks generated by the subduction of Iapetus oceanic crust beneath Avalonia.

Silurian rocks are preserved only in the far west of the region, their most extensive outcrop being the inlier centred on Walsall, north of Birmingham (Fig. 2). They locally rest unconformably on the Lickey Quartzite Formation and their deposition is attributed to a marine transgression that occurred in Llandovery (Telychian) times (Powell *et al*., 2000). Silurian strata mainly consist of mudstones interbedded with limestone-dominant units, the most famous of which is the Much Wenlock Formation, exposed at the Wren's Nest Nature Reserve. The overlying mudstones of the Lower Ludlow Shales and Ledbury Formation (Pridoli age) are the youngest preserved elements of this transgressive sequence, the deposition of which would have been terminated, in earliest Devonian times, by the onset of the late Caledonian earth movements.

East of Birmingham, no strata between Tremadoc and late Devonian age have been found. However, igneous intrusions emplaced within the Precambrian, Cambrian and Tremadoc rock sequences have been radiometrically dated to Ordovician age (Caradoc to Ashgill), by Noble *et al*. (1993). Their calc-alkaline chemistry is compatible with magma generation during subduction of the Iapetus/Tornquist plate system beneath the Midlands, which then formed part of the northwards-migrating Avalonia microcontinent (Pharaoh, 1999). In the Trent region, these igneous intrusions are major sources of hard-rock aggregate and are well known from their exposures in large quarries, such as those currently operating at Croft and Mountsorrel (see article by A. McGrath, this issue). They fall into two chemically and mineralogically distinct 'clans': the Midlands Minor Intrusive Suite, of olivine-bearing lamprophyres and hornblende diorites, is exposed in quarries around Nuneaton (Bridge *et al*., 1998). Farther east are the granodiorites and quartz-diorites of the Mountsorrel Complex and South Leicestershire Diorites (Le Bas, 1972). The Mountsorrel and South Leicestershire plutonic rocks are chemically comparable with the contemporary Caradocian intrusions of Snowdonia and the Lake District, confirming the extension of the Caledonian magmatic system - the 'concealed Caledonides' of Pharaoh *et al*. (1987b) – down the eastern side of England.

Forming the structural template: late Caledonian orogenesis

This important tectonic episode is here divided into two parts a) movements that accompanied the late Silurian docking of Avalonia with the Laurentian plate along the Iapetus and Tornquist suture zones, and b) the Acadian orogeny (*sensu* McKerrow *et al.,* 2000) , which occurred some 20 Ma later, in Devonian (Emsian) times (Soper & Woodcock, 2003). The deformation created a structural template for much of the basement of southern Britain. In the Trent region, however, its effects have mainly been deciphered by considering the movement histories of the late Caledonian, and in some cases Precambrian, faults that have been rejuvenated through an extensive cover of younger (Upper Palaeozoic to Mesozoic) rocks. The orientations of these fundamental basement structures show significant variation across the Trent catchment, outining the three tectonic domains shown in the inset of Figure 4 (Smith *et al*., 2005). The least deformed domain is represented by the Midlands Microcraton, where northerly fault systems were ultimately inherited from the latest Precambrian phase of volcanic arc amalgamation along the 'Malvern lineament', discussed above. Those fault systems are truncated to the west by north-easterly structures of the Iapetus domain, representing Acadian deformation within the Welsh Basin. In the east, they are beheaded by the structures of the Tornquist domain, reflecting displacements within the concealed Caledonides basement of eastern England.

Charnwood Forest provides an important window on local Tornquist deformation, which here was particularly intense and accompanied by upper

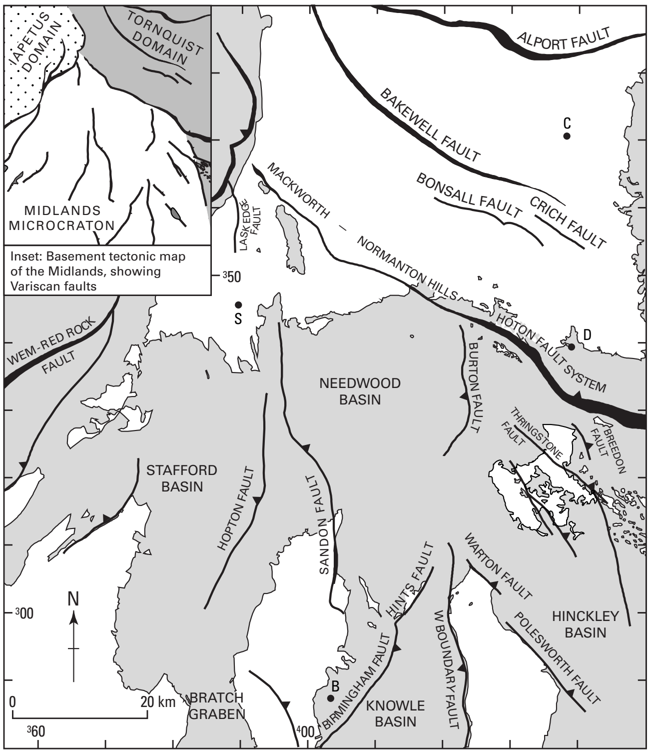


Figure 4. *Triassic outcrop (shaded) and named extensional basins, overlaid with major Variscan faults. For explanation of pre-Triassic rocks (blank areas) see Fig. 2. Inset shows the Precambrian to Palaeozoic tectonic domains that influence the underlying structure of the Trent region. Data from Smith et al. (2005). Urban conurbations shown are: B, Birmingham; C, Chesterfield; D, Derby; S, Stoke.*

greenschist metamorphism (Merriman & Kemp, 1997). The structures that resulted included north-west trending displacements, such as the Thringstone Fault and the adjacent Charnwood anticline, as well as a west-north-westerly trending, penetrative cleavage fabric (Carney *et al*., 2001). Argon isotope dating of mica cleavage fabrics suggest that in this part of Britain the cleavage, and associated folding and faulting, was actually a pre-Acadian event, which occurred in late Silurian times, about 425-416 Ma (Unpublished BGS data). The importance of these structures to the subsequent geological evolution of the region cannot be overstated; they exerted a tectonic control that persisted 'posthumously' long afterwards, and the Charnwood cleavage direction had a particular influence. It is seen in the orientation of Variscan structures such as the Mackworth-Hoton Fault System and other parallel Tornquist domain faults (Fig. 4), some of which remained periodically active into post-Jurassic times.

Late Devonian to end-Carboniferous: sedimentary and structural events

The sheer variety of sedimentary rocks produced during this period is a major feature of Trent Basin geology, and an important landscape agency. It also reflects the underlying influence of the Variscan tectonic cycle that was developing throughout the Carboniferous Period in response to stresses generated by movements within the Variscan suture and associated fold belt, which lay across southern Britain. This orogenic system marked the final stage in the tectonic amalgamation of the Pangaea supercontinent.

Following the fifty million years or so of erosion after the end-Silurian and Acadian uplifts, a change to at least localised subsidence in this region is detected in latest Devonian (Frasnian-Famennian) times, with the accumulation of mainly continental, fluvial deposits. These are only preserved along the western margin of the Nuneaton inlier, as the Oldbury Farm Sandstone Formation (Bridge *et al*., 1998). Progressive crustal extension subsequently affected the north-east of the region, where Eastern Caledonide, 'Tornquist' structures predominate (inset, Fig. 4). Deep, sediment-filled, asymmetric grabens were formed, controlling the syn-rift phase of Carboniferous deposition (Fraser & Gawthorpe, 1990; 2003). Their bounding faults have west-north-westerly orientations suggesting an underlying 'basement' structural control that is related to the tectonic 'grain' produced by the Charnwood Forest cleavage direction. In the Trent area the deepest of these troughs was the Widmerpool half-graben (or 'Gulf'), in which about 5.5 km of turbiditic, mud-dominated sediment accumulated during the Early Carboniferous (Dinantian) Period (Carney *et al*., 2001) along the northern, hangingwall side of the Mackworth-Hoton Fault System (Fig. 4). Coral reefs and carbonate shelves were established in the shallower marine environments created in parts of this tilted block and graben topography (Miller & Grayson, 1982). They belong to the fossiliferous Peak Limestone Group (formerly the Carboniferous Limestone Series or Supergroup), a major landscape-forming sequence exposed within the core of the Pennine Anticline (Fig. 2).

By Namurian times crustal extension had largely ceased, heralding the commencement of the 'post-rift' tectonic phase, characterised by regional thermal subsidence (Fraser & Gawthorpe, 1990). Sediments filled in the remaining basins, eventually expanding outwards across the bounding faults. Turbiditic mudstones, siltstones and sandstones of the Edale Shales (now the Bowland Shale Formation) were the initial products of this cycle. They were followed by the southwards encroachment of deltas that deposited the thick, feldspathic sandstones of the Millstone Grit Group. The resistance of these sandstones to erosion, compared with the intervening mudstone beds, produces the spectacular 'edges' that dominate the landscape of the Dark Peak (Fig. 5). Subsequently, during the Westphalian Carboniferous Epoch, a vast, featureless, equatorial delta plain occupied the gradually subsiding Pennine Basin (Fig. 8A). The strata deposited, belonging to the Pennine Coal Measures Group, mostly comprise repeated sedimentary cycles (Guion *et al*., 1995), commencing with dark grey to black, lacustrine or marine

Figure 5. *Burbage Edge, Derbyshire; typical upland Carboniferous scenery developed on tilted sandstone beds of the Millstone Grit Group. The slope below the sandstone exposure is veneered by a periglacial waste-mantle of Late Devensian age.*

mudstones passing upwards into sandy siltstones of overbank or lacustrine delta facies, then into channel sandstones that are commonly surmounted by a seatearth (palaeosol horizon) and coal seam (swamps and mires). This lithological diversity, when combined with later erosion, has produced a strongly featured terrain that is typical of all Coal Measures outcrops.

It is tempting to attribute this essentially quiescent geological interval to the absence of local tectonism; however, 'growth' faults have been recognized in Westphalian strata, and to the east of the region, in the Vale of Belvoir area, boreholes show that virtually the whole of the concealed Lower Coal Measures sequence was replaced by low-angled shield volcanoes. From these were erupted 'within-plate' -type alkali olivine basalt lavas and peperitic breccias (Kirton, 1984; Carney *et al*., 2004), a style of volcanism that is commonly associated with fissure activity, implying at least localized extension. Coal Measures deposition was terminated by tectonic movements that ushered in better-drained, alluvial environments in which were deposited the predominantly red-coloured mudstones and sandstones of the Warwickshire Group (formerly 'Barren Measures). These Bolsovian to Stephanian sequences are exemplified by the exposures in the South Staffordshire and Warwickshire coalfields, west of Birmingham and Nuneaton respectively (Fig. 2). The reddened, ferruginous palaeosol horizons distinctive to many parts of this group signify deep weathering associated with emergence. Uplift was probably in part fault-controlled, and was a prelude to widespread inversion of the Pennine Basin during the culmination of the Variscan Orogeny in latest Carboniferous to earliest Permian times (Besly, 1988).

The end-Variscan uplifts are most obviously manifested by the fold that formed the limestone-cored Pennine Anticline in the north (Fig. 2). Different structural styles prevailed farther south, however, in the area occupied by the Midlands Microcraton basement block. There, the Pennine Basin Coal Measures were inverted as a series of synclinal structures, the margins of which are both defined and controlled by faults which, with predominant northerly trends (Fig. 4), reflect the underlying but persistent influence of structures associated with the 'Malvern lineament' Precambrian terrane boundary. Intervening between the inverted 'coalfield synclines' were uplifted massifs composed of Precambrian and Lower Palaeozoic basement rocks (Fig. 8B). In the Tornquist structural domain the associated faults and fractures acted as conduits for the expulsion of hot, metal-rich basinal fluids that gave rise to the Derbyshire lead and fluorspar mineralisation (e.g. Ford, 2001), and many faults were bordered by inversion anticlines that favoured oil migration and accumulation, with important economic consequences for the East Midlands (Fraser & Gawthorpe, 2003).

Permian to end-Triassic: sedimentation and structural development

Throughout much of the Permian Period, of almost 40 million years duration, the land surface of eastern England was undergoing erosion within an arid, rock-desert located just to the north of the Equator, in the heart of the Pangaea supercontinent. Late in Permian times, however, marginal marine sedimentation occurred as the Southern North Sea Basin encroached across the northern parts of the Trent region. Strata of the Zechstein Group were deposited (Fig. 2), their main representative being the Cadeby Formation (Lower Magnesian Limestone), which forms the escarpment overlooking the Nottinghamshire-Derbyshire coalfield at places such as Bolsover.

By earliest Triassic times, crustal extension associated with the lead-up to Atlantic opening triggered widespread subsidence across the northern margin of Pangaea (Chadwick *et al*., 1989). In the west of the Trent region this subsidence was greatly accentuated by the development of deep, fault-bounded extensional basins (Fig. 8C). Figure 4 shows that the distribution of these basins was in large part controlled by the rejuvenation of pre-existing Variscan or earlier structures within the Midlands Microcraton, particularly those with inherited northerly, 'Malvernian' orientations; for example, the Hopton, Sandon, Burton and Western Boundary faults.

Three phases of sedimentation deposited the Triassic strata that dominate the Trent valley catchment geology (Fig. 6). Initially, major rivers flowed from the south (Warrington & Ivimey-Cook, 1992), exploiting the developing extensional basins and depositing sandstones and conglomerates of the Sherwood Sandstone Group. These strata, which are major aquifers, host the famous caves of Nottingham (Waltham, 1996), and form the many exposures around Nottingham University campus (Howard, 2003). The magnitude of differential subsidence during this earliest part of the Triassic is exemplified by the 760 m of sandstone present in the Knowle Basin (Powell *et al*., 2000), as opposed to the 50-150 m thickness range that is typical outside such basins.

Later in the Triassic Period, intensely arid climatic environments characterised deposition of the Mercia Mudstone Group. The widespread distribution and thickness of these strata is attributed to regional crustal downwarping that created a basin in which the Triassic sediments were confined and preserved, allowing them to thicken and eventually to completely cover remaining topographical elements, such as the Precambrian mountainland of Charnwood Forest. In the latter area, the basal Triassic unconformity is spectacularly displayed in Bardon Hill Quarry (Fig. 7), and at Buddon Wood Quarry, Mountsorrel (*this issue*). It is the locus of sporadic mineralization that includes base metals (Pb-Cu-V-Mo) and, more rarely, gold and silver (King, 1968). The red-coloured Mercia Mudstone strata that are so distinctive to the landscapes of the Trent catchment have been compared with loess-type deposits, and latterly (Jefferson *et al*., 2002) with the modern 'parna' of the south-eastern Australian desert. A complex of mainly continental environments is represented, albeit with occasional marine influences, in which were accumulated thick sequences of red-brown or rarely green-grey mudstone of aeolian to lacustrine origin, punctuated by fluvial episodes that deposited beds of green-grey dolomitic siltstone and sandstone, commonly referred to as 'skerries' because of their relative hardness and resistance to erosion. Higher in the group, evaporitic

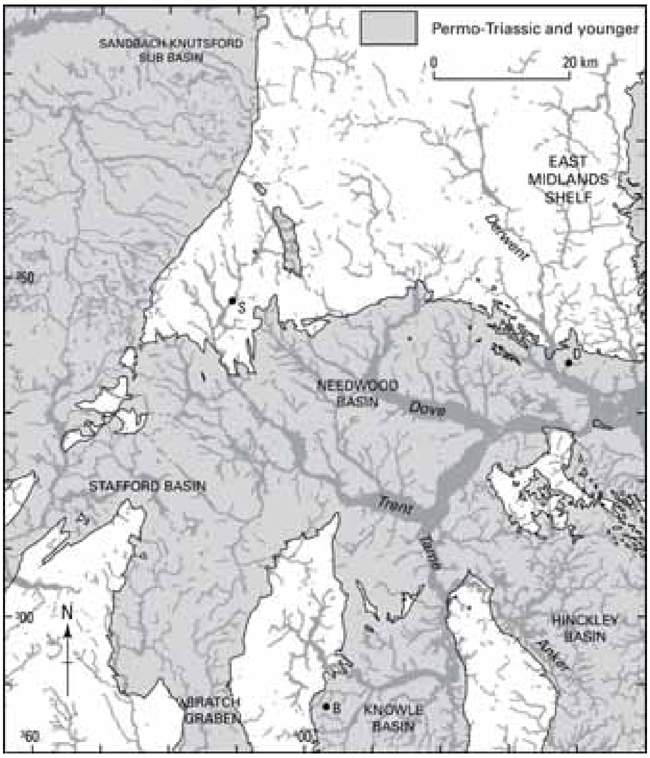


Figure 6. *Outcrop of mainly Permo-Triassic strata (shaded), with named Triassic basins (see Fig. 4), in relation to the distribution of Trent floodplain deposits.*

conditions are indicated by the incoming of gypsum, of local commercial importance.

The Penarth Group, of Rhaetian (latest Triassic) age represents the final phase of sedimentation. These predominantly argillaceous strata are of marginal marine facies (Swift & Martill, 1999) and represent the initial deposits of a major transgression. They form a small but conspicuous escarpment feature throughout the Trent region.

Jurassic to Cretaceous: submergence of the Pangaea margin

Marine conditions persisted throughout the Trent region during this 140 million year interval. Jurassic strata of the Lias and Inferior Oolite groups are the main survivors of later Cenozoic erosion. They are disposed within a 'wolds'- type landscape of cuestas and dip-slopes on the eastern margin of the Trent catchment (Fig. 2). In part, their outcrop limit determines the course of the Trent as it approaches the Humber estuary (Fig. 1). The grey mudstones of the Lias Group accumulated in the warm, shallow, sub-tropical sea that was now established across the East Midlands Shelf. The waters deepened with time, leading to better oxygenation and a transition into hemipelagic shelf environments (Weedon, 1986) that supported a diverse fauna of ammonites and bivalves. The Marlstone Rock Formation gives rise to a particularly dramatic escarpment overlooking the Vale of Belvoir, and has been a major source of ironstone and building stone. With its locally prominent cross-bedding, the unit represents one of the shallow water, regressive episodes on the East Midlands Shelf. A later regression is recorded by the Northampton Sand Formation, which is basal to the Inferior Oolite Group (Hallam, 2001).

Cenozoic uplift and erosion: the modern landscape emerges

Cretaceous strata probably accumulated across the whole of the Trent region during the final stages of the Pangaea shelf sea; however, little is known of their final extent or age because they were largely removed during 60 million years of Cenozoic erosion (Green *et al*., 2001). The latter study suggested at least two episodes of uplift, which are usually attributed to a combination of tectonic events: the opening of the Atlantic Ocean and compression transmitted from the Alpine Orogeny, which developed from the middle Cenozoic onwards. Recent work suggests that the Cenozoic tectonic regime was asymmetric, involving a principal axis of uplift along the western seaboard of England (Bott & Bott, 2004). This produced eastward tilting, about one degree, or less, on average, that allowed erosion to etch out the scarp and dip-slope topography that characterises the 'wolds' landscape on the Jurassic and Cretaceous outcrops in the far east of

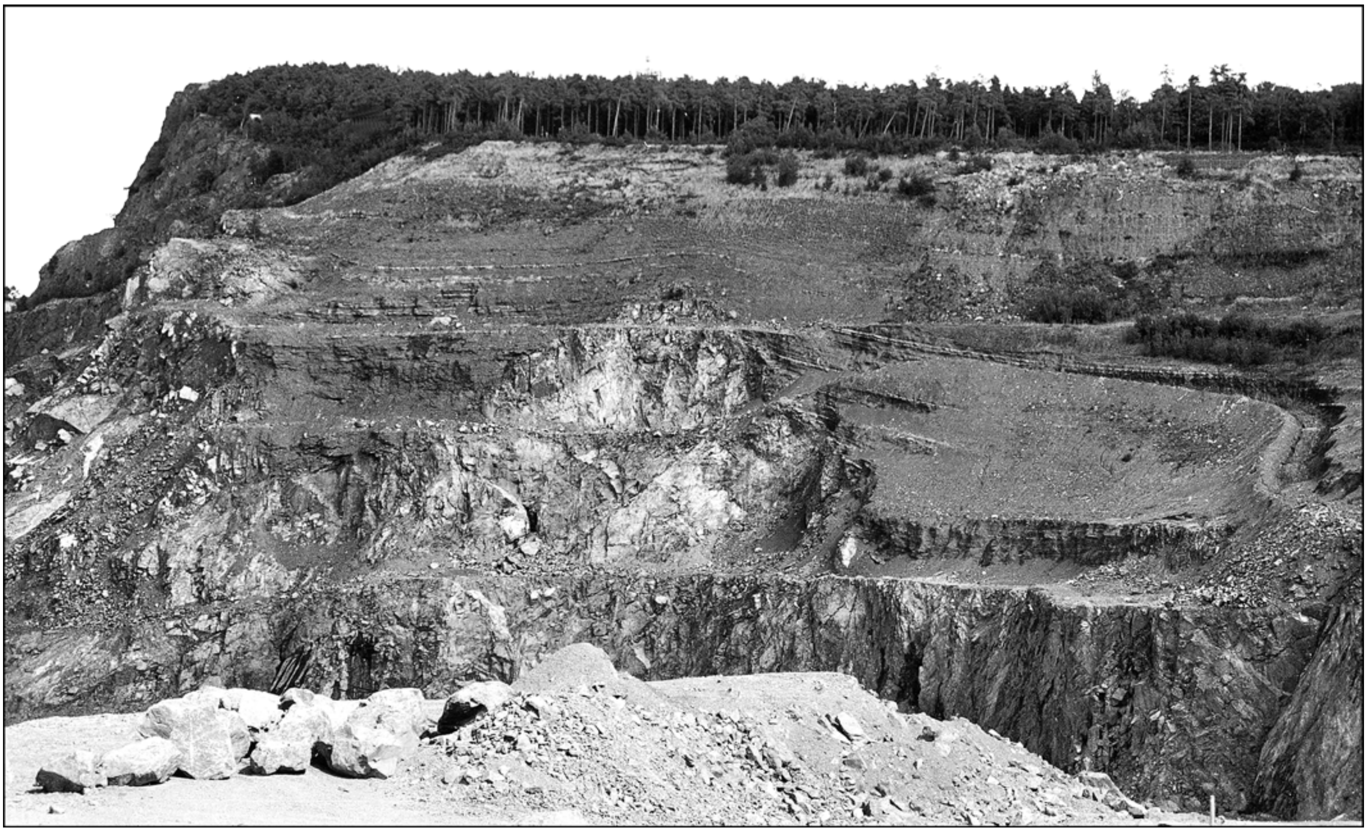


Figure 7. *Early Triassic palaeovalleys excavated on a mountainous Precambrian landsurface and filled with Mercia Mudstone strata, revealed on the east face of Bardon Hill Quarry, Charnwood Forest.*

the Trent region. The tilting initiated systems of east-flowing trunk streams, which were the main agencies for dissecting and removing the Jurassic and younger sequences (Gibbard & Lewin, 2003). One of these systems was the Bytham (or 'proto-Soar') River, the sandy deposits of which indicate that it originally flowed north-eastwards through Leicester (Fig. 1), along the present Soar valley and thence eastwards, along what is now the Wreake valley (Rice, 1991).

The geomorphological process of drainage superimposition, acting on uplifted and tilted Cretaceous strata, explains the eastward-draining river systems proposed by Gibbard and Lewin (2003), and elements of this direction are indeed represented in central England; for example the upper and middle Trent and Dove rivers. This pattern is, however, disrupted in parts where the trunk streams follow northerly courses, as shown in Figure 6. The most obvious control over this deflected drainage pattern is geological structure, with the northerly flowing streams favoured by the former sites of early Triassic rifting; for example, along the Knowle and Hinckley basins, Bratch Graben and parts of the Needwood Basin. This control was most probably facilitated by reactivation of the Triassic structures with Variscan inheritance that originally delineated these basins (Fig. 4). Thus as it was being uplifted and tilted, the Jurassic to Cretaceous cover strata were in places subsiding along fault-controlled troughs (Fig. 8D), the formation of which would have interfered with and locally deflected the easterly-flowing, superimposed river courses. There is abundant evidence in the Trent region for such post-Triassic fault reactivation (Smith *et al*., 2005; figure 44), including displacement of the youngest-preserved (Lower Jurassic) strata; for example by the Princethorpe and Whitnash faults north of Warwick (Old *et al*., 1987).

Quaternary drainage development

The progressive northwards drift of the Eurasian Plate throughout the Cenozoic Period, acting in combination with other factors, culminated in the onset of colder climatic conditions early in the Pleistocene Period. In terms of the deposits left behind in the Trent region, the most significant glaciation occurred during the Anglian Quaternary Stage, about 440 000 years ago, when ice sheets traversed the whole area, depositing locally thick 'superficial' sequences of glacigenic material dominated by till (boulder clay). BGS mapping has shown that the glacigenic deposits mantle a pre-existing topography, which includes pre-glacial valley systems such as that of the Bytham River (Rice, 1991). Thus the topography revealed following the partial erosional removal of the Anglian deposits is largely that of the Cenozoic landscape. Since ice withdrawal, however, there have been many minor, and some significant, drainage reorganisations to the pre-Anglian

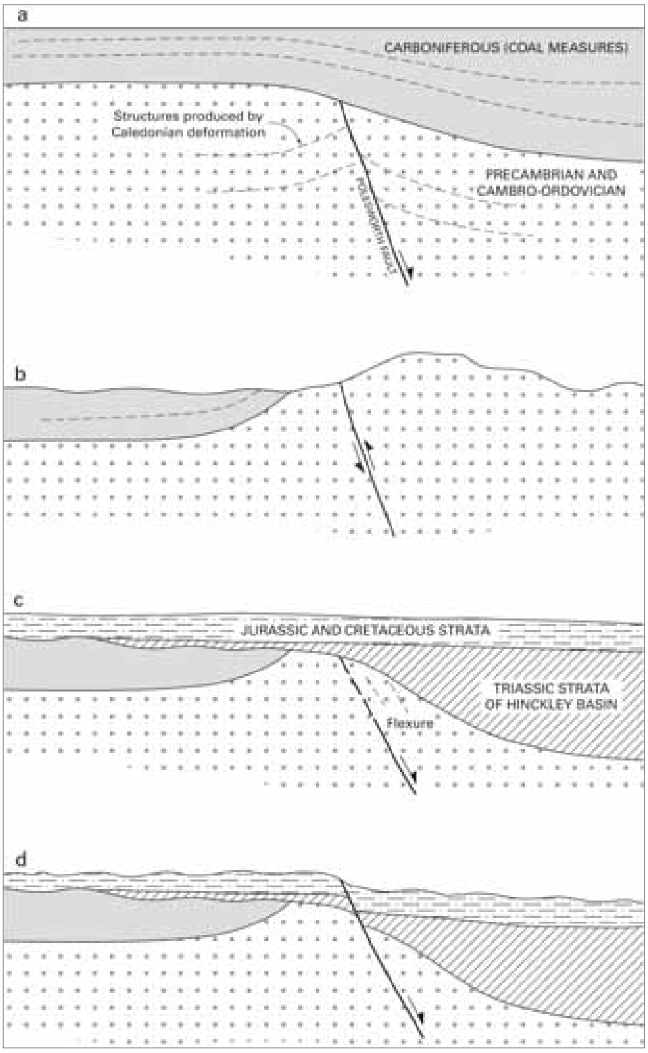


Figure 8. *Schematic rejuvenation history of a typical late Caledonian structure in Central England, using as an example the record of past movements documented for the Polesworth Fault (Bridge et al., 1998). A, possible role as a growth fault during Coal Measures sedimentation; B, end-Variscan fault rejuvenation and basin inversion; C, extensional relaxation and reversal of previous throw, with probable associated flexuring, to form early Triassic rift basins; D, further fault rejuvenation during Cenozoic regional uplift and initiation of the modern drainage pattern.*

systems. For example, the drainage in the Wreake valley (Fig. 1) was reversed to its modern westwards flowing direction.

Regional isostatic rebound and superimposed glacioeustatic fluctuations, dating from the Anglian ice withdrawal, have further influenced not only landscape development, but also the nature and distribution of fluvial deposits throughout the later part of the Pleistocene and into Holocene times. Successive aggradations and incisions over this period have resulted in a ‘flight’ of five Trent river terraces (e.g. Posnansky, 1960; Carney *et al*., 2001), each separated by a 4-7 m vertical interval. The highest and oldest terraces (Eagle Moor and Balderton terraces) have been radiometrically age-dated by Brandon & Sumbler (1991); their outcrops indicate that in pre-Ipswichian (‘Wolstonian’) times at least, the Trent must have flowed eastwards through the gap in the Jurassic escarpment at Lincoln (Fig. 1). Its subsequent diversion northwards to the Humber estuary may be a result of the younger, Late Devensian glaciation that occurred about 30 000 to 12 000 years ago, the ice front of which would have presented a barrier to drainage around the eastern, northern and western fringes of the Trent Basin. The youngest Trent terrace, the ‘floodplain terrace’ of Posnansky (1960), represents the valley-confined glacial outwash deposits of this latest cold stage; it is commonly thickly developed beneath the modern alluvium and is a major producer of sand and gravel. In Figures 1 and 6 its outcrops (named as either the Syston or Holme Pierrepont terraces) have been combined with those of the modern alluvium to provide a geology-based model of the Trent catchment in the form of its active floodplain network. This is perhaps a more realistic depiction of a river system than more conventional portrayals that are simply based on distribution of the main river channels and tributary streams. The mid-Pleistocene through to Holocene geomorphological and archaeological development of the Trent valley is summarised by Knight & Howard (2004).

Conclusions

The protracted geological history of the Trent region has played an important, albeit subtle role in determining its modern physiography. This article has documented the effects of major plate tectonic changes that have underpinned such a role, generating varied rock sequences and perpetuating structures controlling geological and geomorphological processes. The most obvious legacy of this structural evolution is a plethora of ‘weak’ crustal zones in the form of faults, folds and cleavage belts. Many of these were initiated hundreds of millions of years ago but they have persisted through time as a result of their repeated, ‘posthumous’ reactivations, a process recognised by Turner (1949). By extrapolation into Cenozoic time, it is likely that inherited structure continued to be an important geomorphological influence, imparting a differential component to uplift and tilting and contributing to the wide variety of rocks, landscapes and drainage patterns seen today in the Trent catchment.

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The Rock Quarries of Charnwood Forest

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Abstract: The Charnwood Forest area of northwest Leicestershire had a number of small quarries in the late-18th century, supplying broken rock for local road construction. Output increased when transport by horse and cart was superceded by the opening of the Leicester and Swannington Railway Line, one of the world's earliest steam railways, in 1832. Abolition of the turnpikes in 1827, followed by the passing of Local Government Acts in 1888, led to an increased demand for hard rock from the Leicestershire quarries, for bridge building and for new roads. At the same time, construction of the main line railways throughout the country created a constant requirement for railway ballast, and also provided a means to transport aggregate far afield. By 1890, Charnwood 'granite' was the main source of aggregate for Britain, producing over a million tonnes per year by 1900. Leicestershire is the largest producer of igneous rock in the country today, with production of 12.877 million tonnes of rock in 2005. This came from four large quarrying operations at Cliffe Hill, Bardon Hill, Buddon Wood (Mountsorrel) and Croft.

Geological setting

Charnwood Forest is one of the few places in England to expose the resilient Precambrian basement rocks, much valued as an aggregate for the road-building and construction industry. The landscape consists of a series of craggy inliers of Precambrian basement rocks protruding through a blanket of Triassic Mercia Mudstone deposits and Quaternary drift (Fig. 1; Carney, 1999). All of the quarries, both active and historical, exploit the durable Precambrian and Cambrian basement rocks of the Charnian Supergroup, the exception being the younger Ordovician granodiorite intrusions at Mountsorrel Quarry (the Mountsorrel Complex).

The Charnian Supergroup is subdivided into three Groups (Fig. 1), the oldest of which is the Blackbrook Group, a sequence of metavolcaniclastic breccias and sandstones. They are overlain by the Maplewell Group, a series of interbedded volcaniclastic tuffs, volcanic breccias and debris flow deposits, which in turn are unconformably overlain by the Brand Group, from which the famous Swithland Slates are derived. Until recently the Brand Group was also considered to be Precambrian in age, but the discovery of the trace fossil *Teichichnus* in the Swithland Slate Formation reclassified the group to a younger Cambrian age. It is widely accepted that the volcaniclastic material was erupted from a chain of explosive volcanoes within an intra-oceanic island arc setting, similar to the present day situation on the island of Montserrat (Ambrose et. al., 2007). The clouds of ash and dense pyroclastic flows that cascaded down the volcano flanks settled out on the sea floor around the volcanoes, forming the volcaniclastic sediments of the Blackbrook and Maplewell Groups. When subduction ceased, the volcanoes were eroded, and the sea advanced across the landscape in Cambrian times. Sedimentary rocks with little volcanic material (the Brand Group) were then deposited.

Prior to the end of magmatic activity, when the Charnian arc had attained greater maturity (Carney, 1999), the Charnian Supergroup was intruded by a series of younger Precambrian diorites (the North Charnwood Diorite) and granophyric diorites (the South Charnwood Diorite). However, the granodiorite intrusion at Mountsorrel (the Mountsorrel Complex) is a completely different entity. It formed within a new subduction zone setting during the later Ordovician period, when England was part of a small continent called Avalonia. The basement rocks were subsequently folded in Silurian times into an anticlinal structure, the axis of which plunges towards the south east, forming a U-shaped pattern of rock outcrops (Fig. 1). The anticlinal structure of the basement rocks therefore controls, to some extent, the location of the hard-rock quarries in Charnwood.

The quarries in Charnwood extract a range of rock types, including the volcaniclastic rocks of the Blackbrook Group (at Newhurst and Longcliffe Quarries) and Maplewell Group (Bardon Hill) and the younger Precambrian intrusions of the North Charnwood Diorite (Newhurst and Longcliffe) and the South Charnwood Diorite (Cliffe Hill, Groby and Hill Hole Quarries). They also exploit younger Ordovician granodiorite intrusions at Mountsorrel Quarry (the Mountsorrel Complex). Mention must also be given to the quarrying of the famous Swithland Slate Formation of the Brand Group; although they are not a hard-rock aggregate they were never the less an important (and the only local) source of slate during the 18th century. At that time they were extensively quarried from a number of sites in Charnwood Forest, which are outlined briefly at the end of this paper. Limestone quarries were also active at Grace Dieu, Breedon and Cloud Hill at the end of the 18th century (Smith, 1984), but their history is not considered in this paper.

Quarrying history in Charnwood

Quarrying can be thought of as Britain's oldest industry, as stone was primarily worked to make weapons for hunting and tools for everyday prehistoric life. Indeed, igneous rocks have been 'quarried' since at least the Neolithic (c4500-2100BC in Britain), a period that also saw the introduction of farming. The Charnwood axe industry provides the earliest clear evidence for quarrying in the region during the Neolithic period (R. Clark, *pers. com.*). Charnwood Forest was the source area for the manufacture of axes (and other stone implements) in Neolithic times, maybe due in part to the 'intractable nature of the Charnwood material' (Bradley, 1989). The axes were sculpted from a variety of Charnian materials and were widely distributed across the country, with concentrations in Charnwood itself, Derbyshire, East Anglia and Fen Edge. Although no factory has been located, several source outcrops have been identified in Charnwood Forest (Bradley, 1989). A younger axe head sculpted from local igneous rock was also found in the wall of Kellam's Farm (east of Bardon Hill) indicating that Bardon stone was still appreciated as a tool-making material in the Bronze Age (Noble, 1995). Evidence also suggests that granite millstones (or querns) were hewn from the Buddon Wood area of Mountsorrel in the Early Iron Age (Anon, 2003).

The Romans are known to have exploited several small quarries or stone pits in the Charnwood area. They utilised the granite from Mountsorrel, Groby and Hill Hole Quarry, mainly as a rubble stone, in the walls of a number of important buildings in Roman Leicester, of which the Jewry Wall is most notable. It is also believed that they incorporated Enderby stone, a type of medium- to coarse-grained quartz diorite, in to parts of the famous Fosse Way, a Roman road constructed in the mid-1st century AD. The A46 now partly follows the Fosse Way, which runs from Exeter

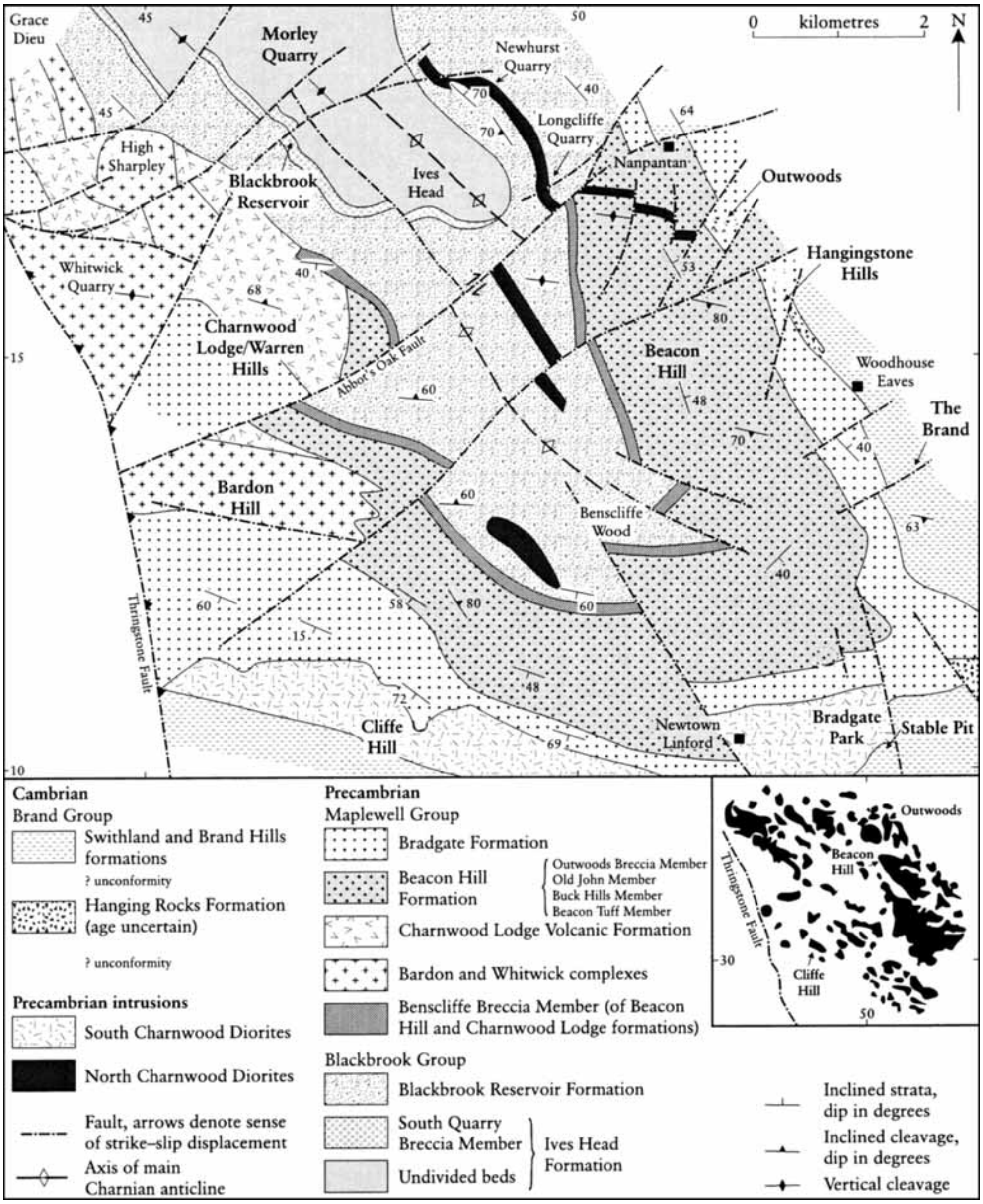

***Figure 1.** Geological map of Precambrian and Cambrian rocks in Charnwood Forest. The younger Triassic strata, Coal Measures and Quaternary drift are omitted for clarity. The inset shows the outcrop extents of the basement inliers (as dark shading) beneath this younger cover. (After Carney, 1999)*

in the southwest, through Leicester to Lincoln in the northeast. One structure that does appear to have been roofed at least partly with Swithland Slate was the Forum (the main administrative centre) in Roman Leicester or *Ratae Corieltavorum*, as it was then known. A recent excavation at a Roman site in Rothley has also yielded a substantial assemblage of characteristically rhomboidal and diamond-shaped tiles of Swithland Slate (R. Clark, *pers. com*.). This could indicate that the slate quarries around Swithland were being worked during the late Roman period (D. Ramsey, *pers. com*.). It is thought that earlier in Roman times the slates were mainly extracted from the Groby area.

Charnwood stone continued to be quarried on a small scale throughout the later centuries, and was mainly used in the construction of religious and defensive structures during the medieval period. In fact, there were 14 known medieval castles in Leicestershire, and each would have used large amounts of local stone in their construction. By the mid-16th century however, the maintenance of roads had become the responsibility of the parish through which the road ran. As a result, each parish generally had their own small quarry (the local 'Parish Pit') to supply chippings and broken stone for road repair. The formation of the Turnpike Trusts from 1726 onwards was a major step forward, representing the first real attempt since Roman times to improve highway conditions, construct new lengths of metalled roads and rebuild bridges. It led to the beginnings of a public transport network, and created a constant demand for broken rock, to both build and repair the road systems. Acts of Parliament carefully defined the limits of responsibility of each turnpike trust, and tollgates or turnpikes were erected to collect charges from road users. The revenues raised met the cost of road repairs and also gave the Trustees a profit on their investment.

By the end of the 18th century, igneous rock chippings were recognised as an excellent hard-wearing material with which to surface a road, and at this time broken granite aggregate from Mountsorrel Quarry was used in the construction of several roads in Leicestershire. John Loudon McAdam became Surveyor-General of Roads in 1827 and famously promoted the use of 'granite Macadam' when he professed that *Roads should be constructed of broken stone…covered by a series of thin layers of hard stone broken into angular fragments of nearly cubical shape*. Incidentally, McAdam provided guidelines for the correct sizing of a piece of granite to be one that could fit easily into a man's mouth. This back-fired on him when one quarryman had broken granite to too large a size; when he queried the workman, McAdam discovered that the man had no teeth, and therefore a much larger mouth cavity than normal!

The increase in road building and repair was further accelerated following two important turning points in history. First was the abolition of the turnpikes in 1827, which resulted in a far greater freedom of movement

Figure 2. *An old Cliffe Hill Quarry logo, date unknown. (Photo: MQP)*

for all vehicles. This encouraged more people to use the roads, which obviously called for additional maintenance of the road surface. The second turning point relates to a Local Government Act in 1888 that compelled local authorities to be responsible for the maintenance of their own roads. The effect of such new developments resulted in a major increase in quarrying activity in Leicestershire, which led to the opening of new quarries at Groby in 1832, Mountsorrel in 1842, Markfield in 1852, Bardon Hill in 1857 and Croft in 1868 (Fig. 4). A second wave of activity occurred at Enderby and Morley in the 1870's, followed by Cliffe Hill in 1891, Charnwood in 1881/91 and Whitwick in 1893. Demand for hard rock was further boosted during the late-19th century, when main line railways were constructed. This not only created a constant demand for railway ballast, but also provided a means to transport aggregate to customers across the country. By 1890 Charnwood Forest 'granite' had become the main source of aggregates for the whole country, from the Midlands southwards, with Leicestershire producing over a million tonnes per year by 1900. A well-known colloquialism at the time sums up the success of Leicestershire granite - *The streets are not paved with gold in London, they are paved with Leicestershire granite* (J. Shenton, *pers. com*.).

Figure 3. *Manually laying a road, Mountsorrel. Date unknown. (Photo: Lafarge Aggregates)*

But why was Leicestershire ‘granite’ so popular? The reason was, and still is, that there are no reserves of hard rock suitable for roadstone in the South of England; Leicestershire therefore provides the nearest and cheapest rock resources to these ever-expanding markets. Between 1990 and 2000, Leicestershire igneous rock ranged between 45% and 52% of the East Midlands total crushed rock production. It is also worth noting that 1.617 million tonnes of limestone were extracted in Leicestershire and Rutland in 2004, and 1.3595 million tonnes of sand and gravel were produced in 2005 (Leicestershire only). Today, Leicestershire is the largest supplier of igneous rock, supplying over a third of the nation’s requirements, three quarters of which comes from Charnwood Forest alone. The crushed rock is mainly supplied to the Southeast, the East and West Midlands and East Anglia. Most of the quarries that are open at present are operated by major industrial public companies, a process that began as early as 1876 when the Mountsorrel Granite Company was incorporated as a limited company.

Bardon Hill Quarry

The slopes of Bardon Hill have been inhabited since at least the Bronze Age as evidenced by the discovery of an axe head made from local Bardon stone in the wall of Kellam’s Farm, to the east of the present day quarry (Noble, 1995; B on Fig. 4). The remains of an ancient

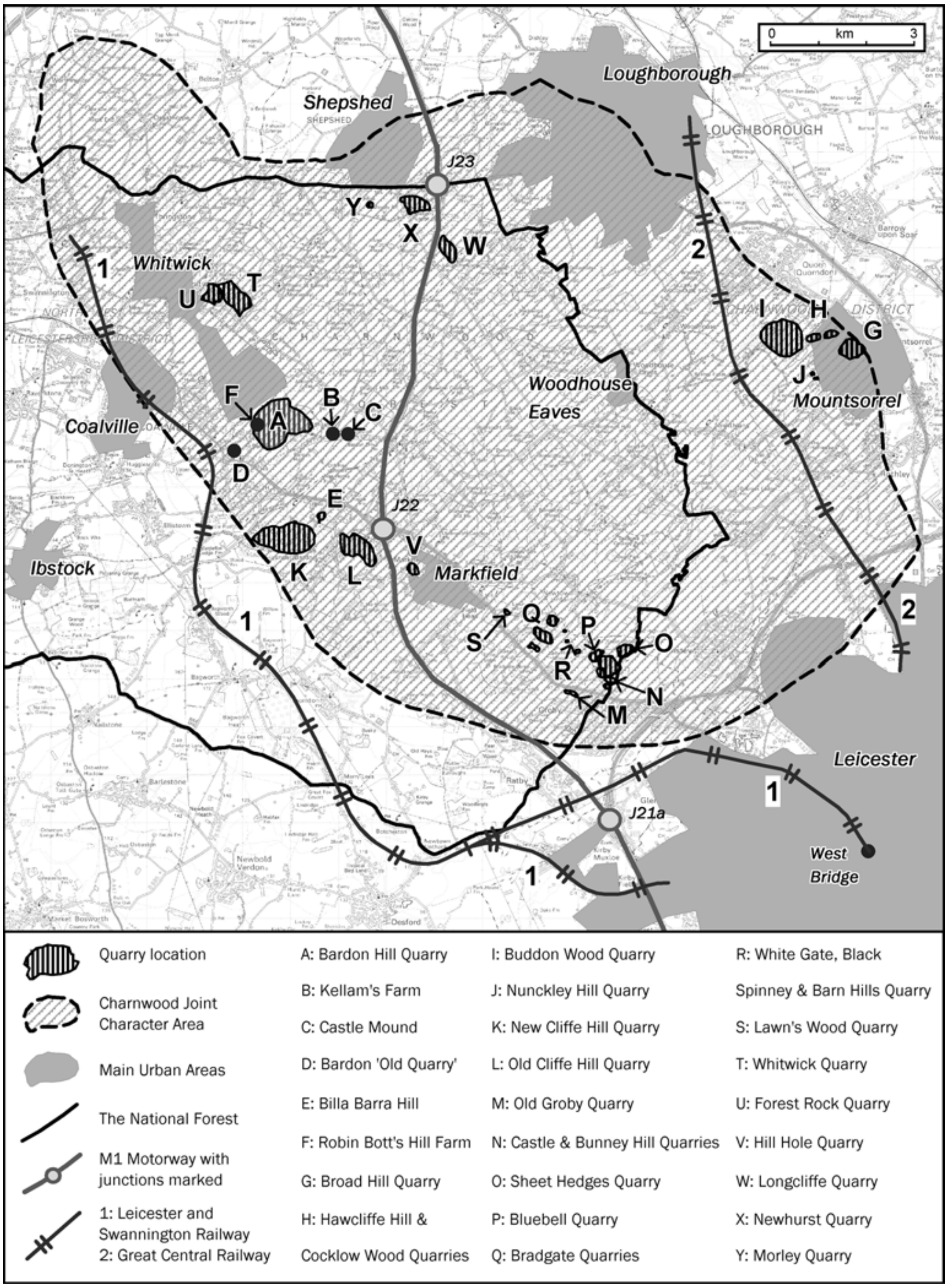

Figure 4. *Distribution of the hard-rock quarries in Charnwood Forest. (Base map by Ordnance Survey)*

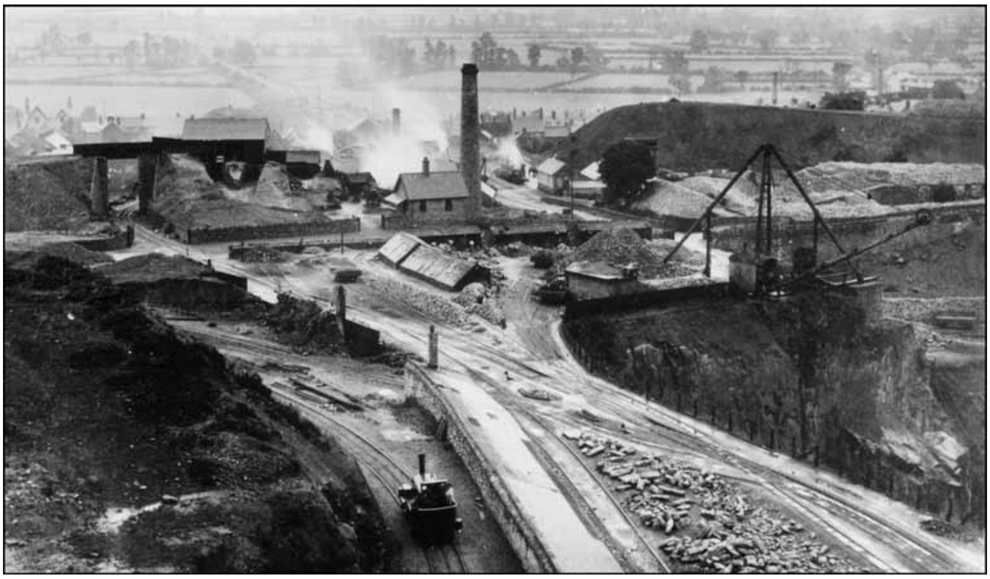

Figure 5. *General view of Mountsorrel Quarry, date unknown. (Photo: Lafarge Aggregates)*

farmstead or burial site dating to c 500 BC can also be found to the east of Kellam's Farm at Castle Mound, suggesting that the area was still occupied during the Iron Age. The Romans are known to have used the high point of Bardon Hill as a look-out post, and there is also some speculative evidence to suggest that Bardon Hill was once an ancient religious site, as the eighteenth century writer Throsby refers to druidical ruins on the north side of the Hill. Unfortunately the ruins have never been found. Blandford also recorded the discovery of gold in small quantities at Bardon Hill in 1880, but obviously not enough to start a gold rush! Bardon Hill Quarry is unique, as it is the only locality to expose the Bardon Hill Complex, which is made up of the Peldar Porphyritic Dacite and the Bardon Breccia. The exposures within the quarry provide a rare opportunity to decipher the magmatic processes that operated within one of the Charnian volcanic centres (Carney *et. al*., 2000).

Bardon originally consisted of a deer park, 1500 acres in size, which formed part of the manor of Whitwick within the 'waste' of Charnwood Forest (Noble, 1995). The earliest printed reference to quarrying within the Park was made by the topographer William Burton (1622), when he incorrectly describes Bardon Hill as having …*great quarries of hard stone, which some take to be a kind of lime-stone*. Bardon Chapel, built in 1694 by John Hood, was constructed from Bardon stone, as was the Old Hall, a moated manor house (built circa 1300-1500), and the summer-house that in 1743 once stood on the summit of the Hill (Fenn, 2003). All provide evidence of early quarries somewhere on the Bardon Estate, if only on a small scale. However, it is known for certain that several minor quarries existed in the vicinity of the turnpikes at Bardon in the early 1800s (and most probably earlier), to supply crushed stone for local road repairs. One of these quarries (the 'Old Quarry', D on Fig. 4; Fig. 6) still exists today and straddles the grounds of Bardon Hill House, built c 1820-40, and the beer garden of the Birch Tree Inn; it is thought to predate both buildings. A second, possibly more ancient quarry, little more than a stone pit, was sadly obliterated in 1993 when the site was included in the new Birch Tree roundabout.

The Ellis and Everard partnership first realised the value of the mineral wealth at Bardon Hill in the 1850s. In those days the best-quality resource was called the 'Bardon Good Rock', which is a type of grey-green andesitic breccia, of Precambrian age.

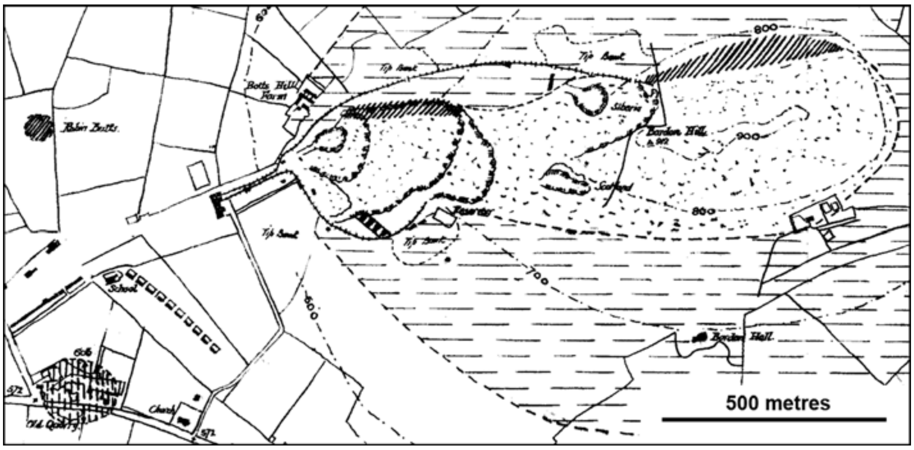

Figure 6. *An old map of the quarries around Bardon Hill, dated 30th June 1906, with the locations of Botts Hill Farm, the Old Quarry (in the SW corner), Scotland and Siberia Quarries (east of centre), the school and the adjacent string of workmen's cottages.*

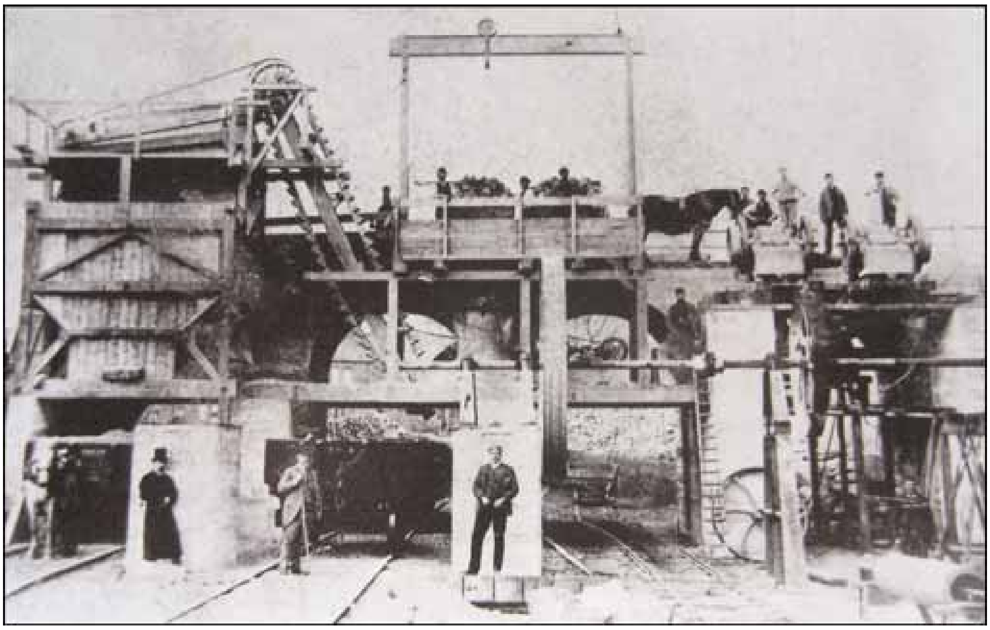

Figure 7. Old crushing machinery, thought to be at Bardon Hill Quarry in the 1800s. (Photo: Aggregate Industries Archive)

Three generations of Ellis and Everard worked the site until Leonard Tom bought in to the quarry in the 1940s. However, Ellis and Everard did not actually own the land in which the quarry was situated, but leased it from the owner of Bardon Park at the time, Robert Jacomb-Hood. The Hood family must have been greatly interested in the construction of a new railway line, the Leicester and Swannington Railway Line (Fig. 4) so close to Bardon Hill during the early 1830s. In fact, it is known that Jacomb-Hood watched the mightily-named locomotives Comet, Phoenix, Samson, Goliath, Hercules, Liverpool, Atlas Vulcan, Ajax and Hector going about their labours (Fenn, 2003). The Leicester and Swannington Railway Line was actually of paramount importance to the evolution and commercial development of the Charnwood Forest quarries, especially Bardon Hill Quarry, and its construction was a pivotal moment in the transport history of the East Midlands. George and his son Robert Stephenson had visited Leicester in 1828 and had declared the construction of a new railway feasible in terms of its construction and financial viability. John Ellis became involved in the project, was duly elected as Chairman of the scheme and was appointed a Director on the board and the young Robert Stephenson was engaged as the engineer.

The railway opened in July 1832 to passenger traffic, with a train hauled by Comet, driven by George Stephenson himself. Reports say that on its maiden voyage the train was decorated with flags and banners proclaiming ‘Cheap coal and granite’ and ‘Warm hearths and good roads’; it is also said that the train had its 4-metre-high chimney knocked down on entering Glenfield Tunnel. The railway consisted of a single line, 25 km long, with branch lines to the collieries at Bagworth, Ibstock and Whitwick, and the Earl of Stamford’s hard-rock quarry at Groby. This was the first steam worked public railway transporting both passengers and freight (mainly coal and ‘granite’) in the Midlands, opening six years before the London and Birmingham line. In the first six months of operation the railways’ receipts for the carriage of ‘granite’ amounted to £82 12s 1d, and 4622 tonnes of stone and slate were carried from the Groby quarries (Clinker, 1954); however, by far the greatest profit came from the carriage of coal (£766 3s 8d). In August 1845, George Hudson, Chairman of the Midland Railway Company purchased the line and changed the station’s name from Ashby Road to Bardon Hill.

In the 1840s, Breedon Everard was a tenant farmer on the Earl of Stamford’s Estate at Groby. In 1848 he started a coal merchants’ business in partnership with Joseph Ellis, in the area between Peterborough and Syston, on the newly opened Midland Railway Line extension (Noble, 1995). They first began ‘granite’ quarrying at Billa Barra, (or Billa Barrow as it was then called), a small quarry consisting of volcaniclastic rocks belonging to the Bradgate Formation. At that time the quarry belonged to Breedon Everard’s wife, Elizabeth Ann Cowlishaw. The partnership then purchased the Markfield Granite Quarries in 1852, which motivated the ever-competitive Earl of Stamford to re-open his quarries at Groby.

In 1857, Joseph Ellis died, which prompted Breedon Everard to enter into partnership with his own sons, James and Joseph Henry Ellis. The following year Breedon Everard, who was then the senior partner, negotiated with Robert Jacomb-Hood for the rights to quarry within Bardon Park. They were granted a lease for 40 acres of land and subsequently opened a new quarry, located in the fields to the southeast of what was then known as Robin Bott’s Hill Farm (Noble, 1995). The original site of the farm is now unclear, but it is thought to have been within the current quarry workings, somewhere to the south of Bradgate Drive, Greenhill (F on Fig. 4; Fig. 6). The quarry also conveniently adjoined the Bardon Hill Station on the Leicester and Swannington branch of the Midland Railway via a siding across the turnpike and into the quarry. The Ellis Brothers were a major asset to the quarry company at this time as they were both directors of the railway line, which enabled them to transport stone to the far reaches of the country. Apparently, the Ellis & Everard partnership paid a rent of £145 per year for the quarry, as well as royalties of 1s 5d (7.5p) per tonne of stone extracted (Noble, 1995). Breedon Everard left Groby and moved to Hill Top House, now known as Bardon House. He abandoned farming in order to devote his full attention to the merchants' business and quarrying.

The demand for stone from Bardon Quarry soon began to outstrip supply, due to the more widespread macadamising of roads and the increased use of ballast on the new railroads. This called for the operation at Bardon to become more mechanised and less labour intensive, to increase output. As a result, in 1859 a powerful crushing machine was commissioned and installed within the mill. It was designed by Charles G Mountain 'of Birmingham' and was the first purpose built steam-driven stone crusher, possibly in the world, to be used commercially (Noble, 1995). Robert Jacomb-Hood died in 1860 and the Bardon Estate was subsequently sold to William Perry Herrick in 1864, the then owner of the Beaumanor Estate at Woodhouse Eaves. The quarry rights at this time extended to nearly 300 acres of Bardon Park, but only a small part of this was quarried, amounting to no more than 4 ha in 1865 (Noble, 1995). It is something of a puzzle as to why the Ellis & Everard partnership did not bid for the estate in 1864, in order to own and expand the quarry workings themselves. The Herrick's improved their property but did not actually move into Bardon Hall; this was originally let for a rental of £150 per year until the Everard family took up the tenancy in the 1870s, apparently for a peppercorn rent.

The demand for aggregate continued to grow, but the workforce required to quarry the stone did not exist, as the thin population of the area was mainly concentrated in the coal mining industry. Houses were therefore built around 1870-3, to attract and accommodate quarrymen in the area, the first of which were built close to the primary crushers, and were known as Spinney Cottages and the Lodgings House. This was followed in 1875-6 by a long string of brick-built terraced cottages, known as The Old Row as well as a Reading Room, school and the remainder of the new village of Bardon (Fig. 6). The architect of the school and houses was John Breedon Everard, Breedon Everard's second son, and all was provided at the joint expense of Ellis & Everard and the Perry Herricks. More cottages were added in the 1890s and were not surprisingly christened The New Row; they were later to be renamed The Crescent.

In 1874, John Breedon Everard, a civil engineer, architect and outstanding man in his profession became a partner in Ellis & Everard and began work on a new stone-breaking mill at Bardon Hill. The Mill House was constructed close to the quarry workings between 1874-8, and when complete, represented a structure of great architectural interest as well as commercial value (Fig. 8). Breedon Everard died in 1882 and his share of the company was passed to his two elder sons. His eldest son, William Thomas Everard, devoted himself to the quarrying business and became a Managing Partner, retaining his share of the company until his death. He rented Bardon Hall, the Park, the Keeper's Cottage and various other cottages from the Beaumanor Estate for £4-10s a week (Noble, 1995). His brother, John Breedon Everard, built an experimental wire rope tramway between Markfield Quarry and Bardon Hill railway station, but as public opposition to the project was great the tramway was left to fall in to disuse (Fenn, 2003).

By 1890, 'granite' from Charnwood Forest had become the main source of aggregate for the Midlands and the South. Bardon Hill Quarries were then amongst the most modern in the country, producing 175,000 tonnes of stone per year, with a work force of between 600 and 700 men. Shortly after the turn of the century the area quarried at Bardon Hill extended to well over 40 ha; so within 50 years the quarry had increased in size ten-fold. In an understandably optimistic mood, John Breedon Everard doubled the size of the stone-breaking mill in 1902 to 'monumental proportions', creating an industrial building that was deemed to be 'large and spectacular' and providing room for four more crushing units. The beautiful old Mill House has fortunately survived to this day, but in a rather more dilapidated state.

In 1913, the Ellis & Everard partnership decided *not to produce Paving Sets at Bardon Hill, but devote the whole of our production to Macadam, and we believe the enormous demand for Granite from this quarry is partly attributable to the fact of our not manufacturing the best of the material into Setts, and using the residue for Macadam*. This was proclaimed

Figure 8. *The Mill House, Bardon Hill Quarry, c 1910. (Photo: J. Burton & Sons, Aggregate Industries Archive)*

in a new illustrated company brochure, printed in 1913 in which the company boasted that they *supply most of the well-known contractors in the Midlands, London and elsewhere*. At this time the company employed nearly 350 men at the quarry, but the onset of the First World War reduced this workforce by 60-70% (Noble, 1995). Demand for stone was still great, but output was seriously reduced and this resulted in the closure of large parts of the plant. After the War, the depression years of the 1920s and 30s led to a considerable reduction in the demand for stone. Perhaps as a result of such lean times, the business was converted into a Private Limited Company in 1930 under the title of Bardon Hill Quarries (Ellis & Everard) Ltd. The advent of the Second World War further affected operations at the quarry and after the War, the Herrick family decided to sell the Bardon Estate *with the exception of Bardon Village and the money making quarry* (Noble, 1995). Over 400 acres were offered for sale, of which 350 ha were contained within Bardon Park. However, the sale was not successful and most of the farms were sold to local farmers for a few thousand pounds each.

A turning point in the history of the quarry was in 1948, when Bernard Everard reached an agreement with a Mr Leonard Tom, for control of the company to be shared, and both men became joint managing directors (Noble, 1995). Three generations of the Cornish Tom family then built upon the success of the Ellis & Everard Bardon Hill Quarries. The Tom family had plans to progressively improve the production of stone at the quarry and so quickly implemented a series of changes as demand for aggregate increased. This was not hampered by the fact that Bernard Everard retired in 1956 and Leonard Tom unfortunately died a few years later. Gregory Tom then succeeded his father in the business, became Chairman and Managing Director of the company and moved his family to Bardon Hill House. The company title was changed to Bardon Hill Quarries Limited. Major improvements were made in the operation of the quarry, including the installation of a Babbitless Crusher at a cost of £70,000, which was famous for crushing 400 tonnes of stone per hour and up to 4000 tonnes on a good day (Noble, 1995). This led to further technological improvements in operations at the quarry as well as an increase in staff numbers to cope with the increased output.

***Figure 9.** Ellis & Everard's steam lorries at Bardon Hill Quarry, c 1920. (Photo: Aggregate Industries Archive)*

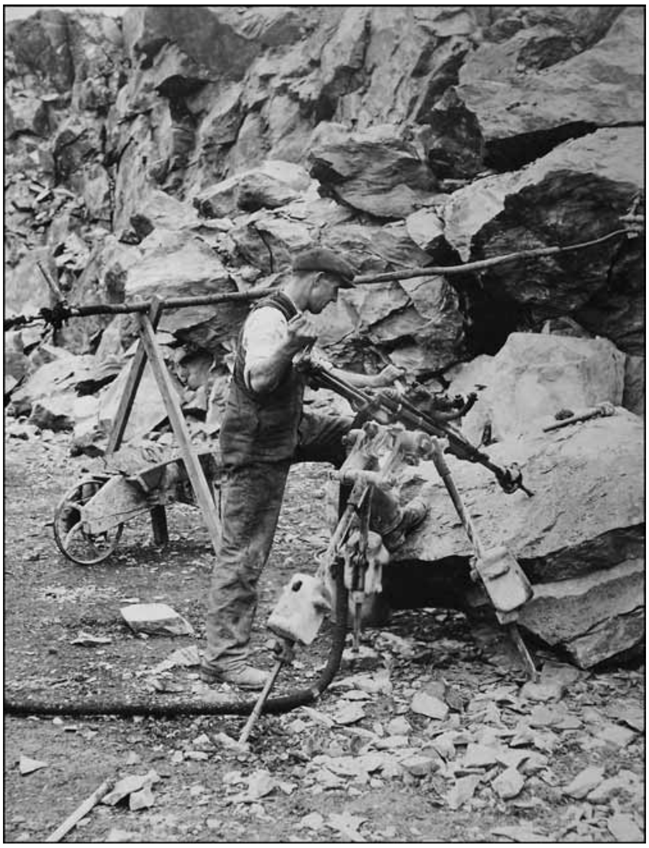

***Figure 10.** Steam drilling, Bardon Hill Quarry, c1920. (Photo: Aggregate Industries Archive)*

In 1975 the Herricks sold the quarry and the village of Bardon to the quarry company, thus ending a Herrick family connection with Bardon Park that had lasted for more than 110 years. However, they apparently left a dubious legacy, as during the Second World War the Herrick family sold a plot of land on the crown of Bardon Hill 'to the country', as a site for a radio pylon, which can still be seen from afar. The reason for this is clear - at 271 m above sea level, the summit of Bardon Hill is the highest point in the county, and is, as Sir Robert Martin alleged, 'only 88 feet short of a mountain.'

The increased demand for aggregate in the late 1950s had necessitated a rapid expansion of the original Bardon Hill Quarry and a larger investment of capital; this is reflected in the fact that by 1975 a large area of the northwestern slopes of Bardon Hill had been quarried away. As a result, by 1978 the private company set up by Leonard Tom had gone public (Noble, 1995). However, the initial building boom did not last when the following rapid recession deeply affected primary producers and the company was slimmed down. The company was eventually put up for sale and merged with the Evered Group in 1991, an organisation with similar quarrying interests to the Bardon Group. The new Evered Bardon plc was formed, headed by Sir Peter Parker and the Chief Executive was Peter W. G. Tom. Bardon Hill Quarries Ltd then became known as Bardon Roadstone Ltd. The old company founded by the Ellis & Everard partnership, built up with so much effort and determination by the Tom family, had now became a component in a much larger organisation operating not only in Britain, but in Europe and the USA as well.

Despite the severe recession, output from the quarry had increased in 1993 by 50%, new sales had been found and the plant was running at capacity. The extraction of rock began in a new area to the north of Bardon Hill, and the Old Rookery Quarry (to the east) was refilled with the overburden stripped off. This went some way towards reinstating and reforming the original shape of Bardon Hill that had been previously quarried away. Test drillings were made and rock was found to extend below the village. By the end of 1993 the new area to be quarried stretched almost to the drive of Bardon Hall. Planning consent was given to extract more rock, which heralded the death knell for the old village of Bardon. The whole of the village, Robin Bott's Hill Farm and the Keeper's Cottage were sadly demolished to make way for the extended quarry. The remaining inhabitants of Bardon village were relocated to newly built bungalows and houses sited between the quarry and Coalville.

Figure 11. *The primary crusher at Bardon Hill Quarry, date unknown. (Photo: Aggregate Industries Archive)*

In May 1997 the Bardon Group merged with CAMAS plc to form Aggregate Industries plc. Peter Tom continued as the Group Chief Executive of the newly created Aggregate Industries plc, continuing the Tom family connection with Bardon quarry to this very day (Noble, 1995). Aggregate Industries UK Ltd now run businesses throughout Britain and Norway and are the fourth largest aggregate and the second largest asphalt producer in the UK. Bardon Aggregates have more than 90 aggregate operations across Britain, comprising crushed rock, sand and gravel and secondary aggregate quarries. Bardon Hill Quarry currently produces three million tonnes of crushed aggregate, half a million tonnes of asphalt and 200,000 tonnes of pre-cast concrete per year, as well as materials created for pitching and rip-rap for coastal and sea defences. The largest output of surface dressing chippings in the country comes from Bardon Hill (J. Campbell, *pers. com*.). The area south of the summit of Bardon Hill is now classified as a Site of Special Scientific Interest, on account of its remnant ancient woodland, heathland and lichen-rich rock outcrops. These important habitats support 247 different species of spider including the famous and rare Charnwood Spider *Mastigusa macropthalma*.

Mountsorrel Quarry

Stone has been worked from the Buddon Wood area of Mountsorrel since at least the Early Iron Age, in 800–500BC (Anon, 2003). Activities were evidently concentrated in the Castle Hill area of Mountsorrel, to the east of the present day operations at Buddon Wood; traces of both Roman and Norman excavations were found here, and it was established that a Norman Castle (destroyed in 1217) once crowned the hilltop. Several important Roman discoveries were made during the process of excavating Broad Hill Quarry at Mountsorrel. They included a Late Neolithic or Early Bronze Age (2000-1400BC) incense cup in 1859, a Roman sepulchral chamber discovered at Broad Hill in 1881, and in 1892 a Roman well that had been sunk 18 m into a natural rock fissure (Anon, 2003). Several pottery objects, bones and two remarkably well preserved wooden buckets, one of which had an ornate handle and bronze bindings were found at the bottom of the well. It is thought that the objects came from a Roman villa situated on Broad Hill during the 4th century AD; they represent a rare example of the Iron Age Romano-British artistic style in the Midlands. It is also thought that some of the pinker granites within the Roman Jewry Wall at Leicester may have come from the Mountsorrel area (Anon, 2003).

Mountsorrel granite, strictly speaking an inequigranular granodiorite of Ordovician age, has long been utilised in the Charnwood area as a building stone, in the walls of older buildings and for war memorials. In the 1800s several local churches and houses were built or repaired using large blocks of the characteristic dark red Mountsorrel granodiorite (Lott, 2001). However, its main use was for paving setts and kerbstones for roads and the construction industry. Rumour has it that Mountsorrel granite was used to pave part of the forecourt of Buckingham Palace; however, this claim to fame can no longer be verified as the area was covered with tarmac some time ago.

The quarrying industry had a huge influence on the economy of Mountsorrel and its immediate hinterland, and for a long time was the single largest employer in the area. The quarry represented the life-blood of the village, but it also had devastating effects on the environment of the adjacent village. Apparently Mountsorrel was colloquially known as 'Mount Sterile' due to the large amounts of quarry dust that periodically covered the village. The quarrymen grew large bushy moustaches in order to prevent dust from entering their mouths, and apparently became heavy drinkers, so they could cope with the dry, dusty environment in which they worked. In fact, such concern was felt at the amount of excessive drinking, that in 1852 the Red Lion public house was converted to a more genteel coffee house, much to the chagrin of the local quarrymen!

The origins of systematic quarrying at Mountsorrel can be traced back to the mid-18th Century. In 1758 a local landowner, Sir John Danvers, owned the local mineral rights (Anon, 2003) and was anxious to encourage the use of the famous 'Mountsorrel Stone'. He therefore offered £200 over a few years to the then Turnpikes Trust to lay a 5-m wide granite causeway through Mountsorrel. This proved a success, and resulted in a second causeway being laid in Leicester in 1774, thus providing regular employment for several quarrymen from the village. Broken granite macadam from the quarries at Mountsorrel was used on the turnpike roads between Market Harborough and Loughborough in 1781, and in 1792 a wharf was built on the Leicester Navigation (canal) at Mountsorrel to handle the increased traffic in local granite.

The Earl of Lanesborough succeeded to the Danvers Estate and in 1803 subsequently leased the Main Mountsorrel or Broad Hill Quarry (G on Fig. 4) to a Mr Jackson, who was then a local landowner. Mr Jackson is said to have taken inspiration from watching Scottish quarrymen at work squaring Aberdeen granite at Chatham in 1812. He thus introduced a skilled workman (or workmen) from Scotland to teach the Mountsorrel quarrymen how to more accurately fashion the setts to a good shape and size. Soon he was employing 50 to 100 men and delivering paving stones to many parts of the country at a price of £1-5-0d to £1-7-0d a tonne, including transport. This compared with the price of Mountsorrel chippings, which in 1821 was 2/8d (14p) per tonne, with a delivered price by canal, at Paddington wharf, of 15/8d. In 1826, Mr Jackson also introduced skilled masons from Scotland to produce granite dressed to a suitable standard for use in churches and other buildings; however, this venture does not appear to have been successful.

In 1821 the Earl of Lanesborough, besides leasing quarries on his estate, also opened his own quarry on the eastern fringe of Buddon Wood (the quarry later became known as the Ashpit Quarry). It is said that in 1844 Mr. W. John Martin, a member of the local landed gentry, was riding past this quarry when he noticed a group of despondent quarrymen at the side of the road. They told him that they had not been paid for several weeks, as no work was available to them. Mr Martin sought out the Earl, and requested that he and his father William be allowed to take over the operation of the quarry. This was arranged, and thus began the Martin family association with quarrying in the Mountsorrel area, that lasted until they sold out to the Redland Group in 1960.

The business thrived, and in 1848, John Martin took over the whole mineral lease including operations at the Main Mountsorrel/Broad Hill Quarry, Hawcliffe Hill and Cocklow Wood (H on Fig. 4); by 1849 the labour force had expanded to 200 men and boys. In 1850, John Martin's father William died, leaving his shares in the business to his eldest son Rev. Robert Martin and, maybe as a result of this, in 1854 the Mountsorrel Granite Company was formed. The newly formed company adopted as its trademark the windmill that stood on Broad Hill, where the main quarry had begun. During the same year the Mountsorrel Railway Act gave consent for a branch line to link the quarry to the existing Midland Railway at Barrow-upon-Soar. The line was completed by 1860, and in that same year a spectacular bridge was constructed to carry rail traffic from the quarry over the canal and River Soar direct to the main line (Fig. 13). It was said to be the finest and largest single span brick-built bridge in

Figure 12. *The crushing mills, known as the High Level at Mountsorrel Quarry, with curious workforce looking on, c1880. The barrels are filled with crushed granite, ready for distribution. (Photo: Lafarge Aggregates)*

> **The quarrying process at Mountsorrel in 1870**
>
> Topsoil and overburden were removed first, and then steel drills were driven into the rock face using heavy hammers. The men carrying out this work were often only suspended in front of the rock face by ropes. A gunpowder charge was then inserted into the drill hole and ignited with a slow fuse, as dynamite was not thought suitable at the time. Blasting was usually timed to coincide with meal breaks, to minimise casualties and prevent injuries to the workforce. After blasting, large masses of stone were broken down on the quarry floor, where they had fallen.
>
> Next came the 'Blockers', a group of skilled men who further split the stone into smaller blocks or strips. The stone was then carried in tubs to the sheds or shelters, located within the quarry, where the sett-makers and kerb-dressers worked. The sett-makers or 'squarers' then worked the stone into cubes of the correct size, and their 'boys' (usually members of their own family) smoothed the surfaces of the setts with small hammers. The kerb-dressers or masons were fewer in number, and required great skill to create the longer, and often curved, kerbstones. Waste left over from making setts and kerbs were arduously broken down by hand into stone chippings. The workmen were expected to contribute towards the cost of repair or replacement of their tools, an allowance being made for their contributions when each stage of the quarrying process was worked out.
>
> *Berger, Mountsorrel Quarry Archive*

England at the time, and it is still in use today. The Mountsorrel Railway has long since been discontinued, its trackway now utilised by conveyor belts that carry the crushed aggregate to the rail-head.

The Company acquired their own rolling stock and throughout the railway era the engines were named after members of the Martin family – mainly the children and female members of the family ('Elizabeth' still survives today in the Rutland Railway Museum at Cottesmore). In 1870 the Main Quarry expanded further into Broad Hill; at this time around 500-600 men and boys were employed by the quarry (Anon, 2003). It is ironic that the famous windmill, the trademark of the company, finally succumbed to the quarrying process in 1874, having stood on that site for more than 100 years.

In 1876 the Mountsorrel Granite Company was incorporated as a limited company, the first quarrying organisation in Leicestershire to take this step (Berger, Mountsorrel Quarry Archive). William John Martin was the proprietor of the company, with £20,000 shares, and Robert Frewen Martin had shares worth £12,000; the rest of the shareholders were members of the Martin family, usually with one share each. In 1877 the Company built cottages, a hospital, and a new school for the workmen and their families. In 1894 another branch line was constructed, linking the quarry to the Great Central Railway at Swithland. Nunckley Hill Quarry (J on Fig. 4) was on the proposed route, so it was subsequently leased from Lord Lanesborough for £86 (plus £29 legal fees).

A major innovation occurred in 1897-8, when electricity was installed in the quarry at a cost of £800. Although costly, this enabled longer hours to be worked in the winter months. In 1899 the quarry employed 600 men and about 30 boys, the men earning, on average, around 30 shillings a week. The boys served a three-year apprenticeship making granite setts, with pay rising from 1s (5p) to 3s per week over three years. Day men worked 10 hours for 4d (2p) per hour, and received no pay for 'wet time'. Archive records show that by the turn of the century, 200,000 tonnes of stone were extracted from the quarry, of which 20,000 tonnes were made into setts, 10,000 tonnes into kerbs and channels, and the remainder was broken into chippings for road construction. At this time the quarry had installed a crushing mill and used steam-generated drilling rigs.

On the outbreak of World War I in 1914, all the directors of the quarry as well as many of the quarrymen joined the army. William Martin was killed in action at Ypres in 1915, but the other directors fortunately survived the conflict. With so many men absent and so little road-building taking place, production in the quarries fell from 14,000 tonnes in 1914, to 7600 tonnes in 1915. Before the onset of war, Northern Quarries Limited had leased a site at Mountsorrel near to the Hawcliffe Hill Quarry, and had set up a tar coating plant. This unfortunately closed in 1917, as production fell due to the effects of war;

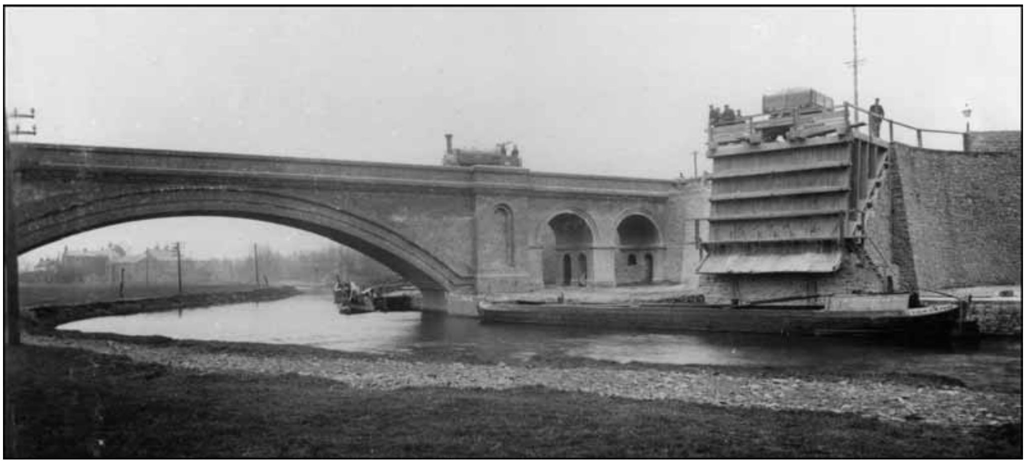

Figure 13. *The bridge at Mountsorrel, c 1870, with a locomotive on it. Right of the bridge are the loading chutes, with side-tip wagons on top feeding aggregate to barges on the canal. (Photo: Lafarge Aggregates)*

however the production of coated granite began again in 1919 under the name of the Mountsorrel Tarred Macadam Company.

During 1918, the company was approached by the Ellis Company of Barrow 'regarding a possible transfusion of the two companies' and the amalgamation took place on January 1st 1920. The workforce then grew from 600 to 900, producing 1500 tonnes per day in 1920. In comparison, workers numbered only 100 in 1984, but due to massive technical improvements, they were able to produce 9000 tonnes per day (Anon, 2003). Mountsorrel Quarry closed for the first time for a whole week at the beginning of August 1931, as 70 men had applied for a week's holiday. Perhaps as a result of this, in August 1939 all quarry employees were granted a one-week holiday with pay.

In 1936 the production of granite setts for paving was phased out in favour of crushed stone, and in 1940 kerb dressing was also abandoned due to a shortage of craftsmen. Thereafter, the only materials produced were crushed stone of various sizes for road materials, concrete aggregate, filter media and railway ballast. Operations simultaneously became more mechanised, as in 1938 the company installed a Ransome Rapier shovel and primary jaw crusher as well as a new conveyor belt system. As a result, the Second World War affected quarry operations less dramatically than WW1, as the modernisations meant that a much smaller workforce could now produce the same amount of broken stone. This was fortuitous, as the building of new aerodromes and runways led to an increased demand for stone and gravel. Hawcliffe Hill Quarry was closed early in the war, and in 1944 was utilised as a reservoir for the new washing plant. The military used Cocklow Wood Quarry for target practice during the war.

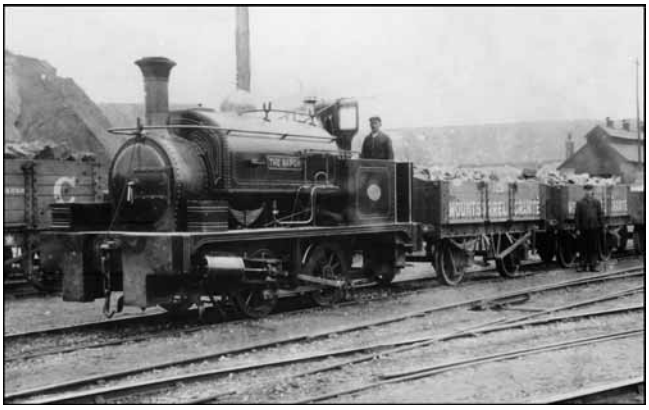

Figure 14. *The Baron and wagons loaded with granite, Mill Yard, Mountsorrel Quarry, c1900. Note the engine shed in the background(Photo: Lafarge Aggregates)*

In 1966 the quarry was taken over by Redland Perle (later known as Redland Roadstone, then Redland Aggregates plc) and in 1967 extraction ceased at the Broad Hill Quarry, which eventually became a landfill site. The plant was then fed by rock from the Cocklow Wood Quarry, adjacent to the Buddon Wood site (I on Fig. 4). Redland Roadstone then decided in 1971 to concentrate their Leicestershire production in the Mountsorrel area, while simultaneously running down production at the Enderby and Bradgate Quarries. A new reserve was located in the western section of the Mountsorrel Quarry complex, around the Buddon Wood area, where earlier test borings had shown 'good stone of a true Mountsorrel colour'. The Buddon Wood site formed part of a lease from the Lanesborough Estates, which expires in 2034. Site clearance work began in late 1971, and the primary crusher was installed by 1973. The official opening ceremony of Buddon Wood Quarry was performed on 24th September 1974.

Figure 15. *Aerial view looking southwest over the active Buddon Wood Quarry, Mountsorrel, in May 2005. Swithland Reservoir can just be seen at the top of the picture. (Photo: Lafarge Aggregates)*

The quarry today is operated by Lafarge UK plc, part of Lafarge Aggregates, the world leader in construction materials, who acquired the quarry from Redland plc in 1997 (Wix & Keil, 2002). The planning consent passed in 1992 allows for a larger area of operation and the area currently in use now approaches one kilometre across, with a total area of 55 ha and a quarry floor that is currently 94 m below sea level. Mountsorrel is now the largest granite quarry in Europe and is capable of producing 10 million tonnes of rock per annum from reserves of 180 million tonnes. The environmental impacts of the site are carefully managed, and the operations are hardly visible to the local communities. The effects of Mountsorrel's most famous and important industry are no longer as devastating as they once were - Mountsorrel can no longer be called 'Mount Sterile.'

Cliffe Hill Quarry

Jones and Fitzmaurice, two businessmen from Birmingham, formed a partnership in the late 1870s to work the stone at Cliffe Hill for the small-scale production of setts and kerbs. However, the quarry closed after a few years and remained so for a decade, until Mr J. Rupert Fitzmaurice acquired the quarry from his father on 9th May 1891 (Billington, 1974). He needed a manager, so he wrote to Mr Peter Preston, who then worked at the quarry in Enderby, to offer him the position. Mr Fitzmaurice apparently interviewed Mr Preston at the quarry site, whilst both men sat on small heaps of stone. Mr Preston accepted the position and a wage of £3 per week – good going by standards of the day! Mr Preston began work straight away, bringing a millwright and a blacksmith with him from Enderby and installing a crusher. A second crusher was soon added and a licence to store and use explosives was obtained on 15th July 1891. The first load of stone produced was sold to a local farmer at a price of 2/6d per tonne (Billington, 1974).

Rock drilling in those days was carried out by steam driven drills with secondary drilling completed by hand. Steam was provided to the drills from the old traction engine that was engaged to transport the drilling equipment from one face to another. Hand drilling was a dangerous and laborious job – a boy would hold a short drill with both hands while a quarryman would hit the drill with a sledgehammer. The boy would turn the drill slightly, and the man would hit it again. This procedure would be repeated until the stone could be split with plugs of steel. The working day at that time was 10 hours and on a Saturday 5 hours. Most jobs were put on a piecework basis, but where this could not be done rates of pay varied between 4d (2p) per hour for Labourers, to 5d per hour for skilled men (Billington, 1974).

In 1894 the company secured its first big railway contract, for 5000 tonnes of stone, and on 1st November 1894 the Cliffe Hill Granite Company Ltd was formed. The aptly named Sir J. Benjamin Stone was elected the first director of the Company. As the demand for products increased, the decision was made in 1896 to install a narrow gauge light railway, connecting the quarry to the London Midland and Scottish Railway line between Leicester and Coalville. The railway was named the Cliffe Hill Mineral Railway, and in 1896 the first locomotive to be bought from W.G. Bagnall of Stafford was imaginatively christened Cliffe (Billington, 1974). Isabel and Rocket joined Cliffe over the next few years, and served to haul stone to the crushers and to the sidings at Beveridge Lane, near Bardon Hill station. Isabel is now preserved at the Amerton Railway in Staffordshire, and Cliffe was apparently sold to Bardon Hill Quarry in 1946, but was scrapped in 1953. The light railway continued to be used until 1947-8, when five Mack lorries were purchased and adapted for use in the quarry. Traces of the railway embankment can still be identified at Stanton under Bardon and on Billa Barra Lane close to Billa Barra Local Nature Reserve.

Figure 16. *Mr Preston and family, 1899, manager of Old Cliffe Hill Quarry.*

Figure 17. *Drilling competition at Old Cliffe Hill Quarry. (Photos: MQP)*

In the early days of quarrying at Cliffe Hill, the Company only crushed the good quality grey stone, preferring to discard the poorer quality brown stone to keep up the high standards and preserve quality. This obviously produced much waste material, so in 1912, the Company decided to set up a secondary business, the Rockside Company to crush and sell the waste brown stone. The dust and rotten stone generated from the plant, known as gingerbread, apparently became popular for covering tennis courts and drives. The 'granite' resource at Cliffe Hill, known locally as Markfieldite, is a distinctive variety of granophyric diorite intrusion, Precambrian in age, which is now termed the South Charnwood Diorite. The quarry serves as a type locality for the diorites, which are the youngest Precambrian intrusive rocks in Charnwood Forest (Carney *et al*, 2000). It had a good reputation as a hard-wearing stone, and Cliffe Hill Quarry provided cities in the Midlands and London with kerbs well into the 1950s.

The Fitzmaurice and Preston families jointly managed the Cliffe Hill Granite Company for 72 years, until Tarmac Quarry Products Ltd acquired the company in 1965. Midland Quarry Products (MQP) was formed in December 1996, as a joint venture between the parent companies Hanson and Tarmac. The company now operates three quarries, one rail ballast depot and seven asphalt plants in the East and West Midlands, including the award winning Cliffe Hill Quarry, the largest quarrying and asphalt operation within Midland Quarry Products.

Cliffe Hill actually consists of two quarries – New Cliffe Hill (K on Fig. 4) opened in the late 1980s and the original Old Cliffe Hill Quarry (L on Fig. 4) (McGrath, 2004b). New Cliffe Hill currently houses a railway line and two plants with a production level of 600,000 tonnes of asphalt materials per annum. The quarry produced 4.5 million tonnes of crushed 'granite' aggregate per year, up until 2006. This was mainly for the rail, construction and road building industry in the Midlands, Southeast England and East Anglia. The Old Cliffe Hill Quarry was brought back into production following the construction of a tunnel connecting it with the processing plant at New Cliffe Hill Quarry; the new tunnel; 9 m wide, 6 m high and 725 m long, was opened in September 2003 (Fig. 19). It was aptly christened the Joskin Tunnel as a result of a naming competition held in the nearby village of Stanton under Bardon. This local name is taken from the Joskins Cottages that were once located on the original quarry site, at the northern end of the village.

Groby and Bradgate Quarries

It is thought that quarrying has taken place at Groby since Roman times, as Groby 'granite' can be found incorporated into the remains of some Roman buildings in Leicester, Ratae Corieltavorum. Apparently the Romans found the Groby stone difficult to work, but due to its impermeable qualities they found a use for it as rubble masonry. However, the location of the Roman quarries in Groby still remains a cause of much speculation. The 'granite' at Groby is actually a continuation of the Precambrian granophyric diorite intrusion quarried at Cliffe Hill and Markfield (Hill Hole Quarry), although the granite at Groby has a more purple and green mottled texture (Lott, 2001). Due to its distinctive colouration and appearance, the

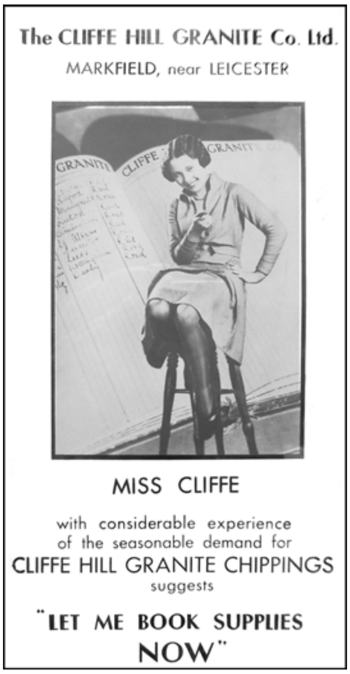

Figure 18. *Sales by Miss Cliffe, date unknown. (Photo: MQP)*

Figure 19. *Entrance to the Joskin Tunnel connecting the Old and New Cliffe Hill Quarries, that enables the company to work the remaining reserves at Old Cliffe Hill, and return them for processing at the New Cliffe Hill plant. (Photo: MQP)*

***Figure 20.** Driller at Old Cliffe Hill Quarry. Date unknown. (Photo: MQP)*

rock has been used locally as a building stone in the walls of the parish church and older cottages in and around Groby (Lott, 2001; Ramsey, 1982).

Local records indicate that the Fifth Earl of Stamford and Warrington initiated quarrying at Groby in the early 1800s. In 1807, the Earl received from a Mr Wyatt of Barton-under-Needwood a valuation of the Swithland and 'Grooby' slate quarries, which at that time were leased to a Mr Hind (Ramsey, 1982). In 1832, the Earl engaged Robert Stephenson to engineer a railway from the Old Groby Quarry (now an industrial unit, located between the present day Newtown Linford Road and the village; M on Fig. 4), to the Leicester and Swannington Railway. On the opening day, 24 wagons of Groby 'granite' were collected by Robert Stephenson's famous steam locomotive Comet, and transported to the West Bridge in Leicester, for further distribution (Ramsey, 1982). At least ten other locomotives are known to have worked on the line over the years, including a Robert Stephenson 0-4-0 tender locomotive dating from 1833 and a 0-4-0 vertical boiler tank locomotive jokingly known as the Groby Coffee Pot (Farmer, 1968).

The Earl continued to produce stone from the Old Quarry through his manager, John Martin, until 1843 when the quarry was leased. The lessee apparently preferred to take the stone to Glenfield by road rather than use the Groby railway line, which subsequently fell into disuse (Ramsey, 1982). The Groby Granite Company then acquired a lease to work the quarry from the Earl in August 1865, and royalties were duly paid on the stone extracted. The Company re-opened the Groby railway in 1870 and added a further section to link the Old Quarry with the newly opened Castle Hill Quarry (located north of the Newtown Linford Road); the Bunney Hill Quarry (N on Fig. 4) was also connected shortly afterwards (Ramsey, 1982). The existing quarry at Groby, known as the Sheet Hedges Wood Quarry (O on Fig. 4), was linked to the railway shortly after it opened in the 1890s. As early as the 1880s, Groby Granite was sent as far afield as London, and granite from the Sheet Hedges Wood Quarry was reputedly used in the original paving stones of Trafalgar Square. At this time the Groby Granite Company was by far the largest employer in the village, having 546 workers on their payroll in 1902, 16 of which came from Markfield (Lockley, 2001)

The Dowry Quarry, which subsequently became a rifle range, was also linked by rail between 1907 and 1916. White Gate, Black Spinney and Barn Hills Quarry (R on Fig. 4) on the northwestern edge of the Company's extractive operations were never connected or extensively quarried, due to the poor quality of stone produced. The Bluebell Quarry (named after the carpet of bluebells that surrounded it in spring; P on Fig. 4) commenced operations shortly after the end of World War I; this quarry lies to the west of the main site today. However, the quarry closed shortly afterwards as the stone quality was deemed to be too low; it was imaginatively named the Chocolate Factory after the brown colour of the stone extracted (Ramsey, 1982).

Years ago, Groby was known as Granite Village, and the Groby quarrymen were said to have been physically as hard as stone. A reporter from the old Leicester Advertiser had conversations with several old quarrymen in 1963, who talked of the days when 500 men from nearby villages were employed in the Groby quarries, starting work at 6.00am and finishing at 5.30pm. Many worked to the ripe old age of 70 and above – remarkable considering that in those days the men had to use a 12-kg hammer to break the rock. For their services the men were typically paid 1/3d (6.25p) per tonne of rock produced, and 12 tonnes a day was considered a good day's work. If the weather was bad, and the men could not work, they received no pay (Anon., 1990).

The Old Groby Quarry has now been partially restored as a recreation ground to the south of Markfield Road, but parts of the original quarry site, engine shed and wharf can still be distinguished in the industrial unit area on Fir Tree Lane. The Castle Hill Quarry has since been infilled so that it currently functions as an extensive allotment area, and the Bunney Hill Quarry site was filled with overburden. The Sheet Hedges Wood site at Groby is the newest acquisition by Midland Quarry Products Ltd, but quarrying at this site is currently suspended (2007) as Groby now obtains its aggregates from the nearby Cliffe Hill Quarry. Groby Asphalt Plant was built on the site in February 2002, and replaces an older plant

***Figure 21.** Aerial view looking northwest over the current Groby Quarry (foreground) and the old Bluebell Quarry (top of the photo), towards Sheet Hedges Wood, an ancient woodland. (Photo: MQP)*

that operated there for over thirty years. The Groby Slate Works (opened in 1833) at Alder Spinney, and the Groby Old Slate Quarry close to Bradgate Home Farm once worked the Swithland Formation for roofing slates and headstones. The quarries closed in 1887 when Welsh slates took over the industry.

The Bradgate Quarries (Q on Fig. 4), opened in 1919, consist of three separate quarries located northwest of the Groby Quarries. In 1971 Redland Roadstone decided to concentrate their Leicestershire production at Mountsorrel, whilst running down activities at Bradgate and Enderby Quarries. It was thought that Bradgate Quarry was difficult to expand, as the rock occurred only within three ridges, and large quantities of overburden had to be removed to maintain the workings. The quarries are therefore currently closed: Redland Aggregates did apply to re-open the quarries, but the planning consent was refused. The central quarry went to landfill some time ago; it will be landscaped back to grassland and woodland on completion.

Whitwick and Forest Rock Quarry

The Whitwick Granite Company bought the site of Whitwick Quarry (T on Fig. 4) from a Mr E. Cooper in 1893, for the princely sum of £3500 for 42 ha (K. Bird, *pers. com.*) – which was rather cheap, even for the time, at £33.65 per acre! The original quarry was called Peldar Tor Quarry; which then consisted of two much smaller sites, the first of which was located in the southwestern corner of the current Whitwick Quarry. The second site was located about 500 m west of the

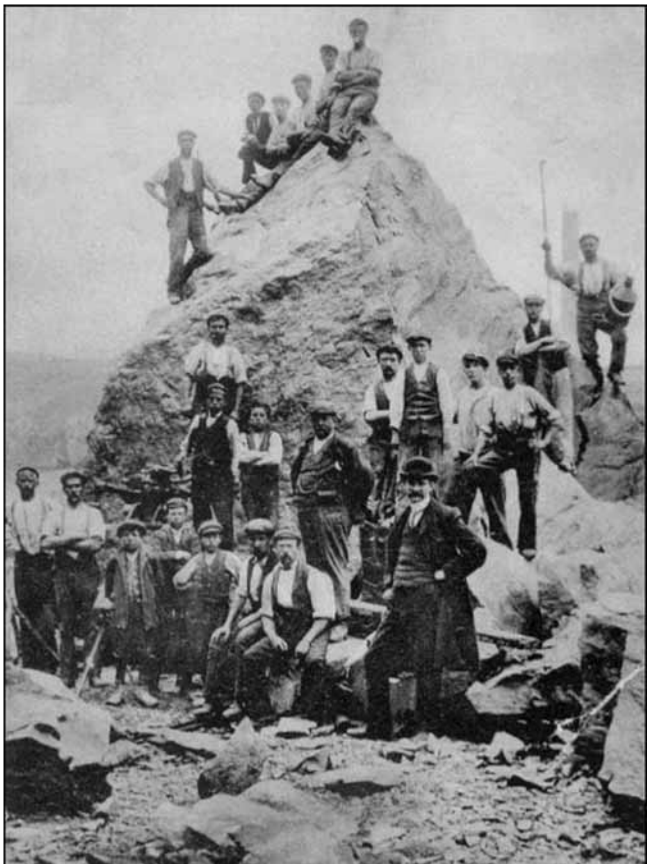

***Figure 22.** The famous '150 ton Stone', the largest single block excavated in any known quarry at that time, in 1911. (From a postcard held by Whitwick Historical Group)*

first quarry, at Houghton Hill, close to Vicarage Forest Farm; this quarry latterly became known as the Forest Rock Quarry (U on Fig. 4). In 1899 the Company bought land to develop a mineral railway, which ran from Coalville East Station (just north of the Coalville junction) to the south side of the quarry; before this, stone was transported by horse and cart. The Whitwick Granite Company operated the quarries until 1938, when they were taken over by Messrs. Thomas Roberts (Westminster) Ltd., later to be known as Roads Reconstruction Ltd. After several more takeovers and mergers, the quarry was owned by the Amey Roadstone Corporation Ltd (Smith, 1984).

In the early 1960s, the M1 motorway was being developed, and Forest Rock Quarry still had substantial reserves left. The quarry companies that operated in the area at the time were apparently extremely worried that the Forest Rock Quarry would be developed to provide the aggregate for the new motorway. As a result, they decided to club together to form a new company, the inevitably named Forest Rock Granite Company, in order to buy the quarry and keep it off the market, so that they could jointly supply the aggregate (K. Bird, *pers. com*.).

The line of quarrying moved progressively northwards and eastwards, towards Ratchet Hill, such that by the 1980s, Whitwick Quarry was almost two-thirds of its present size. The overburden was very deep in the far northwestern section of the quarry, and this needed to be stripped off and removed. Disposal of such large amounts of waste posed a problem for the company, until they remembered the conveniently located Forest Rock Quarry nearby. ARC subsequently bought out the interests of Forest Rock, to dispose of the overburden removed from Whitwick Quarry. In 1984 the first phase of overburden removal at Whitwick partially filled the Old Forest Rock Quarry, and in 1991/2 the second phase completely filled the quarry and land to the west of it.

Figure 23. *Stone is transported by horse and cart from the Bottom Quarry Whitwick, c1920. (Photo: Whitwick Historical Group).*

Figure 24. *Mr J.H. Robinson and family, Manager at Whitwick Quarry from 1897 to the 1950, pictured c1935. Mr Robinson was an important figure in the area, and was colloquially known as 'Mr Whitwick'. (Photo: Whitwick Historical Group)*

There is a happy ending to the sad demise of Forest Rock Quarry. Originally, the infilled quarry was restored to hillside pastureland, but in 1995, the creation of the National Forest Company enabled Hanson Aggregates to further improve and restore the old quarry site. Hanson submitted a successful bid to the National Forest Company in 1995, and the land was planted with more than 20,000 native trees and shrubs over the following two years. The newly planted woodland has now transformed this site, blending sympathetically with nearby mature woodland and creating valuable new wildlife habitats in the area, including meadow grasslands and a spring fed pond. Public access to the site is actively encouraged, with the construction of more than a kilometre of new footpaths that link into the wider local network. The footpaths converge on a high

Figure 25. *New Years Day 1915, at Whitwick Quarry, with seasonal greeting written on the front of the steam engine. Origins of this photograph are unknown, but it is thought that it could be either soldiers requisitioning a steam lorry from Whitwick Quarry, or former quarrymen visiting the quarry on leave. (Photo: Whitwick Historical Group)*

plateau 200 m above sea level, on the summit of which is built a stone circle with an enormous 10-tonne rock as a central feature. Excellent panoramic views to the south and west can be enjoyed from the summit. The aptly named Forest Rock Quarry has now been transformed into a new National Forest site.

During the early 1900s the residents of Whitwick enjoyed many days out, walks and picnics at a local beauty spot known as Bilberry Common, a rolling section of heathland between Spring Hill, Ratchet Hill and Mount St. Bernard's Abbey; the day was not complete without a visit to the Spring Hill Farm Tea Room. Sadly, the Bilberry Common and Spring Hill Farm were quarried away as the site was enlarged, but the good times stay alive in the childhood memories of the local people of Whitwick. The original Peldar Tor and Whitwick Quarries are now closed, but substantial reserves still exist in the northwestern part of the site (Carney, 2005). Whitwick Quarry is famously known as one of the Charnian volcanic centres (alongside Bardon Hill) and is the type locality for the Whitwick Volcanic Complex (Carney, 2000), consisting of the highly porphyritic Sharpley Porphyritic Dacite and the Grimley Andesite. It is one of the few places in Charnwood where the Peldar Dacite Breccia or 'peperite' (Carney, 2000; 2005) can be examined in detail. The quarry is now owned by Midland Quarry Products Ltd, which stopped working at Whitwick when the company was formed in December 1996, and operations were subsequently concentrated at Cliffe Hill Quarry. The company head office is now located on the Whitwick site, an Italian Marini asphalt coating plant operates on the opposite side of the road and the weighbridge is still in use today.

Hill Hole or Markfield Quarry

Hill Hole Quarry (V on Fig. 4) is the type locality for the Precambrian granophyric diorite known locally as Markfieldite, much admired as a building stone for its colour and beauty. A stone implement made from Markfieldite (now known as the South Charnwood Diorite) was discovered at Ulverscroft in Charnwood Forest, indicating that this rock was appreciated as a durable and hard-wearing material several thousand years ago. Markfieldite has also been identified within the Jewry Wall in Leicester, which forms the back wall of a Roman bathhouse complex. Markfield Quarry is now situated on the site of what was previously known as Knoll Hill, one of four granite hills in the area that included Billa Barra Hill, Cliffe Hill and Bardon Hill. A windmill stood on the summit of the hill in 1743, and may have dated from the early 17th century; unfortunately the site of the windmill was quarried away in the 1870s.

Breedon Everard and Josh Ellis purchased the Markfield Granite Quarries in 1852, although the quarry was already active in 1830. Markfield stone was then described as *....of fine quality and beautiful appearance, but being much harder than the granites of Scotland and Westmoreland, cannot compete with these stones for architectural purposes*. The stone quarried was therefore mainly used as highly marketable broken aggregate screenings or Macadam for road building; larger blocks were used for paving setts and kerbstones. At first, the stone was broken into pieces by hand, but when crushing machinery was installed at the Bardon Quarry, stone was transported there for processing until a small crusher was installed at Hill Hole in 1892.

Figure 26. *Cliffe Hill Granite Company truck delivers mixed concrete. (Photo: MQP)*

Stone was initially transported from the quarry via horse-drawn carts to the new Ashby Road railway station at Bardon (later known as Bardon Station). However, this mode of transport proved to be both slow and expensive, so the son of Breedon Everard, John Breedon Everard, designed and constructed an overhead ropeway system to carry the granite quarried from Hill Hole to the railway sidings at Bardon. This followed what is now the line of the A50 all the way to Bardon, a distance of 5 km. It was built in the 1870s, and the quarrymen called it a it Blondin, after the French high-wire artist famous for his jaunt across Niagara Falls. However, the Blondin was not a success, as public opposition to it was great, and even on a good day it could only manage to carry 50 kg of stone per bucket, so it soon fell into disuse.

In 1863, out of Markfield's 1391 inhabitants, Ellis & Everard employed around 90 at their newly opened granite quarry. The youngest quarry worker was Michael Russell, who was a mere nine years old in 1861. At about this time, the houses in New Row were built to accommodate the workers, located behind the present parish church. Quarrymen were mainly local to the area, but some travelled from much farther afield to work in the quarry; records show that workers came from Scotland, Wales and even America. Quarrying was a dangerous process, and at least six men died at Hill Hole during the latter half of the 19th century alone. Despite this, the quarry was proudly promoted by Ellis & Everard as being the supplier to *....15 County Councils, 10 Cities, 22 Boroughs and 72 Urban and Rural District Councils*.

Quarrying of stone at Hill Hole had two major drawbacks. The operation depended on a steam crane that not only had to lower all tools and machinery into the quarry void, but also had to raise all the quarried stone to road level. In wet weather the quarry started to fill with water, and as a result the crane was required daily to scoop up the water from the floor of the quarry in a large flat bucket. Production at Hill Hole Quarry was therefore sporadic, until the quarry filled with water and was abandoned by the time of the First World War (Lockley, 2001). After that, the quarrymen found work at Cliffe Hill and Bardon Hill Quarry. Hill Hole Quarry then had a rather novel change of use when it was often used as a communal bath, before the village had a full running water supply. Men would cheerfully bring a towel and a bar of soap to have a quick dip in the flooded quarry. During the Second World War, two 'strategic observation posts' or wooden look-out towers were sited on Markfield Hill, for use by the Home Guard; one of these was set on fire to celebrate the end of the war.

Midland Quarry Products sold the quarry to the Tarmac Company, as an overburden tip for its new quarry at Stud Farm, but fortunately it was never used for that purpose. The Hinckley and Bosworth Borough Council subsequently bought Hill Hole Quarry, with grant aid from the National Forest Company. The site now supports a variety of unusual flora and fauna, including a protected species of rare white-clawed crayfish within the lake, the only species of freshwater crayfish native to Britain (McGrath, 2004b).

Charnwood Granite Quarries

Charnwood Quarry near Shepshed actually consists of two individual quarries sited on either side of the M1 motorway, near to junction 23. To the east is Longcliffe Quarry (W on Fig. 4), and to the west is Newhurst Quarry (X on Fig. 4), which is more than 100 m deep. Both quarries are largely in the Precambrian North Charnwood Diorites, and older volcaniclastic sediments belonging to the Blackbrook Reservoir Formation of the Charnian Supergroup (Carney, 1994). The quarries date from around 1850, when a horse-worked railway was built to convey rock to the processing plant (Farmer, 1968). The Ellis & Everard partnership purchased the quarries from the Charnwood Granite Company in 1891, when partners in the enterprise were James Ellis, William Thomas Everard, John Breedon Everard and Charles Everard.

John Breedon Everard installed new machinery in the quarries and the stone was initially transported from the sidings by horse and cart. Later on, the stone was carried by rail, via a short branch line to the Charnwood Forest (Keil *et al*., 1991) and London and North Western Railway at Shepshed Station. In 1913, the quarries produced various sizes of broken macadam, screenings and chippings 'with or without dust', washed chips, unbroken granite for breaking by hand and rubble for road formations. Steam operation of the 2-foot-gauge railway was introduced at an unknown date into the quarries, and two locomotives were in use, a Brush and a Bagnall saddle tank; the latter was owned earlier by the Ministry of Munitions (Farmer, 1968), and was sent to Bardon Hill Quarry in May 1936, when control for the quarries passed from Ellis & Everard to the Amalgamated Roadstone Corporation (ARC). ARC continued to trade under the name of the Charnwood Granite Quarries, until Hanson Quarry Products Europe Ltd. acquired them in 1999. In 1960, around 65 men worked in the quarries, extracting about 600 tonnes a day (Keil *et al*., 1991), but by 1992 this number had dropped to 50, who worked the quarries 24 hours a day (Wix & Keil, 2002). More recently only a handful of men were employed in the quarries.

Longcliffe Quarry, originally known as Longcliff Plantation, had major developments in 1984, to expand it to almost 90 ha (K. Bird, *pers. com*.), but by 1995 quarrying had ceased as it was no longer considered to be economical. At that time, Newhurst Quarry was

Figure 27. *Aerial view of the Charnwood Quarries in 1969. The haul road and conveyor belt pass under the M1 motorway, transporting rock and aggregate between Newhurst (to the northwest) and Longcliffe Quarry (to the southeast). (Photo: Hanson Quarry Products)*

dormant, but on the closure of Longcliffe the decision was made to re-open and expand it to almost twice its original width. Stone was then extracted from Newhurst Quarry and taken by 60-tonne dumper truck to Longcliffe Quarry, where the primary crusher reduced it down to 200-mm lumps (Wix & Keil, 2002). Aggregate was then returned to Newhurst via a conveyor belt that ran under the M1 to the secondary and tertiary crushers adjacent to the quarry (Fig. 27).

By 1997 production of crushed diorite and Precambrian volcaniclastic rock was around 1 million tonnes a year, but later a severe decline in the demand for roadstone reduced annual output to 400,000 tonnes (Wix & Keil, 2002). Reserves at Newhurst were recently estimated at around 2 million tonnes, which would take only four years to extract, and it is known that there are still small reserves remaining at Longcliffe Quarry. However, Newhurst Quarry also ceased to operate in April 2000, and is currently allocated in the Leicestershire Waste Local Plan as a potential landfill site.

The Leicestershire slate industry

The Romans exploited the outcrops of Swithland Slate in Charnwood Forest during the period 100–400 A.D., and fashioned the slates into characteristic diamond shaped tiles for roofing purposes. Swithland Slates were used to roof important buildings in Roman Leicester, but they have also been found at another Roman site at East Bridgford, Nottinghamshire (then known as Margidunum). There is no further evidence for the use of Swithland Slate until the 1300's, when Borough Records show that it was then used to roof major buildings in Leicester. Swithland slates are referred to in the Mayor's accounts for 1305-6, and ten years later the Borough purchased slates at ….2s/2d (11p) per 100, carriage paid (Ramsey, 2000).

The actual locations of the slate quarries are first mentioned in 1343, when the quarries at Swithland and Groby Park are referred to in the Records of the Borough of Leicester 1103-1603. In 1377-8, work on the Leicester Castle included *...2000 slates bought from John Bareman with cartage from Swithland, with 3s 1d a thousand* (Fox, 1944). In the same year, builders at Frith Lodge purchased 1500 slates from Swithland at the same price. It is also known that Bradgate House, once the home of the ill-fated Lady Jane Grey, was roofed with Swithland Slate, and reference is made to the use of slate from Groby Park in the building records for the Kirby Muxloe Castle (Ramsey, 2000).

Slate was not commonly used as a roofing material until the late-17th and early-18th centuries, and even then it only tended to be used for the houses of the nobility and gentry (Ramsey, 2000). Most of the quarrying activity took place in the 18th and 19th centuries, when the principal slate quarries were at Swithland Wood, The Brand, Groby and Woodhouse Eaves. The two landowners with slate resources on their estates were the Herrick family of Beaumanor Hall, Old Woodhouse and the Earl of Stamford at Groby and Swithland (Ramsey, 2000). A series of tenants operated the slate quarries, on lease from the landowners, but paid them a commission on every tonne of slate sold. Swithland Slate was utilised for a multitude of purposes, including the manufacture of roofing slates, headstones, milestones, wall stones, flag floors, sundials, paving, fencing, shelving, gateposts, kerb-edging and some household items. Traditionally the slates were laid on a roof in sizes reducing from eaves to ridge, thus enabling even the smallest pieces of slate to be used (Lott, 2001). Swithland Slates were widely used in country dairies due to their ease of cleaning and resistance to grease.

The Swithland quarries consist of The Great Pit in Swithland Wood, The Brand and Pike or Tower Water near to the 'triangle' at Woodhouse Eaves (Fig. 28). Their slates tend to be pale grey, blue-green-grey or purple in colour; they are from the Cambrian Brand Group of the Charnian Supergroup. The Hind family were frequent tenants of the Swithland quarries, having their first lease granted from the Earl of Stamford in 1688. However, their involvement in the slate quarries may have been as early as 1622, as Robert Hind is mentioned in the Stamford list of lease holders (Ramsey, 2000). The Ellis family took over the

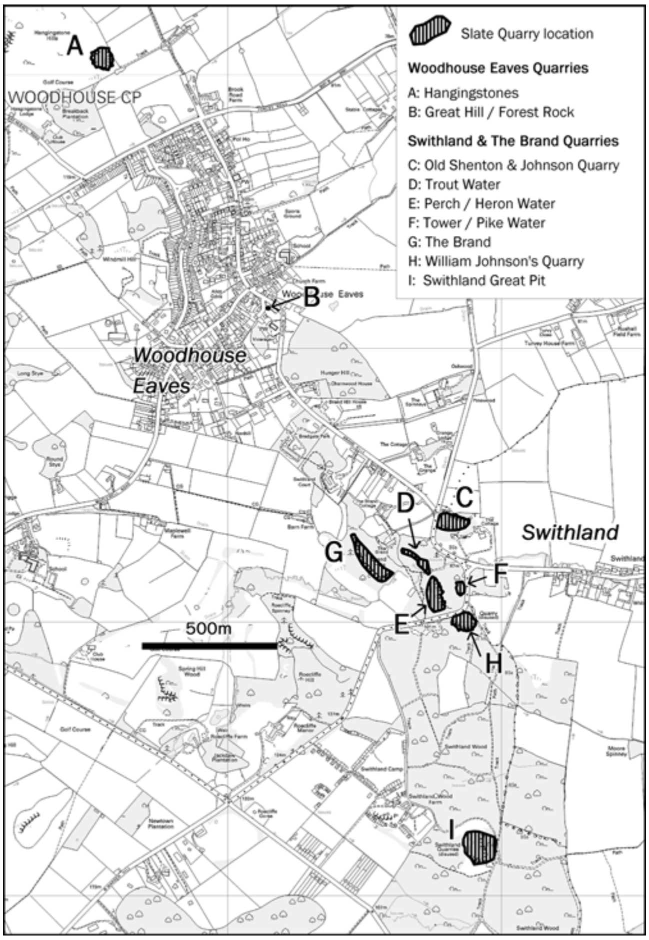

Figure 28. *Locations of the Swithland and Woodhouse Eaves Slate Quarries. (Base map by Ordnance Survey)*

Swithland quarries sometime during the period 1852-65 and operated them until they closed in 1887. They also reopened The Great Pit when they took on the lease in 1859, apparently using 'modern methods and machinery'. The best bed of slate in the quarry was apparently only 5 m wide and almost vertical. As a result, the quarry was worked to a depth of more than 60 m at its northern end, which presumably earned it the name of Great Pit; poorer quality slates were extracted from the south end. Excavated blocks of slate had to be raised to ground level before being split, sawn and polished (Lott, 2001; McGrath, 2004a).

Slate quarrying was a growth area in The Brand (Fig. 28) during the 17th and 18th centuries. It was also one of the localities in Charnwood Forest where cattle could be annually branded with the mark of their owners, hence the unusual name. The quarries were purchased and operated by the Hind family during the 18th century and then sold in 1851 to John and Joseph Ellis. The Ellis family continued to work The Brand quarries, and built a stone tower in the north end of Tower Water (also known as Pike Water), to house a pumping engine (Ramsey, 2000); the tower still remains today as a prominent feature of the abandoned slate pit. When quarrying ceased, the Ellis family transformed the abandoned slate workings into a nature reserve. They landscaped the original Hind quarry by partly filling the middle section of the site to create two separate lakes, Trout Water (to the north) and Perch (or Heron) Water (Fig. 28) to the south (Ramsey, 2000). The Brand Estate was subsequently sold to Robert Frewen Martin in June 1887 for £9850; the Martin family still own and live on the estate.

The Groby land tax records for 1773-1829 indicate that three quarries existed in the area at that time - the Groby Slate Works north of Grey Lodge at Alder Spinney, and two earlier quarries, located close to Bradgate Hill Farm and the present A50. Waste material from construction of the Groby by-pass has now levelled the site of the Groby Old Slate Quarry close to the A50 (Ramsey, 2000). As early as 1766, Henry Hind and his son were leasing the Groby slate pits from the Earl of Stamford (Ramsey, 2000). In 1866 the Ellis family took on the Groby and Swithland quarries and worked them until their closure in 1887. The slates from the quarries at Groby are geologically the same as those at Swithland, but they are more brittle and cleave more easily; their colours range from dark to pale green-grey, and from pale to dark green.

The quarries at Woodhouse Eaves (Fig. 28) were owned by the Herrick family, and are located at Hangingstones and Great Hill. They are not slates in the true sense of the word, as they actually belong to the older Precambrian Maplewell Group of the Charnian Supergroup. Unsurprisingly, they did not cleave so easily as the true slates from Groby and Swithland, and, as a result, their use was not so widespread (Ramsey, 2000). However, this distinctive deep purple slate was used locally as a building stone, a good example being the Almhouses in Woodhouse Eaves. The quarry at Great Hill has since been called Church Quarry and Forest Rock Quarry and is now known locally as Stone Hole. The quarry is situated near to the churchyard, next to the Forest Rock pub (now closed), and had been long abandoned in 1877.

The Swithland Slate quarries supplied stone to local markets, but they were also able to make use of the Rivers Soar and Trent to transport slate farther afield. The construction of the Grand Union Canal in the early 19th century opened up even greater markets, so Swithland Slates were sent as far as Lincolnshire, Northamptonshire, Warwickshire and Derbyshire (Lott, 2001). However, the improvements in transportation that allowed the Leicestershire slates to be more widely distributed also enabled the cheaper Welsh slates to flood the market. These had been available in the county via the Midlands Canal System since the late 1700s (Ramsey, 2000), and Francis Shenton was able to offer Welsh slates for sale at both Mountsorrel and Leicester Wharf in May 1795; one of the earliest documented sales of Welsh slate was made in 1806 to William Oldham, a builder at Braunstone Hall. In 1831, a tax imposed on the carriage of slate by sea was lifted, which resulted in a rapid increase in the amount of Welsh slates imported into England. Welsh slates swamped the market even more effectively when national rail links were established in the 1840s; as a result, the local Swithland Slate industry went into rapid decline. Welsh slates were easier to split, and they produced a more precisely cut, thinner slate; they were also larger and more uniform and weighed less than the local material (Ramsey, 2000). The Leicestershire slates had a more poorly developed cleavage, making them more difficult to split and dress; they were thicker, heavier and rougher than Welsh slates, a feature that is greatly appreciated and admired today, but not so in the past!

A certain Frederick Mott summed up the situation in 1868 in no uncertain terms, when he declared that *These old slates of Charnwood are quarried at Groby, Woodhouse Eaves and Swithland……..and every one of which is worth three Welshmen (or Welsh Slates), both in respect of durability and picturesqueness, although an age of cheapness and bad taste prefers, of course, the flimsier article*. By 1887, most of the Leicestershire Slate quarries had closed, signaling the end of an era. Charles Wesley continued to work the Old Groby Slate Quarry until March 1897; it is thought that he was probably the last person to quarry slate in Leicestershire (Ramsey, 2000). Although no quarries produce roofing slate in Charnwood today, recycled Swithland Slate is still very much in demand (Lott, 2001) and can command a high price. It is greatly prized for its character and variety of colours, and it still adds beauty to the Charnwood villages.

A final note…

The quarry industry has been vital to the socio-economic development of Charnwood Forest for well over a century now, and will continue to be so for at least another 50 years. Abandoned quarries can and often do become a positive feature of the landscape, as with age they produce a wealth of varied habitats for wildlife and plants, as well as providing a multitude of recreational uses. The quarrying industry plays a major role in the conservation of many old quarries, as mineral companies often work together with local authorities and conservation groups to restore and reclaim old quarry workings, to enhance the local biodiversity and geodiversity value of the area. Over 12% of the area of Charnwood Forest is notified as a Site of Special Scientific Interest, including sections of the quarries at Bardon Hill, Old Cliffe Hill, Newhurst, Buddon Wood, the Old Mountsorrel Quarry as well as Swithland Wood and the slate pits. To date, there are seven confirmed and six candidate Regionally Important Geological and Geomorphological Sites (RIGS) within Charnwood Forest. All of the RIGS are within quarries, covering a total (confirmed and candidate) of 502 ha. The scientific usefulness of many quarries will long outlive their commercial life, as some of the most fascinating geology in this part of England is revealed in them (McGrath, 2004b). They should therefore be carefully and sensitively conserved to ensure that they remain a valuable teaching and research asset for future generations of geologists.

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Further valuable source data in ephemeral literature is traceable in the Leicestershire County libraries (notably at Hinckley), in the archives of the Bardon Hill and Mountsorrel Quarries, and in the files of the Whitwick Historical Group.

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The British Geological Survey's Glaciological Expedition to Arctic Norway in 1865

Peter Worsley

Abstract: During the two decades after 1841, the Glacial Theory was, at best, quiescent in Britain. The 1865 expedition arose from a progressive resurgence of interest in glacigenic sediments. The members were three young Geological Survey officers, Archibald and James Geikie and William Whitaker, all with recent drift mapping experience. Their objectives included making 'actualistic' observations of modern glaciers, comparing Norwegian and Scottish glacial features, and better comprehending glacial deposits, both ancient and modern. Field investigations were focused on two areas of Arctic Norway - Holandsfjord (Nordland) and Bergsfjord Peninsula (Tromsø-Finnmark). Their work produced the earliest known detailed glacial geological analysis (including accurate drawings, sketches, maps and cross sections) of any Scandinavian ice-marginal environments. These data permit a comparison of ice marginal and proglacial environmental changes between 1865 and the present day associated with the key Holandsfjord glaciers - Engabreen and Fondalsbreen. The characters of the ice margins in 1865 and 2005 are compared and, in conjunction with other observations, yield one of the most comprehensive records of Neoglaciation anywhere. In the Bergsfjord Peninsula, the 1865 details are more sparse, except for the Jøkulfjord regenerated glacier. The impact of the 1865 work on the Glacial Theory and subsequent careers of the participants was clearly significant.

In the summer of 1865, Archibald (Archie) Geikie (1835-1924) in the company of his brother James (Jamie) Murdoch Geikie (1839-1915), and William Whitaker (1836-1925), undertook a landmark glaciological expedition to northern Norway (Figs 1 and 2). All three were then junior serving officers of the Geological Survey of Great Britain. They appear to have had official encouragement to gain 'actualistic' field experience relating to 'the hot topic of the day' in Quaternary geology, namely the debate over the land-ice v marine-iceberg hypotheses in accounting for landforms and sediments associated with former glaciation in Britain and elsewhere.

The expedition formed a key stage in development of the Glacial Theory in Britain, and had a major impact on the participants' subsequent geological work, but it also provides an opportunity to compare the glaciers in 1865 with their equivalents of today.

The participants

Archie Geikie was born in Edinburgh in 1835, the same year that the Geological Survey of Great Britain was founded. Twenty years later in 1855, he joined the Survey after a classical high school education and uncompleted university studies. He progressed rapidly since, in the 1870s, he concurrently held the foundation Murchison Chair of Geology and Mineralogy at Edinburgh University and the Directorship of the Survey for Scotland. Ultimately, he rose to become Director General of the whole Survey and after retirement, President of the Royal Society, the only geologist ever to attain this prestigious position (Charles Lyell declined to be nominated in 1863). In the last year of his life he wrote an autobiography (Geikie 1924) the last achievement in an extremely prolific record of publication (Cutter,1974; Oldroyd,1990).

William Whitaker was born in Hatton Garden, City of London and read chemistry at University College London before graduating in 1855. After joining the Survey, his first Survey notebook shows that he commenced mapping work near Pangbourne, in the Goring Gap area of Berkshire in May 1857. Thereafter, for his entire career, he remained based in the southeast becoming a specialist in both Cretaceous and Tertiary sequences. He is best known for his seminal work on the geology of the London Basin and water supply issues (George 2004). During his career he mapped glacial deposits of varying ages in greater East Anglia, including some immediately prior to the expedition early in 1865.

Jamie Geikie was a younger brother of Archie and was born in 1839. He became an assistant geologist with the Survey in 1861 and commenced publishing during the year after returning from Norway. His epic book, *Great Ice Age*, was first published in 1874 and established him as a world authority on glacial geology. In 1882, he resigned from the Survey in order to succeed his elder brother in the Murchison Chair. This was not an easy decision for him and he would dearly have liked to have maintained a dual appointment like that of his elder brother but this was not approved by the civil service. He occupied his chair until retirement in 1910.

Glacial Theory before the expedition

Some of the earliest steps in the history of British glacial theory are recently reviewed in this journal, (Worsley 2006). One perplexing aftermath of Louis

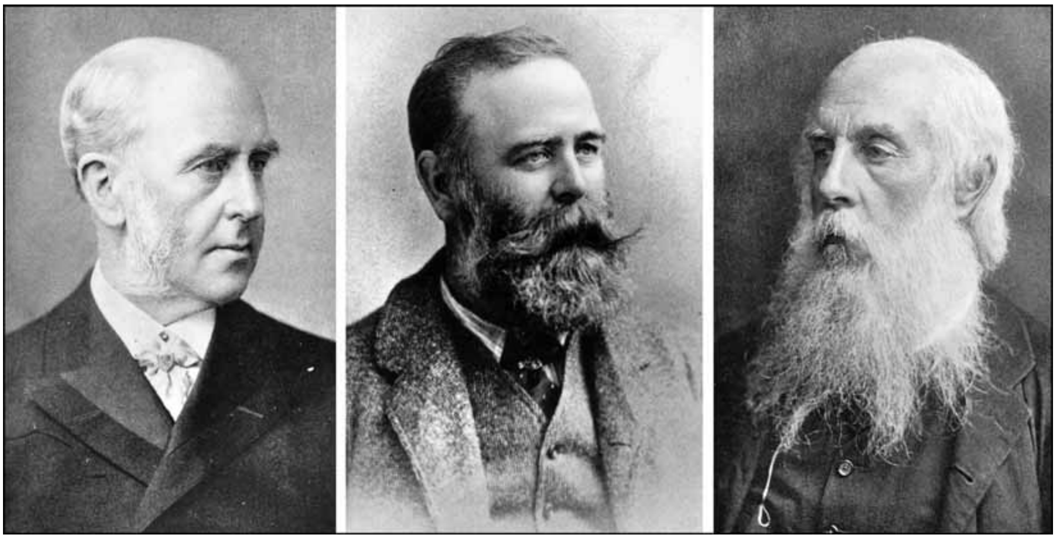

***Figure 1**. The three expedition participants: left: Archibald Geikie, centre: James Geikie, right: William Whitaker*

Agassiz's famed visit in 1840, is that after a short euphoric phase, when senior geologists such as William Buckland and Charles Lyell declared their conversion to the land ice hypothesis, very serious doubts started to reassert themselves. An oft quoted sentence is that of Buckland in a letter to Agassiz (1885 p309) which reads *Lyell has adopted your theory in toto!! On my showing him a beautiful cluster of moraines within two miles of his father's house* [Kinnordy in the Vale of Strathmore], *he instantly accepted it, as solving a host of difficulties that have all his life embarrassed him*. Unfortunately, Lyell was soon to repudiate the land ice concept to again favour a marine iceberg theory and the British geological community at large remained highly sceptical. Buckland, finding himself almost totally isolated, tried in vain to adopt a conciliatory compromise position.

An American historian, Hansen (1970), asserted that before his study, no one had directly addressed the problem of explaining how or why the glacial theory was not accepted by the geological community in the 1840s. Lacking the advantage of direct experience of British superficial geology, it is understandable that he seemingly missed the principal point in comprehending this conundrum by not fully appreciating the influence of two key factors. First, the common occurrence of now isostatically raised *in situ* faunas in sediments originally deposited below sea level. Secondly, that glacially-derived marine faunas of existing species were often present in both till and outwash, on occasion at particularly high elevations (almost 400m) as at Moel Tryfan in north Wales (Thompson & Worsley 1966). The geologists of the day sought to interpret and reconcile the factual evidence afforded by these well-preserved faunas while not familiar with basic processes such as glacial ice rafting and glacio-isostatic loading.

In the introduction to his seminal book on palaeoglaciation, Ramsay (1860 p2) summed up the situation succinctly by stating *It is now 20 years since Agassiz and Buckland announced that valleys of the Highlands and of Wales had once been filled with glaciers. Few but geologists heard the announcement, and with rare exceptions, those who cared at all about it, met the glacial theory of the Drift in general, and that of extinct glaciers in particular, with incredulity, and sometimes with derision*. We should note that Charles Darwin was one of these exceptions since at Cwm Idwal he had identified supraglacial debris associated with cirque glaciation in north Wales (Darwin 1842, Worsley 2007). Later, Ramsay (1864 p106) observed *men sought to explain the phenomena of this universal glaciation by every method but the true one*. Indeed, Bailey (1952) notes the irony that in 1845 Ramsay attended a Geological Society of London meeting and afterwards wrote *Jolly night at the Geological. Buckland's glaciers smashed*. Apparently he converted to a marine version of the glacial theory in 1848 following a joint examination of the Llanberis Pass area of North Wales with Robert Chambers, a committed glacialist who wished to compare the Welsh with his native Scottish glacial evidence.

From 1845 onwards, Ramsay's sway on British geology grew, since in that year he became Local Director of the Survey for Great Britain, with responsibility for a field staff of six. His first public declaration of his belief in the former existence of glaciers in Wales came at a discourse held at the Royal Institution in 1850. He instigated a Survey mapping programme in Scotland in 1854 and this expansion of activities led to the appointment of Archie Geikie in the following year. In his 1860 book, Ramsay continued (p3) *it was necessary for competent observers to investigate the subject both of existing glaciers in other regions and of drift-ice in the northern and southern seas; and, accordingly, I have considered it needful for the thorough understanding of ancient British glaciers, that some of the phenomena now easily seen in Switzerland should in the first place be noticed*. Ramsay had twice visited Switzerland, in 1852 (on his honeymoon) and in 1858 in the company of John Tyndall who also published on Swiss glaciers in 1860. The first part of Ramsay's book (pp5-34) is mainly devoted to his observations of the Swiss Aar

Glacier. In the second part (pp35-116), he argues in favour of a phase of land ice glaciation in North Wales but also for a subsequent major marine submergence phase accompanied by ice bergs.

With Ramsay as his line manager, it is not surprising to find that Archie Geikie recalled (1924 p94) that in the following year *I deliberately set myself to undertake a serious study of them* [drifts]*, with the view of trying to make out the history of the events of which they are the record. They were commonly regarded as various marine sediments, spread over the country when it was submerged under a sea on which icebergs and rafts of floating ice transported rock debris from northern lands*. He continued by saying that after field examination of the till and rock head surfaces beneath, *one became more convinced that the phenomena could not at all be accounted for by floating ice, but demanded the former existence of a great terrestrial ice sheet or sheets, as Agassiz had insisted, twenty years before*. He then devoted his 1862 summer holiday leave to making a traverse across southern Scotland specifically to obtain a better understanding of the glacial deposits and allied features. In the following year he accompanied Ramsay in making a transect along the East Coast from Berwick to the Humber, examining the glacial successions and making stone counts (clast lithological analysis in modern jargon!). As he comments in his autobiography *my mind was rather obsessed at this time with glacial questions* (Geikie, 1924 p99).

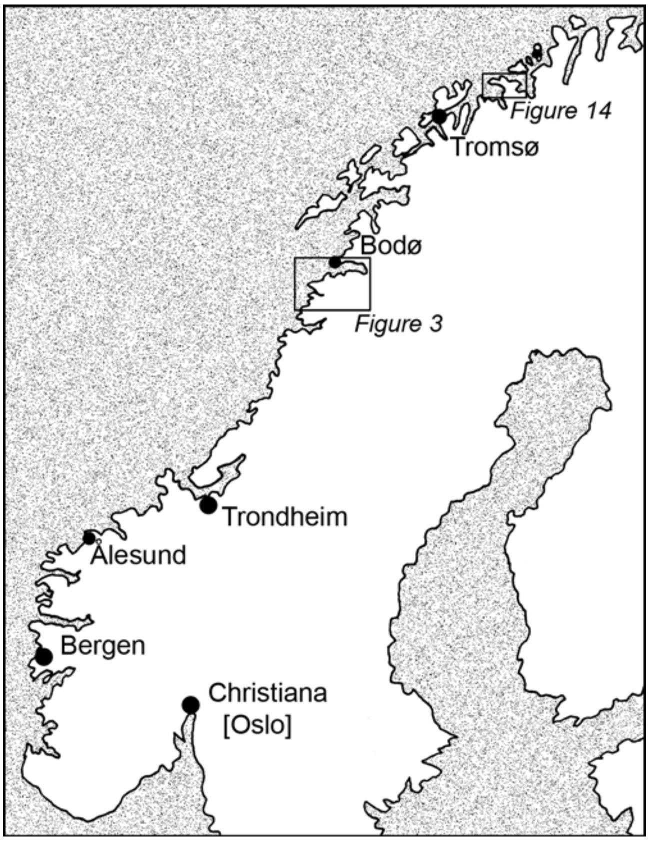

Figure 2*. The two main study areas in Norway, within the counties (fylke) of Nordland and Troms/Finnmark.*

Archie Geikie's first major glacial paper (1863) was described as *The first attempt to present a connected view of the sequence of events in the history of Scotland during what is known as the Glacial Period or Ice Age*. This was a formidable achievement for someone working on a topic largely in their leisure hours. The paper is particularly illuminating since Geikie describes how his own interpretations switched from a drift ice standpoint to a perspective which accepted land ice as the main agency in the generation of glacial landforms and deposits. He did not, however, totally reject the marine submergence concept and came to adopt a compromise position whereby a main phase of land ice glaciation was followed by a submergence episode. Bailey (1952 p73), observed *Ramsay, Jamieson and* [A] *Geikie at this date* [1863] *retained a great deal more submergence in their philosophy than is commonly admitted today*. Indeed, Jamie Geikie (1881) later wrote *...German geologists continued to hold the opinion that all drift phenomena of the low ground were due to the action of icebergs and marine currents until 1875*. Even as late as 1916, J.E. Marr, one of the leading glacial geologists of the day, stated (p144) *the glacialists were divided in opinion as to the relative importance of land-ice and floating sea-ice as agents of glaciation, and for some areas in Britain the matter cannot be yet ultimately settled*.

Both Geikie and Ramsay were aware that ultimately they were subject to the approval of Sir Roderick Murchison, who at the relatively advanced age of 63, had become Director General of the Survey in 1855. Murchison's views were anti Darwin's evolutionary model and strongly critical of glacial theories. As Oldroyd (1990) succinctly put it, *Geikie was an uniformitarian (or quietist) while Murchison was a catastrophist (or convulsionist)*. Indeed, Murchison died in 1871 still an unrepentant neo-diluvialist. Hence, in the first edition of his North Wales memoir published in 1866, Ramsay was requested by his superior to be brief in his physiographic account that favoured glacial erosional processes in cirque genesis (Bailey, 1952).

Nevertheless, Ramsay must have given his backing to the proposed expedition since there was a very close relationship with both Geikie brothers. This is exemplified by the dedication of the first edition of Jamie Geikie's *Great Ice Age* to '*A.C. Ramsay dear friend and teacher*'. Additionally, after his death, Archie wrote a full sympathetic biography on Ramsay (Geikie, 1895), saying *He was almost my earliest geological friend, and for many years we were bound together by the closest ties of scientific work and of unbroken friendship*.

Archie, writing the preface to his just completed book *The Scenery of Scotland* immediately prior to departure on the 1865 expedition, noted that the principles of denudation were laid down long ago by Hutton and Playfair but that the question of the origin of valleys remained a controversial issue, and with

Murchison in mind, possibly disingenuously wrote *the views to which I have been led, run directly counter to what are still the prevailing impressions on the subject, and I am therefore prepared to find them disputed, or perhaps thrown aside as mere dreaming* (Geikie, 1865b p96). Later, in the preface to the second edition (Geikie, 1887), he recalled the controversy raging in 1865 and how William Whitaker's ideas on sub-aerial Wealden denudation had contributed support to his position.

Earlier glacier observations in Norway

Sensibly, some preparatory desk studies were undertaken prior to the 1865 expedition and these included the narrative of the Prussian savant Leopold von Buch (1774-1853), first published in 1810. In this von Buch described a prolonged journey during 1806-8 in which he followed a circular route extending from Christiania (Oslo) to the North Cape and back with the objectives of (i) investigating the geology, (ii) examining the role of latitude in determining the character of the natural vegetation and (iii) observing human land use *till at last, the noxious influence of snow and ice is destructive to everything which has life*. The translator of the English edition (von Buch, 1813) was John Black, and in a gloomy preface he anticipated *that country (Norway) will in all probability soon become the theatre of a bloody war, in which the British nation are pledged to co-operate*. Incidentally, Charles Darwin took a copy of von Buch's volume with him during his voyage on the Beagle, enabling him to appreciate how snow line elevations and calving tide water glaciers in the southern hemisphere lay at latitudes much closer to the equator than their equivalents in the European Arctic.

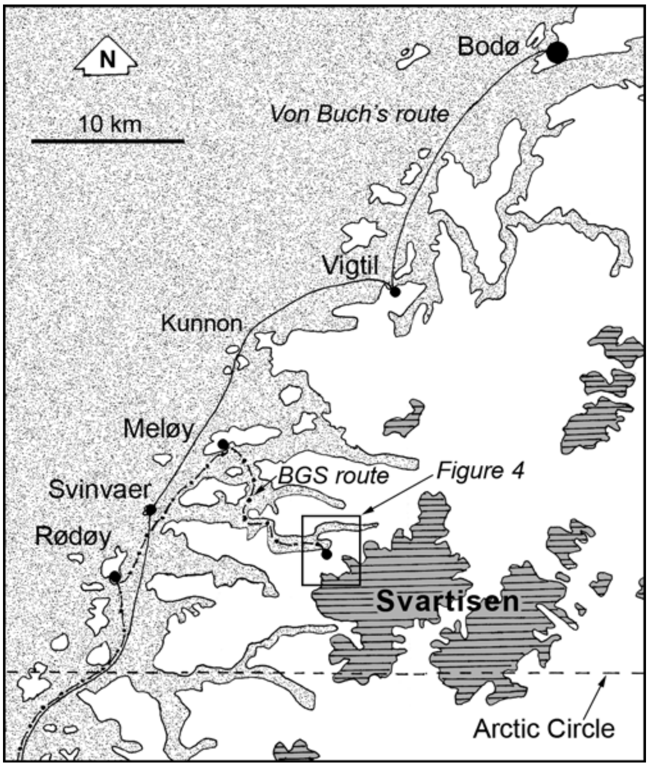

Figure 3. *The Nordland coastal area between Rødøy and Bodø showing the location of places mentioned in the text.*

Two parts were relevant to the BGS expedition. Firstly, von Buch's account of the Arctic Circle coastal districts made during mid June in 1807 (Fig. 3). He commented *perpetual snow lies here and what is still more the snow has generated glaciers*. Between Lurøy and Bodø his precise route is unclear since the geographical names which he uses are no longer in current use. He reported *about 4 or 5 English miles south from the cape [Kunnon] opposite the trading station of Haasvär, a glacier descends from the height, and the ice comes into immediate contact with the sea, a circumstance perhaps peculiar to this glacier. Even then, the warmth of the summer had merely driven it a few steps from the shore, but it would probably regain its former space in a short time*. Here he was referring to the snout of Engabreen part of the Svartisen ice cap which, uniquely in Scandinavia for an outlet glacier, descended to sea level. The description of Haasvär as being opposite is misleading (probably an artefact of the translation) since it is a small uninhabited island just beyond Rødøy, over 30 km west of Engabreen.

Secondly, a description of the Bergsfjord Peninsula (halvøya) glaciers (these are 450 km northeast of Svartisen), as viewed from the east above Alteid. He remarked (p232) *They remain pendent in the middle above the steep and almost perpendicular rocks and in summer the great masses of ice are incessantly precipitated from above into the Fiord causing the sea level to rise by several feet for miles* (i.e. mini tsumanis). With the iceberg hypothesis being so favoured in 1865, the BGS expedition was naturally attracted to this iceberg-generating locality. Indeed, British trawlers operating out of the Humber ports utilised this free freshwater ice in packing their catches for many decades. Von Buch did not round the peninsula because of poor sea conditions (Fig. 14).

Another important source of guidance came from the pioneer Scottish glaciologist J.D.Forbes relating to a journey he made in 1853 (Forbes 1854). He had consulted widely with northern experts in Oslo before heading north. He included a map in the rear of his book showing his route and, rather crudely, the distribution of the main permanent snowfields. Curiously, he labelled the Svartisen ice caps collectively as Fondalen. The significance of this will be apparent later. After calling at Rødø [Rødøy] Forbes sailed non-stop to Bodø but wrote *on the right with more than common majesty; and over the snowy summits of Fondalen* [Svartisen] ..... *clearly distinguish true glaciers, descending from the hollows of the mountain towards the level of the sea.* He was understandably frustrated that the coastal configuration foiled his desire to see the glacier termini. He recalled that von Buch had stated that these glaciers of Fondal [Svartisen] fall *into the sea* (Forbes's italics). He also expressed scepticism that von Buch or any other *traveller who has published his observations* had visited the interior of these fjords. However, the insight shown by von Buch into the mechanism of annual frontal variations, whereby summer ablation exceeds forward movement resulting in frontal retreat, suggests that either he or an associate had first hand knowledge of the glacier. Archie Geikie made several pages of notes in his field note book from Forbes's account prior to departure for Norway.

Sources relating to the expedition

Archie Geikie's paper (1866) is a vivid account of their activities in Norway, and later a slightly revised version formed a chapter in his book *Geological Sketches at Home and Abroad* (1882a). A short socially oriented outline is included in his autobiography written almost 50 years later (Geikie 1924). His unpublished field note book, DD, gives both logistical and further valuable observational data and sketches (Geikie, 1865a). This is preserved in the archives of Haslemere Educational Museum, an institution that Archie encouraged in the last decade of his life while living in that town.

Unfortunately Jamie appears to have left little written material specifically relating to his expedition experiences. As his biographers wrote *Unfortunately only the barest notes of this visit remain ....and we do not know what impressions were obtained* (Newbigin & Flett, 1917). Nevertheless, they were able to fill in some details of the expedition which otherwise would not be known.

Sadly, no record has been identified concerning observations made by William Whitaker while in Norway, other than oblique comments. He appears not to have published anything specific arising directly from his experiences (see later). His official Geological Survey notebooks are in the BGS archive at Keyworth, but, alas, the volume covering the period October 1864 to August 1865 has a tantalising gap in his dated notes extending from June 19 to August 16. It is probable that he kept a separate field notebook (as did Archie) specifically devoted to the expedition, but its location is not known.

Expedition organisation and route

The expedition had originally been planned for the summer of 1863, consisting solely of Archie Geikie and his friend and colleague John Young (1835-1902). They had been school friends and sometimes Archie's junior brother Jamie was 'allowed' to accompany them on fossil hunting trips. Young first went into medicine but then decided that a geological career was preferable, so as Dr Young, he joined the Scottish branch of the Survey at the same time as Jamie Geikie in 1861. Unspecified, 'unforeseen circumstances' caused a year's postponement and during that time Young withdrew, with his place being filled by both Jamie and William Whitaker.

The principal objective was the examination of modern glacial environments as an aid to the interpretation of landforms and deposits in Scotland *where the ice still remains on the heights and creeps down the valleys in glaciers, some of which even descend to the edge of the sea, ...'there was every probability that ...light would be thrown on [the ice-age] in Scotland* (Geikie, 1924 pp106-7). Although access logistics played a role, Norway was selected primarily since its geological character was similar to western Scotland. It was known that some glacier margins were close to the sea, something which Ramsay knew that the Alps could not provide. The departure date, June 1865, was apparently determined by when Archie Geikie could finish correcting the proofs of his book *The Scenery of Scotland* (1865b). Just before their departure, Archie learned that he had been elected a Fellow of the Royal Society of London (later, the other two members were also elected FRS).

Archie Geikie was leader of the expedition and one wonders on how a small party consisting of two Scots brothers and a Londoner related to each other. Certainly in later years there were disputes between Geikie senior when he was Director General of the Geological Survey and William Whitaker over mapping policy. Furthermore, Jamie is said to have resented his brother's dictatorial style and reputedly did not inform him of his forthcoming book *The Great Ice Age* until it was published (Harry Wilson, 1985, pers. comm.) and this rumour gains support from a total absence of any mention of Archie in the preface. Similarly Archie makes no mention of Jamie in his magnum opus (A Geikie 1882b). Despite this, Archie did fairly acknowledge that his 1866 paper was the result of their conjoint observations, although joint authorship would probably have been more appropriate. The rear pages of Archie's field note book record the financial transactions during the expedition in great detail and there is little doubt that he also acted as treasurer (Geikie 1865a). Apparently there was a budget to finance the expedition in the field (possibly a subvention from the Survey), and his accounts separate personal items incurred by each participant from corporate expenses with William Whitaker being the most frugal personal spender.

Uncertainty surrounds the precise initial outward route. In his 1866 account, Archie mentions sailing from Bergen northwards along the coast, whereas in his autobiography (written 58 years after the event) he asserted that it was from Hull direct to Trondheim. In contrast, Newbigin (1917) reveals that Jamie's notes indicate a route from Newcastle to Ålesund and then up to Trondheim. All sources agree that in Trondheim they transferred to the daily north bound coastal steamer and disembarked at the island of Rodoy [Rödö]. The next leg was by a local ship to the island of Meløy [Melovær] about 30 km north of the Arctic Circle (Fig.3). There they overnighted at Melöegaard [farm] with a Mrs Hagen as host and she introduced the party to a range of Norwegian cheeses. Thereafter, it was a journey of at least 15 km by an open rowing/sailing boat with four oarsmen to their initial destination at the head of Holandsfjorden. There were other passengers on board, one a Lutheran pastor with whom Archie attempted a conversation. Use of successively English, French and German failed to solicit a response but was finally met with success when he spoke Latin. He commented that this was aided by him having been taught to speak Latin in Scottish High School tradition.

Close to the end of the fjord, on the crest of a morainic terrace on the southern flank, lay the farm of Fondal Gaard (Fig. 4). There Johan Peter Olsen was the host and his farm served as their base for the following week during which they investigated both Engabreen and Fondalsbreen glaciers and the immediate surroundings (Engabreen is locally known as Engenbreen). The two glaciers were of the outlet type and sourced by the same plateau icefield (Fig. 8). In 1865 Fondal Gaard consisted of a single farm building dating from c1670 and Knut Dahl, the grandson of Johan Peter, still lives (2005) in the original building (Fig. 5). An adjacent building (Hovedbygningen) dates from c1873, and after 1900 Knut's father, Adolf Dahl, used it solely to accommodate the many tourists who arrived by sea.

Concluding their work, the party returned to Meløy before embarking on a north bound steamer as far as Bodø. After a stay of four days, the party sailed further north, unfortunately in poor weather, via Lofotn and

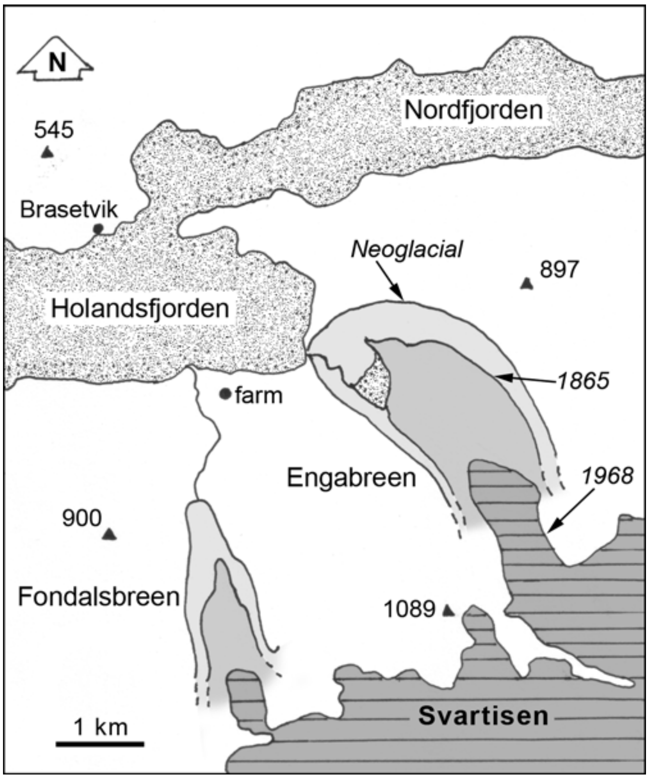

Figure 4. The inner Holandsfjorden region, showing the Engabre and Fondalsbre outlet glaciers at three stages – Neoglacial maximum, 1865 and 1968.

Figure 5. The original Fondal Gaard building dating from c1660 AD. and where the expedition stayed when based in Holandsfjord. The current owner, Knut Dahl, still lives there, and the white building behind is the Hovedbygningen.

Tromsø to the island of Skjaervö (Fig. 14). There they chartered a sailing boat for the not insignificant journey across Kvænangenfjord and on into its branch of Jökelfjorden, part of the Bergsfjord Peninsula. At the head of the inner part of this latter fjord (the appropriately named Isfjorden) they expected to find a calving glacier as reported by both von Buch and Forbes. This proved still to be the case, with the sea dotted by small icebergs. This glacier is technically a regenerated glacier being fed by snow and ice avalanching from a short lobe of the Øksfjordjøkel plateau icefield. After a night in a fisherman's hut, they could not move far because of an adverse wind. As a consequence, the following night was spent in the boat as it headed west back to Skjaervö. Two days were spent recovering before embarking again on a northbound coastal steamer to the next port of call at Loppen [Loppa]. From here, another boat was chartered for a journey initially south up Sørdre Bergsfjord, to the hamlet of Bergsfjord where they landed. They climbed up an adjacent valley in order to observe two outlet glaciers sourced by the Svartfjelljøkel ice cap. They then sailed northeast down Nordre Bergsfjord and subsequently eastwards as far as Nusfjorden where they again landed. After this they returned to Loppen to join another coastal steamer, which took them to the most northerly latitude they attained (over 70˚ N) at Hammerfest.

Here, they then turned south and returned direct by coastal steamer to Trondheim, staying at the Bellevue Hotel before continuing along the coast down to Bergen before crossing the North Sea to Grimsby in a Dutch steamer. It is most probable that William Whitaker took leave of his Scots companions in Grimsby and caught a direct Great Northern Railway train south to London since his Geological Survey field note book (p54) shows him mapping close to Canterbury on August 16. Certainly, the two brothers first travelled to Hull (via the Humber ferry from New Holland) and then onto York and finally Edinburgh. This inconvenient routing was taken, because the Keadby rail bridge over the River Trent was not completed until October, 1865.

Chronology of the modern glaciers

Current conventional wisdom accepts that during the Last Glacial Maximum (c20 ka BP), most, if not all of northern Norway, was buried beneath part of a single Fenno-Scandinavian ice sheet which extended towards the edge of the continental shelf. After this event, a phase of essentially continuous recession followed, resulting in many of the outer fjord and skerry areas being ice-free by c12 ka BP. Further retreat freed many of the fjords, but during the subsequent Younger Dryas climatic deterioration a widespread glacier resurgence was induced and some recently abandoned cirques were reoccupied. This is the same re-advance event which led to the construction of the Vassrygg end moraine in S W Norway (Worsley 2006).

This Younger Dryas readvance is often delineated by a chain of prominent moraine ridges, especially in the fjords, with Holandsfjord and the Bergsfjord Peninsula being no exceptions to this model. Also, relative sea level in the area lay at around 100 m higher today's. This correlates with a significant bench feature, the Main Shoreline, forming a prominent component of the modern landscape since it is often eroded into the bedrock, indicating particularly effective shoreline processes at that time. Many Younger Dryas glacier lobes ended in the sea, creating glacio-aquatic end moraines characterised by a crude deltaic structure. An excellent example is the terminal moraine ridge on which Fondal farm is located. In recent decades glacio-deltaic facies exposed below the farm in a large aggregate quarry have confirmed its sub marine origin. A coeval consanguineous feature at the mouth of the Enga valley is probably present, but here a combination of Holocene fluvial, glacier and marine erosional processes has resulted in the removal of the emerged (above sea level) component. Hence, there is a very marked contrast in the degree of post depositional modification by erosion between the relatively protected north-facing Fondalen and the exposed high energy environment at the mouth of the west-facing lower Enga valley at the head of the fjord.

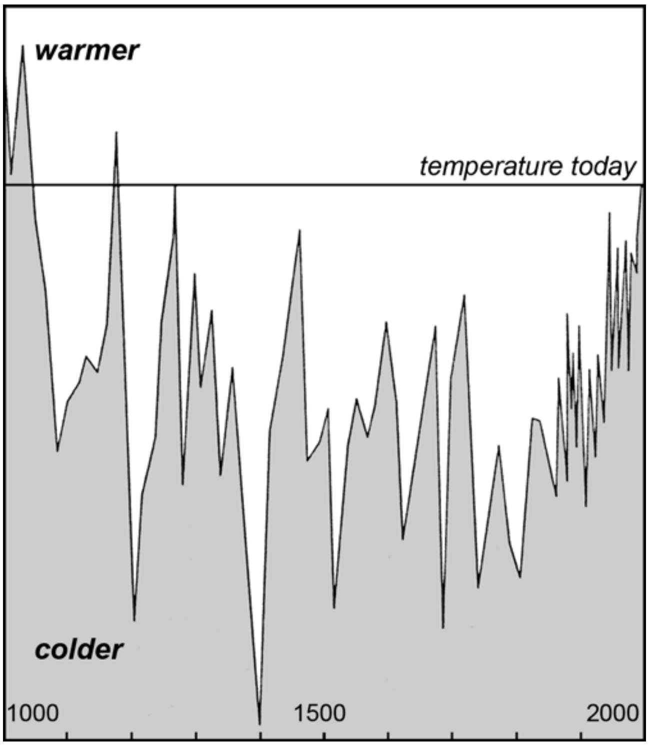

__Figure 6.__ The Little Ice Age as represented by the oxygen isotope signature from a central Greenland ice core in a record from 1000 to 2000 AD that indicates temperature variations relative to today's. Engabreen reached its maximum extent at c 1300, whereas Fondalsbreen was at its most extensive in the mid-18th century, as were virtually all the other Scandinavian glaciers.

With the advent of rapidly rising temperatures heralding the Holocene Interglacial, ice recession recommenced and by the mid-Holocene little glacial ice, if any, remained, even in the mountains (Andersen, 2000). Following the climatic optimum, in the late Holocene there was renewed glacier growth heralding the start of the Neoglacial. Generally, in the eighteenth century, the Neoglacial maximum ice extent was attained, i.e. the culmination of the Little Ice Age (Fig. 6). No instance of Neoglacial ice extending beyond the Younger Dryas ice advance limits has been identified although the Engabreen Neoglacial limit is almost coincident with that of the Younger Dryas (see later). Generally, Little Ice Age maximum advance limits are expressed by a significant contrast in the vegetation on either side of an end/lateral moraine's trim-line system. In the rarer instances where this limit lies below tree line, as is the case in Holandsfjorden, its location within the present day forest is less obvious in the field. In 1865 there was, of course, no knowledge of this glacial chronology, although it was generally understood that there had been overall ice recession from an outer maximum off-shore to the modern glacier margins. Hence, there was the reasonable assumption, that any moraine ridges reflected either ice marginal oscillations or standstills during a single recession.

Neoglaciation at Engabreen and Fondalsbreen

With most glaciers, little is known about pre-eighteenth century glacier variations, and this is the case with Fondalsbreen. Uniquely for Scandinavia however, the ice advance maximum of Engabreen dates not from the classical Little Ice Age maximum of the eighteenth century but rather is significantly earlier, and probably dates from the early 13th century. This conclusion is supported by a range of evidence, including stratigraphy and spatial relationships of a buried soil, comparative development of surface soils on the crests of a series of moraine ridges, and sandur geomorphology. Since the lower part of the glacier lies below the regional tree line, the rates of weathering and pedogenesis in the deglacierised zone are enhanced relative to areas above it. A key factor in dating the glacial variations lies in an ability to unravel the chronosequence of soil development, specifically being able to confidently identify where the 1865 AD

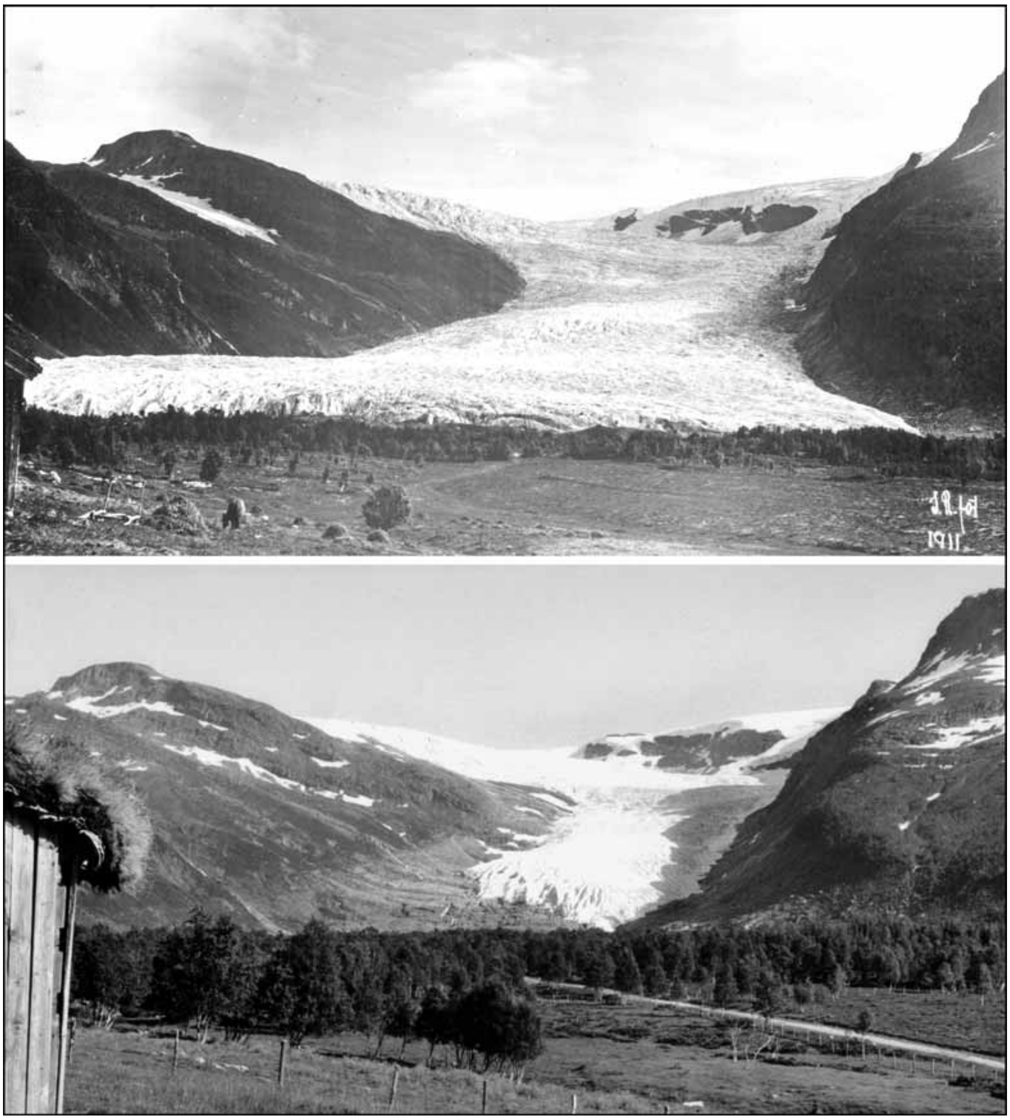

***Figure** 7. The glacier of Engabreen seen from the same location at the edge of the palaeosandur close to Steinar Johansen's Svartisen farm, showing the degree of ice recession through the 20th century – from 1909 (above) to 1976 (below). The wooden building has since collapsed under heavy snow and no longer exists.*
(Photos: 1909 by J. Rekstad; 1976 by P. Worsley)

ice margin was situated. That this is possible is entirely due to the observations made by the 1865 expedition. Using this datum, Worsley and Alexander (1976), were able to map those parts of the distal sandur which ante-date the classical Little Ice Age and identify the likely site of the farm Storsteinøren, which was so badly damaged by the eighteenth century ice advance that it was deleted from the tax roll.

In 1865 the snout of Engabreen displayed two distinctive types of ice margin. The more southerly was a proglacial lake into which the glacier was calving, yielding a scatter of icebergs. The lake was impounded by a series of moraine ridges, with a breach through them controlling the height of the lake. Through this cut a short river flowed directly into the fjord. This river still functions, with the controlling threshold height above sea level appearing to be unchanged. The feeding lake, Engabrevatn, is now vastly larger following glacial recession.

To the north of the lake, the ice margin was characterised by the glacier riding into and over glacial debris consisting of *a loose sandy clay or earth full of stones*. This debris contained a reworked fragmentary marine molluscan fauna derived from sediments beneath the glacier bed where the glacier was eroding pre-existing fjord deposits, possibly that part of the Younger Dryas end moraine which has survived below sea level. Archie's sketch sections (Fig. 8) show two profiles from the glacier across the proglacial area through the lake and land-based margins. About a decade after the expedition, the Norwegian geologist J Rekstad, commenced a long term programme of monitoring frontal variations in conjunction with photography. An early photograph (Fig. 9) was taken from below the icefall looking to the northwest and this shows that in 1891 the glacier margin had changed very little from that prevailing in 1865. It gives a good impression of the ice proximal terrain when the expedition was in the field.

From the mid 1880s onward there is a continuous annual record of the terminal position. A significant readvance culminated in 1911 but this did not attain the 1865 limits. Thereafter, for the next four decades, a progressive retreat followed and the marginal meltwater lake, Engabrevatn, expanded. Surprisingly, since c1960 the position of the glacier terminus has changed very little, and it has shunted by alternately advancing and retreating over short distances on the relatively steep bedrock floor above Engabrevatn. This departure from the global retreat norm is accounted for by an increase in snow accumulation on the ice cap which has counter balanced a rise in temperature. Since the completion of a hydroelectric power scheme in the 1990s, the main melt water streams have been tapped sub-glacially, resulting in a greatly reduced discharge into the lake. This will tend to favour slower wastage of the glacier tongue.

Fondalsbreen in recent decades has displayed readily observable frontal changes as the degree of connectivity of the ice cap margin and a lower regenerated glacier has varied. During some years there has been a direct link between the two producing what is technically an outlet glacier whereas during others this status has been lost leaving an entirely regenerated feature. Avalanching of ice blocks from the plateau ice cap margin down the steep bedrock backwalls above the regenerated glacier produces a granular ice mass with a texture not unlike a breccia. Again, sub-glacial tunnelling has intercepted the melt water and drastically reduced the discharge at the snout. The contemporary glacier bears no similarity to that of 1865. In that year the snout of a classical outlet glacier lay just below an icefall over a bedrock step and was confined by the bedrock geometry. In sharp contrast with Engabreen, there was very little glacial debris at the glacier bed but the bedrock was heavily striated and smoothed. This is probably the spot where the expedition members were first able to crawl beneath an ice margin, being less than a half hour walk from Johan Peter Olsen's farm. Here Archie experienced *the revelation which the first sight of a glacier flashes upon the mind of a geologist* and *caught the ice, as it were, in the very act of doing the work of which I had hitherto only seen the ancient results* (Geikie, 1924 p108). Earlier he had recorded *I crept some yards under the ice, and found the floor of gneiss on which it rested smoothly polished and*

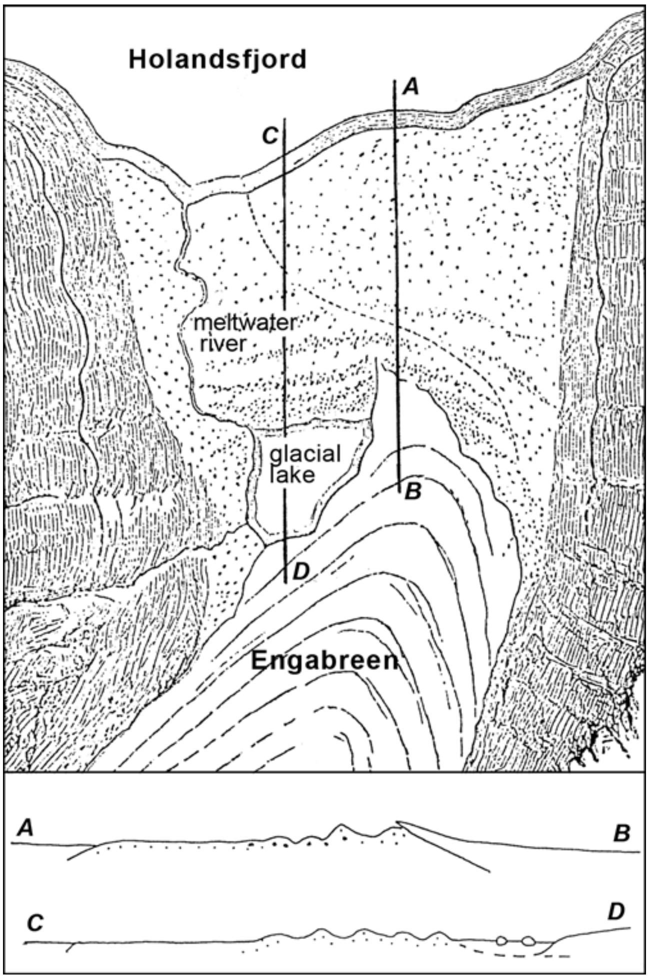

***Figure 8**. Map of the lower Enga valley as drawn by Archie Geikie, with the two long profiles through the ice margin. The ice proximal zone has a complex of end moraine ridges and a sandur extending to the fjord shore.*

***Figure 9**. Engabreen, in 1891, with a glacier marginal position and ice marginal lake very similar to those in 1865, when visited by the expedition. (Photo: J. Rekstad)*

***Figure 10**. A group of late-19th century investigators at the snout of Engabreen. Notable visitors at this time included the German Keiser Wilhelm II and the Prince of Monaco. Despite the remoteness of Holandsfjord, it was readily accessible by sea, and numerous cruise liners now visit the fjord in the summer months.*

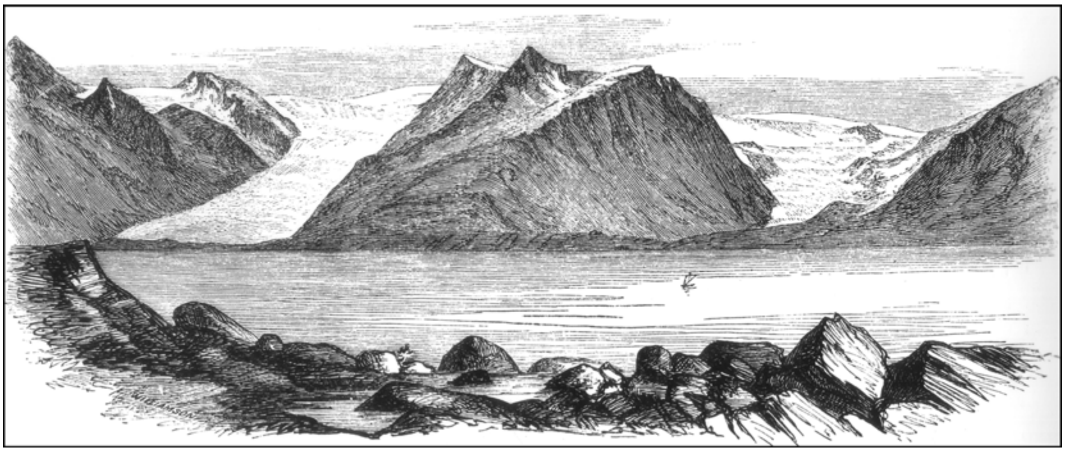

***Figure 11**. Field sketch made by Archie Geikie at Brasetvik on the north shore of Holandsfjord (Fig. 4), showing both the Enga (left) and Fondal (right) outlet glaciers.*

covered in scorings of all sizes, exactly the same in every respect as those high on the sides of the valley, in the fjord below and away on the outer islands and skerries. Figure 12 is a facsimile sketch from Archie's notebook showing the form of the lower part of the glacier from a vantage point on the mountainside to the east. Today the Fondalsbreen outlet glacier depicted in the sketch has almost completely disappeared and the rim of the Vestisen (western half of Svartisen) plateau ice field occupies the left hand skyline above a steep rock wall. It is from this rim that ice avalanching feeds a small regenerated glacier at the base of the slope.

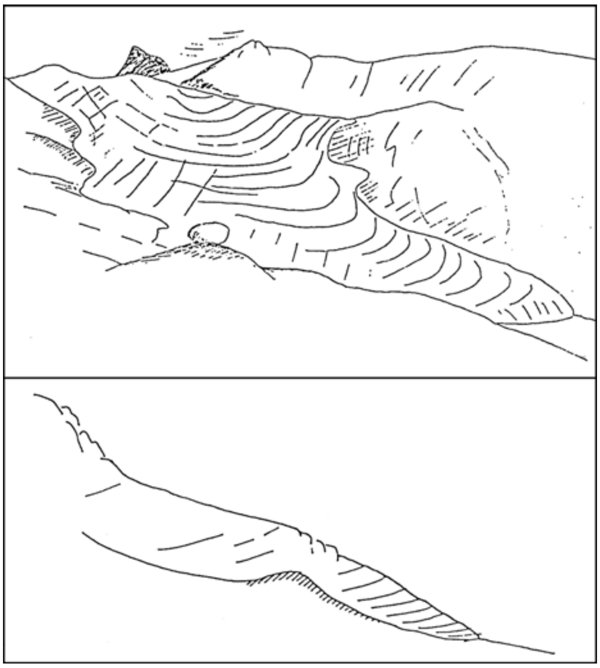

***Figure 12**. Facsimile of the notebook sketches of Fondalsbreen drawn by Archie Geikie from a position on the steep eastern hillside below Midnatsoltind. In 1865 the glacier had the morphology of a typical outlet glacier, not unlike that of the modern Engabreen. The long-section anticipates the presence of a buried rock bar, and subsequent glacial retreat has shown this to be entirely correct. From this viewpoint, only the rim of the ice cap at the top left corner would now be visible.*

Neoglaciation in Isfjorden

Neoglaciation of the Bergsford Peninsula, is principally related to three plateau icefields (Fig. 14). These have been investigated by Gellatly *et al* (1989) in conjunction with an evaluation of the observations made by earlier investigators. A comparison of the reports by Hardy (1862) and A. Geikie (1866) suggested that the separation of the Jøkullsfjord regenerated glacier from the plateau ice sheet above may have occurred between 1859 and 1865. They indicate that the names *fall jøkull* and *Nedrebreen* (the lower glacier) have both been applied to the same glacier. With this exception, Gellatly *et al* (1989) make no other use of the expedition's observations in the peninsula, supporting the opinion expressed previously that the Bergsfjord data are generally ephemeral in contrast to those from Holandsfjord.

Thus, scientifically, the critical locality visited in 1865 was the head of Isfjorden. In the context of the time, when the drift ice hypothesis remained in the ascendancy in British glacial geology, it was important to examine a location where the presence of a calving

***Figure 13**. Fondalsbreen in July 1980. The subglacial meltwater river discharges from beneath the ice cap on the right at the top of the rockwall and then disappears beneath the regenerated glacier below.*

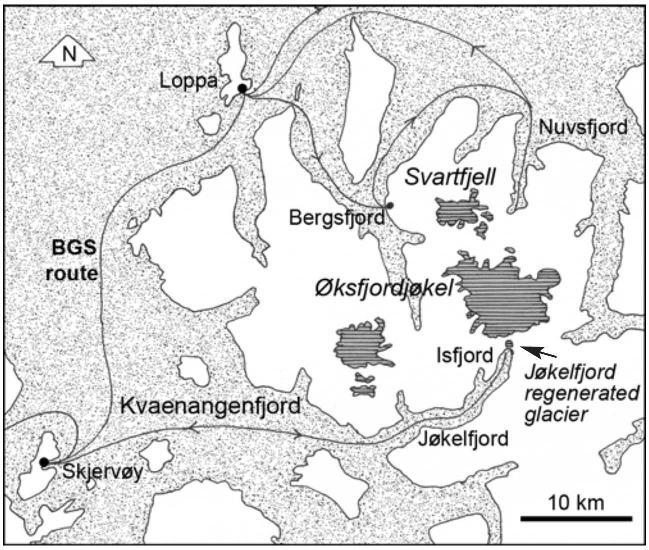

Figure 14. *The Bergfjord Peninsula, showing the current plateau ice fields, the Jøkulfjord regenerated glacier and the route taken by the 1865 expedition.*

glacier had already been established by earlier workers. However, this calving glacier proved not to be of the normal kind where an outlet valley or ice shelf glacier directly entered the sea. Rather it was what Archie termed a *re-cemented glacier* [regenerated or reconstituted glacier].

He wrote a vivid description (1885) of its dynamics: *When making the sketch from which Fig. [15] was made, I observed that the ice from the edge of the snow-field above slipped off in occasional avalanches, which sent a roar as of thunder down the valley, while from the shattered ice, as it rushed down the precipices, clouds of white snow-dust rose into the air. The debris thus launched into the defile beneath accumulates there by mutual pressure into a tolerably solid mass, which moves downward as a glacier and actually reaches the sea-level - the only example, so far as I am aware, of a glacier on the continent of Europe which attains so low an altitude. As it descends it is crevassed, and when it comes to the edge of the fjord, slices from time to time slip off into the water, where they form fleets of miniature icebergs, with which the surface of the fjord (f in Fig 138) is covered*. This must be one of the first descriptions by a geologist of this particular glacial process.

The essence of this behaviour still prevailed in the early 1970s according to the North Scandinavian Glacier Atlas (Østrem *et al* 1973) which stated that calving was still ongoing. But this was different from the earlier behaviour (pre-1938), since rather than the regenerated glacier extending into the sea and releasing icebergs, some massive ice blocks were breaking away from the plateau ice cap margin with sufficient momentum to reach the sea and form bergs of non-brecciated ice (Brian Whalley, pers.com).

Outcomes from the expedition

Archie Geikie's accounts of 1866 and 1882 outline the main expedition discoveries. Paradoxically, neither of these sources appears to have been referred to in Jamie Geikie's subsequent extensive writings despite the obvious excitement of experiencing a modern glacial environment for the first time. To a much lesser degree this omission applies to the works of Archie. This is strange when it is realised that both brothers independently wrote several text books, some specifically for school audiences. Another curious finding is that in the context of Holandsfjord, no modern Nordic worker is known to have made reference to the Geikie papers (e.g. Gjelle *et al*, 1995), even though their importance has been highlighted by Worsley and Alexander (1975, 1976) and discussed by Worsley (1984). These latter authors have emphasised

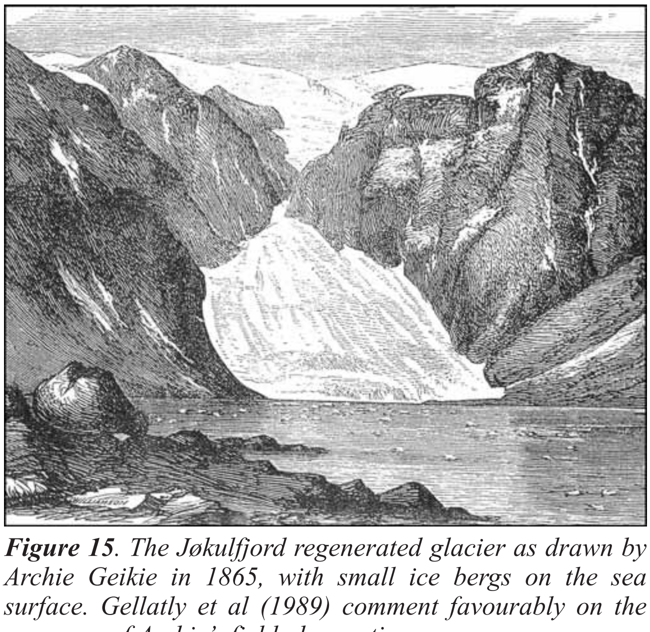

Figure 15. *The Jøkulfjord regenerated glacier as drawn by Archie Geikie in 1865, with small ice bergs on the sea surface. Gellatly et al (1989) comment favourably on the accuracy of Archie's field observations.*

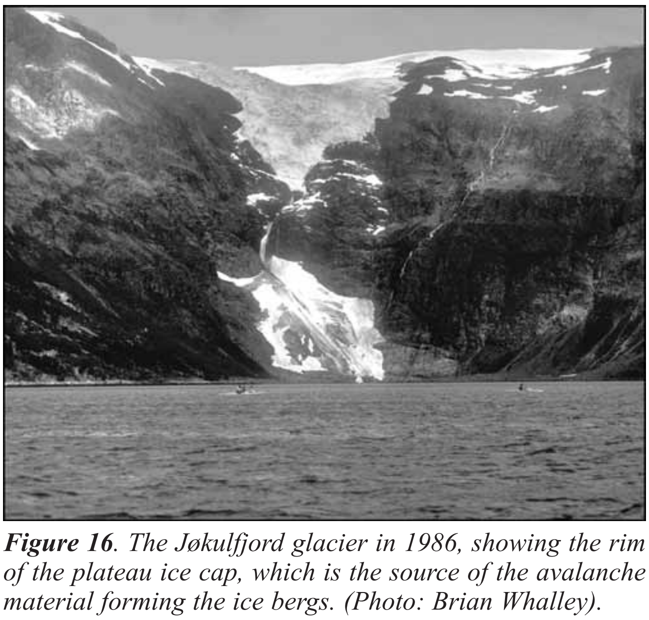

Figure 16. *The Jøkulfjord glacier in 1986, showing the rim of the plateau ice cap, which is the source of the avalanche material forming the ice bergs. (Photo: Brian Whalley).*

the value of the maps and sketch sections made by Archie Geikie and that they antedate the earliest work undertaken by Scandinavia workers.

Jamie's momentous book, *The Great Ice Age*, was published nine years after the expedition (Geikie, J., 1874) with the declared objective of explaining the character of the drifts as a function of the efficiency of land ice. In his subsequent later editions, in *Prehistoric Europe* (1881), and in other of his books such as *Earth Sculpture* (1902), there are general descriptions of fjord scenery clearly based upon his Norwegian observations. However, he did not make any specific reference to his observations in 1865 and one wonders whether he was discouraged by the thought that to do this would require him crediting his elder brother.

Whitaker had an active interest in earth surface processes generally and shortly after his return from Norway he submitted a paper to the Geological Society of London in which he argued that the morphology of the chalk escarpments was not the product of marine erosion as had been argued by Charles Lyell, but rather the result of sub aerial denudation. He wrote how he slowly became convinced that *the irregularities of the earth's surface have chiefly been caused by subaërial actions, by rain, rivers, frost and springs, forces that can be seen in action every day* (1867 p451), with understandably no mention of glaciers *per se* on the North Downs. However, in arguing for a lesser role for marine erosion in landscape fashioning he drew attention to *the wonderfully intricate coastline of Norway .... well known to have been caused by the sinking of the land and not by the action of the sea .... so clearly seen to be submerged valleys*. He continued *moreover the sea would have little power to act in so narrow and sheltered place but would be harmless as in the Norwegian fjords where I have seen the old ice-scratches run down to (and perhaps below) high-water mark, unaffected by the waves* (pp 451-2).

Unfortunately this paper was officially considered to be *withdrawn by permission of the President*. This was a cosmetic device to cover the unfortunate fact that it had been rejected by the Geological Society establishment of the day and only an abstract (with an error in the title) was published under Society auspices. He then resubmitted his manuscript to the Geological Magazine, whose editor took a more enlightened view of its scientific credentials (Whitaker, 1867). The paper was published in two parts and significantly included a statement from Lyell in which he supported Whitaker's argument and in effect recanted his earlier views. It was later highly commended and praised by Charles Darwin, who was then living at Down House and fully familiar with the geomorphological character of the North Downs escarpment (Darwin, 1883). It was described by Archie Geikie as *the excellent paper* (A. Geikie, 1885 p434), and by another Director of the Geological Survey as *a masterly account of the position by that time reached* (Bailey, 1952 p70). Anomalously, despite these commendations, Chorley *et al* in the first volume of their magisterial history of geomorphology (1964, Part Three: Marine versus sub aerial erosionists 1846-1875) omit any mention of Whitaker's denudational papers. Yet three entries are included in their Part Three reference list, suggesting a serious oversight by the authors. His subsequent official survey work did involve the mapping of glacial deposits including Last Glaciation sequences in The Wash area and the heavily weathered and dissected Anglian glacigenic deposits of southern East Anglia and the lower Thames. Despite this, Whitaker's work is not normally associated with glacial geology *per se*.

Conclusion

Following c 1860, the pendulum of British opinion started to swing away from the drift ice hypothesis towards one in favour of terrestrial glaciation. Undoubtedly, the return of three enthusiastic young geologists fired by their first hand knowledge of modern glacial processes in the Norwegian Arctic, boosted the crusade initially launched by the visiting Louis Agassiz over two decades previously. The momentum behind verifying the land ice concept through actualistic field work in currently glaciated areas continued in the summer of 1868, when Archie Geikie, as the newly appointed Director of the Geological Survey for Scotland, took three of his staff (Ben Peach, John Horne, and brother Jamie) to Grindalwald in Switzerland for *a little bit of mountaineering* and a descent of the Unter Aar glacier. The constraints imposed by the aging Murchison's views were soon pushed aside as the books authored by both Geikie brothers, giving full accounts of basal terrestrial glacier processes, became standard texts during the following decade.

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Appendix

Currency units used by Archie Geikie in his accounts

The currency of 1865 is no longer used and most Nordics would not be familiar with it. The basic unit was the Thaler or Daler – a silver coin used throughout much of Europe for almost 400 years. The word dollar is derived from this root. The Daler was replaced by a Swedish krona (crown) and a Danish kroner in 1873. When Norway joined the Scandinavian Monetary Union in 1876, the new Norwegian kroner had parity with the Swedish and Danish kroner. Before 1813, 1 Riksdaler/Riksmynt = 4 ort or 6 mark or 96 skilling but after the transfer of Norway from Denmark to Sweden at the conclusion of the Napoleonic wars, in Norway from 1816 to 1875, 1 Speciedaler = 5 ort or 120 skilling. i.e. 1 ort = 24 skilling. Hence this was the currency used by the expedition (in 1876, 1 Speciedaler = 4 Nkr). Archie's accounts use the speciedaler, ort and skilling but unexpectedly also the mark. It is possible that the mark was being used by the Sami (Lapps) who were the indigenous people of North Norway since in the mid nineteenth century they were much more widespread in Nordland than is the case today. The Tsar approved the Grand Duchy of Finland using the Finnish Mark from 4th April 1860 with a rate of 0.25 marks to the rouble. It appears that the Sami in 1865 were using the recently introduced mark.

REPORT

Black baryte from Derbyshire

A long-standing problem in Peak District mineralogy has been the source of the black baryte recorded by Prof G. Koenig in 1878. He provided a short note about a single specimen with the locality recorded simply as *Derbyshire*. It was then specimen no. 5435 in the mineral collections of the National Academy of Sciences in Philadelphia, USA, but how it reached there is unknown.

The Koenig specimen was borrowed and photographed some 45 years ago when the brown stalactitic baryte (oakstone) of Arborlow was being studied by Ford and Sarjeant (1964), but at that time they were unable to throw any light on the provenance of the black variety (Fig. 1). The Academy has recently been re-named the National Academy of *Biological* Sciences and the mineral collections have been sold. The black barite is currently on its way back to England, into the collection of the second author, when renewed study may reveal more about it.

The only other published reference is a listing by Greg & Lettsom (1858) who noted black baryte at Middleton-by-Youlgreave without any other details. However, a specimen of black baryte was obtained by C.S.Garnett (of Derby) around 1920 and was recorded as from Smerrill Grange when Garnett's collection was acquired by Gregory, Bottley & Co in the 1930s. The specimen subsequently passed into Bob King's collection (Fig. 2) and thence into the National Museum of Wales collections in Cardiff, where it is today (NMW 83.41G.M.8792). Smerrill Grange covers a substantial area near Middleton-by-Youlgreave and a further hint at the provenance is that there was a manganese mine working from at least 1881 to 1904 at Mount Pleasant Farm, about 900 m west of Smerrill Grange (SK190619); there were two other mines nearby (Burt et al. 1981, p86). The Ordnance Survey map marks two shafts 100 m or so NW of the Mount Pleasant Farm.

XRD analysis showed baryte with no obvious contamination though the black colour was attributed to inclusions of manganese (letter from Tom Cotterell of NMW to R.J. King, 22nd Feb. 2007).

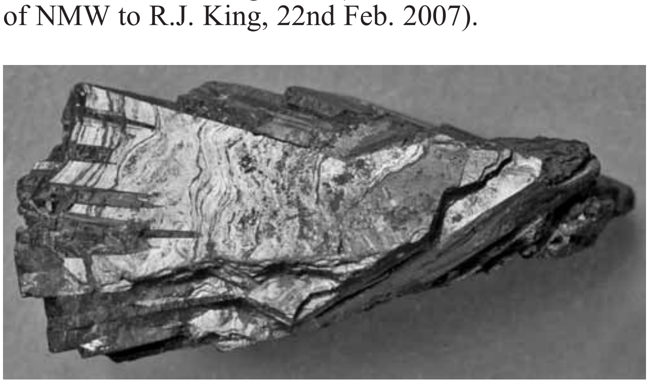


Figure 1. *The Koenig specimen of black baryte, that was in Philadelphia; the specimen is about 50 mm long.*

Figure 2. *The Bob King specimen of black baryte, now in the National Museum of Wales.*

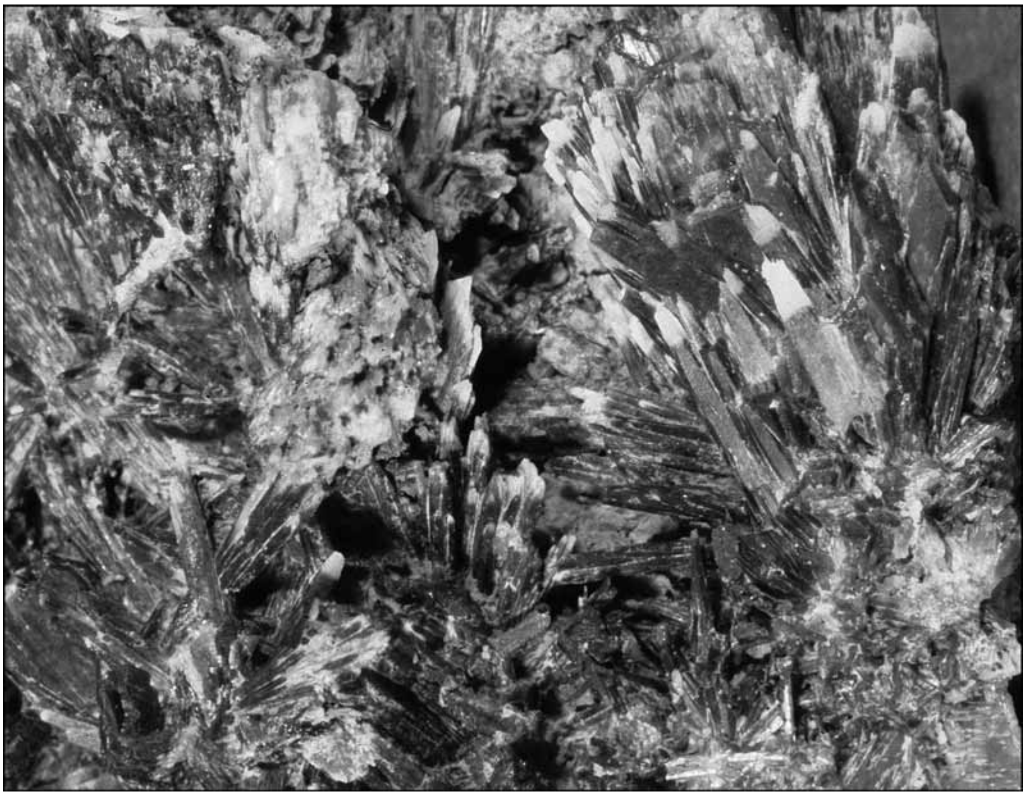
One of us (J.A.J.) has recently found black baryte (Fig. 3) comparable to Koenig's specimen during exploration of an old lead mine (SK255563) on Red Rake (also known as Foulslow Wells Vein: Flindall, 2006) which crosses Marks Dale, a southern branch of the Via Gellia. Red Rake and other veins were worked intermittently 1874-1920 from adits on both sides of the dale. This black baryte was in the eastern adit, which is 72 m long, and is known to have been worked in 1879.

The black baryte of Koenig's specimen matches both Marks Dale and Mount Pleasant specimens, so it is here proposed that either of these could have been the original locality for Koenig's specimen. However, the similarity of the last known working date for Marks Dale (1879) with Koenig's note (1878) supports the former locality. Some of the black crystals in the Marks Dale adit have white terminations suggesting that growth continued after the wad ran out.

As most Derbyshire baryte is white or cream-coloured, with occasional pink, red or brown varieties, black baryte naturally attracted attention in the 19th century. How Koenig obtained his specimen is unknown, but he was curator of the geological collections in the Natural History Museum in South Kensington. He evidently had more material as he was able to analyse some, presumably by wet chemistry. He found 3.1% MnO_2, implying that the colour was due to an admixture of manganese wad. Indeed wad was found adjacent to baryte in the Marks Dale vein.

Analyses of the Marks Dale material by SEM Energy Dispersion have determined: BaO_2 56.562 and 63.552%; SO_2 19.588 and 23.895%; MnO 3.556 and 2.115%, with small amounts of aluminium, iron, silica, potassium and calcium oxides. The manganese figures compare with Koenig's and demonstrate that 2-4% manganese wad is sufficient to cause the black colouration.

Figure 3. *A John Jones specimen of baryte that forms black blades up to 10 mm long, with white tips, in vein material from Red Rake (see also colour photo on back cover).*



Copy of Koenig's Note

as recorded in TDF's files about 1963.

Koenig, G.A. 1878. Black barite from Derbyshire. Proc. Nat. Acad. Sci. Philadelphia. Pp.99-100

A brief report on the examination of a specimen in the academy's collection labelled "Manganese from Derbyshire". It is jet-black in colour with a metallic lustre. Lamellar structure without distinct form. Strong cleavage giving angles of barite. Specific gravity 4.345. On boiling in HCl lost black colouring and left a white substance.

Analysis: $BaSO_4$ 96.40%; Mn_2O_3 3.10%; H_20 0.25%. Total 99.75%

There remains a chronological problem. Manganese wad in Derbyshire was deposited within sedimentary fills in caves during Plio-Pleistocene times (Ford, 2001, 2006) whereas the main mineralization, including baryte, was late Carboniferous (Plant & Jones, 1989). Secondary redistribution of baryte is known elsewhere in the mineral field, so it is quite likely that the black baryte coloured by wad was a feature of a late episode of mineral re-distribution. Furthermore the black baryte is strongly fluorescent with a straw colour under ultra-violet light and this has only been found in secondary baryte elsewhere in the Peak District, e.g. the nodular grey baryte in Masson Hill opencast pit.

Acknowledgments

Thanks to Dr R.J.King for his useful comments and to Tom Cotterell of the National Museum of Wales, Cardiff, for his comments on an early version of this note and for supplying photographs of their specimen.

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REPORT

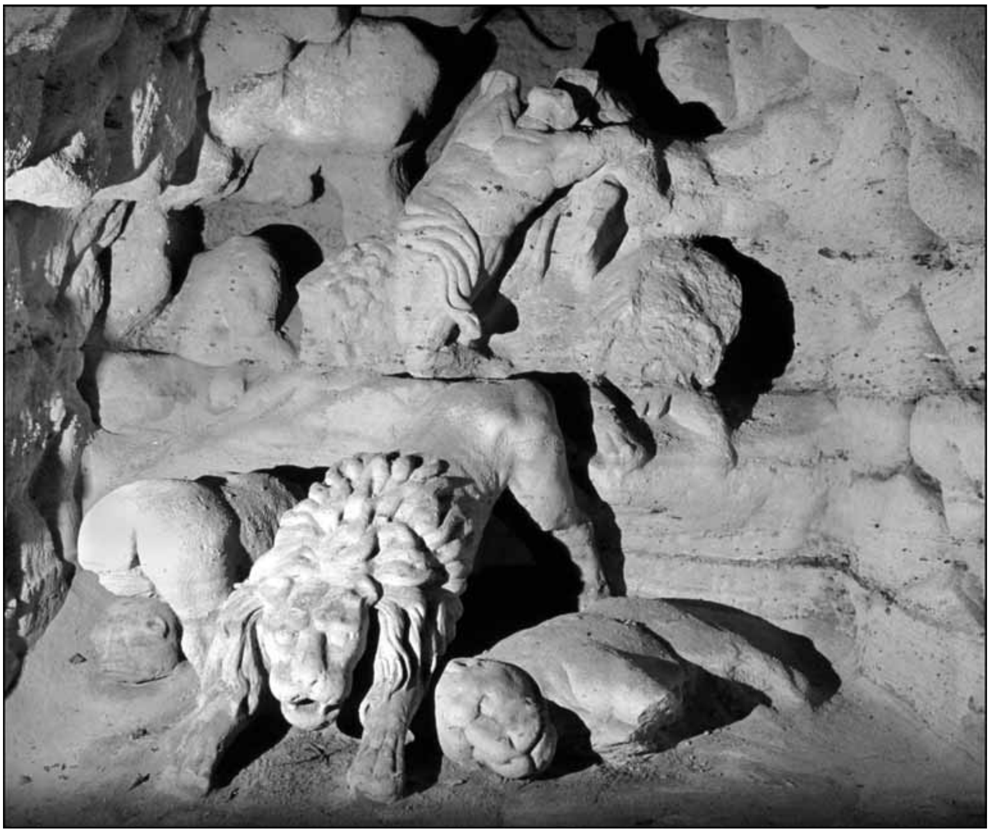
Conservation of the cave statues in the Nottingham sandstone

Without doubt the finest single feature within the sandstone caves that underlie Nottingham is the group of statues depicting "Daniel in the Lions' Den", which lie inside a cave cut into the sandstone escarpment overlooking The Park from the northeast. These life-size statues are a real work of art, carved from bedrock in the back wall of a cave excavated under the garden of Alderman Thomas Herbert some time in the mid-1800s (Waltham, 1996). Sadly, they are suffering from the ravages of time, and a measure of conservation was becoming appropriate. The owner of the site was unable to take action, and the city of Nottingham takes almost no interest in its cave heritage (this cave has no listed status, unlike six elsewhere under the city), so the East Midlands Geological Society stepped in.

Preservation of the statues would ideally be by improving the very porous and weak sandstone. Various techniques exist whereby a strengthening fluid can be injected into the stone or painted on to its surface so that it soaks in. However, all known attempts at doing this on the Nottingham sandstone have resulted in stability for some few years followed by the improved surface layer flaking away in small slices and chunks. No method has yet been found that appears to be totally satisfactory and is also worth the major problems of applying it by hand to the complex details of the statues. Recent work on Castle Rock has successfully prevented erosion by applying a thick layer of fibre-glass, with its surface disguised by loose sand brushed onto it before setting, but this is not applicable to the intricacies of the statues. Rock treatment remains an option for the future, though there is a certain reluctance to start experimental work on the statues themselves.

The alternative was to reduce the natural weathering. Previous investigations within the caves had shown that the rates of sandstone weathering were directly related to exposure to outdoor weather, in terms of the access and distance from open entrances (Waltham & Cubby, 1997). It appears that weathering is mainly due to cyclic changing of atmospheric conditions that induce wetting and drying of the weak clay cement that bonds the grains of sands in the decalcified sandstone. Local variations in the sandstone lithology also have an effect, but these are uncontrollable. The statues are particularly vulnerable because they stand at the back of a cave that has a doorway and window holes that open out to the garden through the locally steep sandstone slope.

Consequently wooden doors and shutters were fitted to the cave late in 2005. These were paid for by the Society, notionally and appropriately from proceeds from sales of the Society's book on the caves (which is shortly going into a third edition). The new doors and shutters are solid panels of treated wood



The cave statues of "Daniel in the Lions' Den", as they are today; the detached head of one lion can be seen on the floor below the missing back leg of the same lion.

monitoring period	weathering rate
Nov 96 – Mar 97 Mar 97 – Dec 97	0.110 mm/year 0.080
November 2005	***doors installed***
Dec 05 – Apr 06 Apr 06 – Oct 06 Oct 06 – Dec 06 Dec 06 – Apr 07 Apr 07 – Aug 07	0.005 mm/year 0.040 0.002 0.003 0.007

Table 1. *Weathering rates beside the statues.*

attached to the iron railings that were there before and thereby provide the seating into the rock. These will hugely reduce air circulation in and out of the cave in times of changing weather. Their frames were cut to follow closely the irregular rock profile, but they do not provide tight seals. This was intentional, as a complete lack of air circulation can allow growth of mosses and fungus on the exposed rock, which is currently very clean within these caves.

The effect of the new doors will only be seen in the long term, but monitoring of the cave has been carried out over the last few years. This follows the method started by Tommy Cubby in 1996, whereby sand grains falling off a measured area of wall are caught in trays and then weighed to derive a mean rate of wall retreat due to weathering within the test period. Weathering rates have been measured on a section of wall adjacent to the statues and recalculated into annual rates of wall retreat (Table 1). These do indicate that weathering has been reduced to about one tenth of its rate before the doors were installed. The data have been matched by that recorded (on fewer occasions) within the corridor cave from the "Haddon Hall stairs", that lies adjacent to the statues cave (Table 2), which again show the reduced weathering further away from the open entrances.

The high values from the summer of 2006 were of some concern, until it was learned that a TV crew had briefly worked unsupervised in the caves just before the end of this period. Loose wall sand could have been rubbed off by the crew (or accidentally kicked into the trays), but wall desiccation by the heat of strong film lights would have had a similar effect. Either would have caused loosened sand to fall into the trays, and would then have left wall surfaces that were temporarily stabilised, and thereby also account for the very low weathering rate recorded in the following period. There was no recognisable impact from the very heavy rainfalls in June 2007.

monitoring period	weathering rates in mm/year	
	3 m in	*12 m in*
Nov 96 – Mar 97	0.057	0.029
Mar 97 – Dec 97	0.068	*no data*
November 2005	***doors installed***	
Dec 05 – Apr 06	0.009	0.0002
Apr 06 – Oct 06	0.033	0.002

Table 2. *Weathering rates in the corridor cave.*

The cave from the outside with its new doors and shutters.

Monitoring has not been totally systematic, and has not been fully correlated with internal and external micro-climates, but it does appear to indicate that installation of the doors has reduced the rate of rock weathering inside the caves to less than a fifth of its previous rate. If this extends the life of the cave statues on a comparable scale, the new doors will have proved worthwhile.

Past years of open access to the caves had also allowed deterioration of the statues by rather more than weathering, probably deliberate vandalism, by which they had lost various limbs. Rumours of a "souvenir head" that someone had in their own garden were followed up, but yielded only a life-size head of Jesus, instead of that of a lion. This had come from the site, but was made of Ancaster Limestone, and was probably from an ornamental feature within Thomas Herbert's garden; it now stands within a dark corner of the caves, much to the consternation of some unprepared visitors! One lion's head has been found, half-buried in sand within the cave, but this is from the inward-facing lion, so the expense of restoring it to the lion has not been undertaken.

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Tony Waltham

REPORT

Charnia masoni - 50th Birthday Party

In 1957 Roger Mason and his two climbing friends, Richard Allen and Richard Blachford, found the original specimen of *Charnia* in the north quarry on the Charnwood Golf Course – 50 years ago.

The same fossil had had been seen by a local schoolgirl, Tina Negus, a year earlier, but her teachers had refused to accept that there could be fossils in Precambrian rocks, and nothing therefore came of her find. As the quarry had been disused at least since the 1860s, it makes one wonder how many others had seen *Charnia* before Tina and had done nothing about it. To make matters more uncertain, a person unknown had hammered the rock alongside the specimen between the writer's first and second visits. Indeed, in the 1860s it was known as the "Ring Quarry" from the enigmatic circular markings not then regarded as fossils. Roger Mason and his father took Trevor Ford out to see it, and a year later a short paper was published naming two frond-like impressions *Charnia masoni* and *Charniodiscus concentricus* and, in the absence of anything comparable in geological literature, it was tentatively suggested that they might be impressions of soft-bodied algae.

With the aid of two quarrymen the type specimens were extracted and taken to Leicester Museum, on a block weighing about 200 kg. Later this was split down to a block weighing a more reasonable 30 kg, which is still on display in the Museum (Fig. 1).

To celebrate the 50th birthday of what turned out to be one of the most important fossil finds in Britain, the Geology Section of the Leicester Literary and Philosophical Society in conjunction with the Geology Department of the University of Leicester organized a seminar at the University on Saturday, March 10th 2007, under the "local heroes" theme sponsored by the Geological Society London, whose bi-centenary is also in 2007. The local hero in this context is *Charnia*. Abstracts of the lectures are available on the website of the Philosophical Society's Geology Section at www.Charnia.org.uk .

With twelve speakers from around the world and about 150 delegates present, the seminar presented an opportunity for a re-assessment of views as to what sort of organisms the Charnian impressions (variously listed as Charniomorphs, Rangeomorphs or Petalonamae) were, their ecology and environment, their chronological range within the Late Precambrian (Neoproterozoic), and whether they were direct ancestors of the Phanerozoic Phyla or not. Most of these questions have been asked several times before, and one important outcome of the seminar was that we still do not know all the answers, though we are perhaps getting a little closer.

Discovery of the Charnian fossils

The seminar started with three short talks on the discovery (Roger Mason), naming and potential interpretation as "algae" (Trevor Ford), and the later discovery of further Charnian fossils at other localities (Helen Boynton). Roger was able to pin-point the discovery from his father's diaries as April 19th 1957. Trevor took photographs to his former palaeontology lecturer Peter Sylvester-Bradley at Sheffield University and that is how it came to be published in the *Proceedings of the Yorkshire Geological Society*, as Sylvester-Bradley was the editor then (subsequently he became the first Professor of Geology at the University of Leicester).

Australian fossils

Within a few months, Professor Martin Glaessner of Adelaide University in South Australia published a note in *Nature,* drawing comparison between *Charnia* and a frond found in the Pound Quartzite (now Rawnsley Formation) of the Flinders Ranges, some 400 km north of Adelaide. He interpreted the fronds as fossil sea-pens (Pennatulids). Whilst Glaessner and his associate Mary Wade regarded the abundant discoid impressions in the Flinders Ranges and many other localities, including Charnwood Forest, as jellyfish (medusoids), others have seen them as holdfasts for frondose organisms. Current opinion is that there may be a mixture of the two, but there is still no consensus of views. Both fronds and discs are impressions of moderately soft-bodied, perhaps of leathery consistency, organisms with no hard parts.

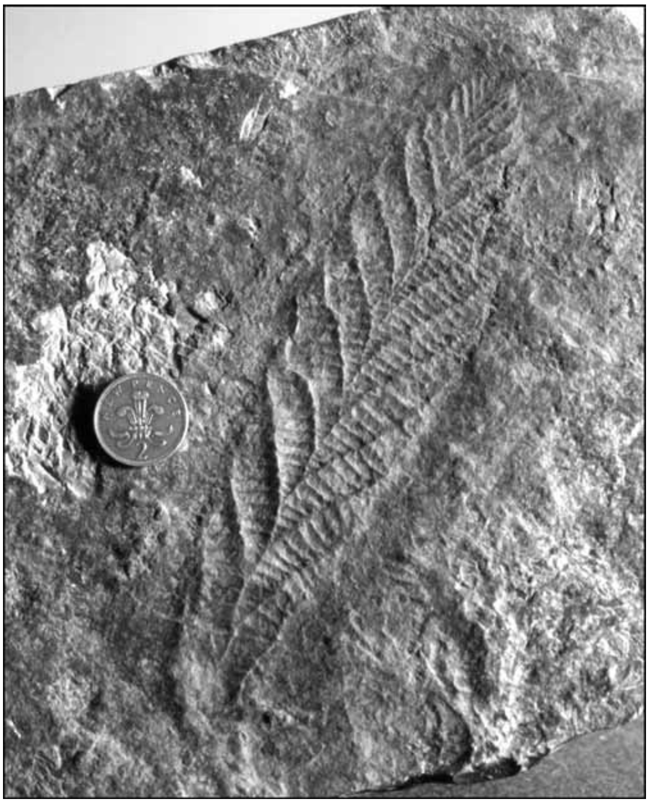

Figure 1. *The original* Charnia masoni.

More Charnian fossils

A few years later, Trevor Ford reported the discovery of a disc on a loose block in the Outwoods (NE Charnwood) and this led to the finding of several discs on a bedding plane there at a stratigraphic horizon comparable with that bearing *Charnia* (Fig 2). A student whose attention wandered away from a field class in cleavage/bedding relationships in Bradgate Park found more discoid impressions on a bedding plane in Bradgate Park, later leading to the discovery of *Bradgatia* and a variety of other impressions on the same surface. Helen Boynton and Trevor Ford described both these and the discs found in Cliffe Hill Quarry at Markfield, and the assemblage of older fossil impressions of uncertain biological affinity in the considerably lower strata of Ives Head, notably *Ivesheadia, Shepshedia* and *Blackbrookia*, which occur 2000 m below the *Charnia* horizon.

The Charnian environment

John Carney (British Geological Survey) outlined the geology of Charnwood Forest, of which a new map has just been produced by BGS. In particular he compared the sedimentary environment with the recent volcanic eruptions on Montserrat in the West Indies (Fig. 3). The Atlantic floor adjacent to that island is now mantled with debris flows and turbidites comparable with the so-called Bomb Rocks and volcaniclastic turbidites of the Charnian succession. *Charnia* and the other Precambrian fossils were laid down on bedding planes showing little sign of shallow-water features such as ripple-marks, and are thus generally regarded as having been deposited below wave-base at depths perhaps as great as 500 to 1000 m in sediments derived from Charnian volcanoes. Later in the seminar Professor Guy Narbonne (Queens University, Kingston, Ontario) reported that the sedimentary environment of the Newfoundland biota was much the same. This was not surprising as both Charnwood and the Avalon peninsula of Newfoundland were parts of the ancient land mass of Avalonia, and their rock sequences of volcanics and turbidites represent parts of the same volcanic arc, then some 30º south of the equator.

Figure 2. Cyclomedusa davidi *from the Outwoods.*

Note that the term *biota* is used in preference to *fauna* while there is doubt on whether the Charniomorphs were animals or not. Also the term Metazoa may not be applicable if they are not animals.

Dating the Charnian biota

Assigning dates to the Charnian biota was discussed by Steve Noble (BGS). Ongoing research places the *Charnia*-bearing strata at 562 Ma on the basis of U-Pb dates derived from zircon crystals in adjacent ash-beds. This is close to dates for the Newfoundland strata, but the fossil-bearing strata in Namibia and South Australia lack sufficient ash-beds with zircons and the dates are less constrained at around 540-575 Ma. The Charnian date of 562 Ma is an appropriate mean. A recent discovery is the date of 606 Ma for the Ives Head biota. The Ives Head Formation is 2000 m stratigraphically below the *Charnia* horizon, and this would make the fossils there the oldest macro-fossils in the world. The gap of 40 Ma raises the question of the possibility of a major hiatus in deposition of the Charnian sequence, perhaps between the Blackbrook and Maplewell Groups. In Newfoundland, the Gaskiers Tillite (at about 580 Ma) would have been emplaced during that gap. It represents the last of a series of "Snowball Earth" glaciations in Neoproterozoic times, but with no equivalent of the tillite known in Charnwood, either it was never deposited or was eroded during the hiatus.

Dating the Ediacarian

In more on-going research, Dan Condon (NIGL, Keyworth) discussed zircon dating and other potentially applicable methods in more detail with the varied constraints on how data may be interpreted. He made particular reference to dating the beginning of the Ediacaran Period recently established by the International Stratigraphic Commission (see *Mercian Geologist*, 2005, p75). This new geological period is regarded as starting immediately after the Marinoan glaciation ended at 635 Ma with a Global Stratotype Section showing the base of the Ediacaran period defined at the top of a glacial tillite in the Flinders Ranges National Park, in South Australia. Thus Charnian strata are clearly of Ediacaran age and entirely post Marinoan glaciation.

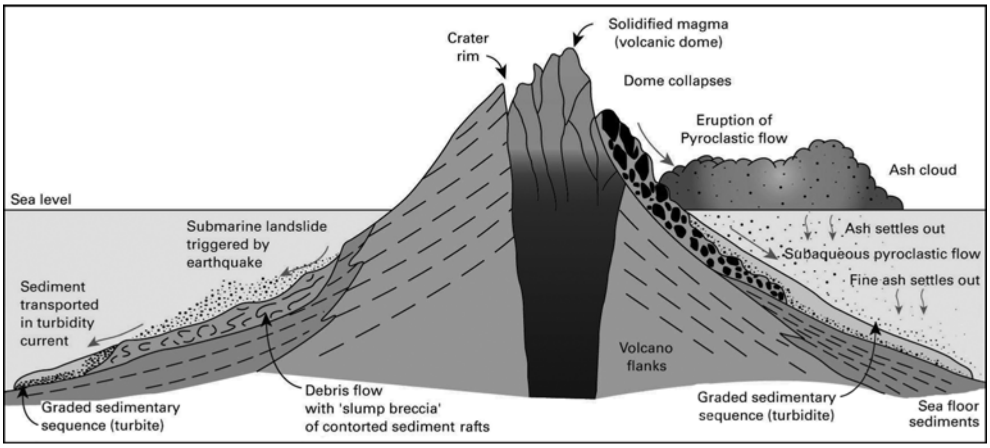

***Figure 3**. A Caribbean (Montserrat) model for Charnwood's volcanoes, with debris flows and turbidite sedimentation around a volcano (courtesy John Carney, BGS).*

The status of the Ediacaran biota within the Earth's history of macro-evolution, mass extinctions, adaptive radiation and uniformitarianism was discussed by Dr Nick Butterfield (Cambridge University). The 3000 Ma before the Ediacaran period was one of very limited evolution with life represented almost entirely by unicellular algae and bacteria which showed little evolutionary change. However, after Snowball Earth, the Ediacaran period was a phase of much increased oxygen levels with the appearance of diploblastic and triploblastic Metazoa, with early bio-mineralization demonstrated by the impression fossils such as the Ediacaran and Charnian biotas (the possibility of bio-mineralization would be disputed by some researchers). The Phanerozoic "explosion" of life forms followed little more than 20 million years later.

More Australian fossils and dates

Dr James Gehling (South Australian Museum, Adelaide) took up the story with a review of the chronological ranges of some 20 of the key genera now known in the Ediacaran biota. Most of them have a global distribution in strata of Namibia, Newfoundland, Western Canada, USA, South Australia, England (Charnwood Forest), Russia and China. He opined that the lower half of the newly defined Ediacaran was characterized only by microfossils (acritarchs) but that from 575 Ma there were also abundant trace and impression macro-fossils as well as a few body fossils such as the segmented *Spriggina*. While Sprigg had found discs interpreted as jellyfish as far back as 1947, the Pound Quartzite was then regarded as basal Cambrian because it had fossils – a circular argument which meant that they did not hit the headlines as Precambrian! With more intensive searches of the appropriate strata in the Flinders Ranges, many more fossils were found and new finds are still being made. At a new locality on the western flank of the Flinders Ranges many fossils had been found on a succession of bedding planes. Sedimentary environment interpretations showed that some fossils seemed to be restricted to certain facies, and an alternation from shallow to mid-depth littoral-marine conditions had been deduced. Dr Gehling concluded with comments on conservation and security (one choice specimen had been stolen and re-appeared in a Japanese dealer's list with an exorbitant price tag, but it had later been returned to Australia). A large part of the Flinders Ranges is now a World Heritage Site and this assignation was marked by a visit from the Prime Minister of South Australia.

The Newfoundland biota

Although a Precambrian fossil, the possible medusoid *Aspidella*, had been found in Newfoundland in 1872, it was written off as inorganic by the American palaeontologist, C. D. Walcott. A century later, and ten years after the discovery of *Charnia*, Misra and Anderson, of Memorial University, St Johns, Newfoundland, found abundant fossils in the Late Precambrian Conception Group rocks at Mistaken Point and many other localities on the coast of the Avalon Peninsula of southeast Newfoundland. Professor Guy Narbonne described the biota as very similar to that in Charnwood Forest but with thousands more specimens and several extra genera, notably the "spindle-shaped organism" (Fig. 4). On the cliffs of the Avalon Peninsula, single bedding plane exposures can have more than a thousand fossils. With many such bedding planes over a length of some 200 km of coast, there was a wealth of material, some still awaiting formal naming and description. Almost all the fossil-bearing beds occur above the Gaskiers Tillite on turbidite bedding planes covered with thin layers of volcanic ash, but a few were also found in the much older Drook Formation, one being *Charnia wardi*, a frond more than 2 m long. Prof. Narbonne quoted geochemical work by D. Canfield and others which indicated that the post-glacial sediments were much more oxygenated and this might be because the release of nutrients from the weathering of periglacial sediments encouraged blooms of photosynthesising micro-organisms. In turn these could provide food for the Ediacaran biota, but the lack of evidence of mouths or alimentary tracts could be taken to suggest that nutrition was absorbed directly from the sea. In short, were the macro-organisms absorbing nutrients instead of eating microbes? The recently discovered three-

Figure 4. *A compound spindle-shaped colony, from Mistaken Point, Newfoundland.*

dimensional fronds in the rocks of Spaniard's Bay supported the absorbtion concept, and suggested that there was evidence of a fractal growth pattern, whereby the same frondose structure is repeated on a decreasing scale down to a fourth order. Professor Narbonne reported that the Mistaken Point area was now a World Heritage Site, and that some of the local people had been enlisted as guardians. A Visitor Centre was a boost to the local economy.

One of the most abundant Newfoundland fossils is the spindle-shaped form, as yet un-named. A speaker from the audience suggested that as they occurred in the Conception Group at Mistaken Point, there was an opportunity to have a latinized biological name based on Mistaken Conception!

The White Sea biota from Russia

The White Sea coasts and an adjacent river section in Arctic Russia provided a wealth of specimens which were briefly described by Dr Dima Grazhdankin (University College, Dublin). The metamorphism seen in Charnwood and Newfoundland was lacking and the fossils were in soft sediments, some still with carbonaceous traces. Following Seilacher's concept of a failed evolutionary experiment, Dr Grazhdankin regarded many as having a quilted body structure where growth was by inflation. There were now over 100 named genera and species in the Ediacaran biota. He reported that there appeared to be several environmentally-controlled communities, notably the Nama-type characteristic of distributary bar shoals, i.e. shallow water, the Ediacara community characteristic of pro-delta environments (shallow to medium depths), and the Avalon-type biota characteristic of low-energy shelf environments. Although there was some overlap of these biotas, the fossils of Charnwood Forest were within the Avalon community. However, the inferred water depths there, below wave base, were too great to permit photosynthesis, though it was possible that the fossils drifted from moderate into deeper waters. More than 40 years ago Professor Martin Glaessner had invoked a beach environment to explain the Ediacaran fossils preserved in a sandstone in South Australia.

As with several other speakers, Dr Grazhdankin was of the opinion that the Ediacaran fronds were not related to Pennatulids (sea-pens); nor were the discoid fossils jellyfish as proposed by Glaessner and Wade. There was some feeling at the meeting that the Ediacaran fossils were neither plant nor animal but somewhere between. So the biota could not be direct ancestors of the Phyla which arose in the Cambrian "explosion" of life forms. Dr Grazhdankin thought that some of the various alleged medusoids bore a resemblance to circular bacterial colonies.

New techniques

As several speakers referred to the Ediacaran biota as a "failed experiment" in the evolution of life, it leaves us with two questions - "where did the Phanerozoic Phyla come from", and "how did pre-Ediacaran microbes evolve into multi-cellular fronds?".

As part of a research project on Animal Ancestors Professor Martin Brasier and Jonathan Antcliffe (of Oxford University, together with associates in Newfoundland) have started using laser scanning techniques to extract as much information as possible from the Charnwood and Mistaken Point fossils. In particular they have been able to show that *Charnia* had fourth order subdivisions of the "cells" on the frond branches and that *Charniodiscus concentricus* may have had three fronds growing from a central disc. No evidence of polyps such as might be expected on Pennatulids had been found so far and the growth pattern was unlike Pennatulids. They confirmed that *Bradgatia* was a bush-like form of many fronds. Other details of ontogeny and phylogeny were also emerging from on-going research, in particular using the technique of morphometric analysis whereby one fossil image can be changed into another by a simple geometric process of rotation on a computer screen.

Concluding remarks

To return to the questions asked at the beginning of this report, it seems that the jury is still out on what sort of organisms the Ediacaran fossils were – plant, animal or somewhere between, and whether they were a failed experiment in evolution. To a large extent we still have little idea of how they fed and grew, or how they reproduced. No evidence that the Ediacaran fossils represented ancestors of the Cambrian phyla was put forward. Their age range is post-Gaskiers tillite at 580 Ma to the very end of the Precambrian at 542 Ma. However, the Ives Head fossils at 606 Ma pre-date this and *Charnia wardi* from the Drook Formation in Newfoundland seems to be of comparable age. While it might be expected that the earliest Ediacarans would be small, one fossil in the Drook Formation was 4 m long! There is some evidence of differentiation of assemblages in environments ranging from river-mouth shoals, through pro-delta shallows to low-energy shelf below wave base. There had also been a suggestion that many of the organisms were floaters which were punctured by hot volcanic ash and then sank into the deep water environment.

Surprisingly some aspects of the Ediacaran story were overlooked. What were the few "worm-trails" in the Charnia horizon? The presence of apparently segmented body fossils such as *Spriggina* amongst the Ediacaran biota in South Australia was only briefly mentioned and its possible significance as either annelid worm or arthropod was not discussed. The alleged flat-worm *Dickinsonia* and the putative coral *Tribrachidium* found in Ediacaran assemblages were barely mentioned. The late Ediacaran frondose fossils from Namibia *Pteridinium* and *Swartpuntia* are surely part of the Ediacaran fossil story too. The cup-shaped *Arumberia* found in Australian and Longmyndian rocks was not discussed. The miniature conical fossil Cloudina found in very late Ediacaran limestones in California may have been an ancestor of corals. Was the intensively burrowed and bioturbated Swithland Slate at the top of the Charnwood stratigraphic sequence now confirmed as Cambrian and thus no longer part of the Charnian/Ediacaran story, or did the burrowing organism which produced the *Teichichnus* borings evolve in the latest Ediacaran?

Two days later, the annual Bennett Lecture in Leicester University was given by Professor Stefan Bengtson of the Swedish Museum of Natural History in Stockholm. Among other matters he drew attention to trail-like markings on rippled quartzites aged 1.0 to 1.6 billion years. If these were to be interpreted as trails made by mobile animals it puts the whole evolutionary story back much earlier than the Ediacaran, but if they were not of biologic origin, what were they?

Thanks to Helen Boynton, John Carney and Mark Purnell for constructive comments on earlier versions of this report.

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REPORT

Spiers Farm Quarry, Long Itchington, a new exposure of Blue Lias Formation

Historically, the Early Jurassic Blue Lias Formation has been widely quarried in southern and eastern Warwickshire as a source of building stone, agricultural lime and as raw material for the Rugby Cement Industry. In particular, cement manufacturing during the twentieth century provided large exposures of the classic 'Blue Lias' alternations of mudstone and fine-grained limestone (Hallam, 1968), now assigned to the Rugby Limestone Member of the Blue Lias Formation (Ambrose, 2001).

A number of disused quarries remain, but most are poorly accessible. Until recently, Southam Cement Works Quarry, Long Itchington (SP420630) provided extensive sections through the uppermost Triassic (Rhaetian) Langport Member, overlain by the Saltford Shale Member (Liasicus up to Angulata Chronozone) and lower part of the Rugby Limestone Member (Angulata up to Bucklandi Zone) of the Blue Lias Formation. Accounts of this section have been provided for example by Clements (1975), Old *et al*. (1987), Ambrose (2001) and Radley (2002). Recently, pumping operations were halted and much of the section is now flooded or otherwise poorly accessible.

A new excavation (Spiers Farm Quarry; at SP425638) is now providing good sections through the upper part of the Saltford Shale and a comparable Rugby Limestone succession to that at the flooded site, where Clements (1975) documented roughly 24 m of beds. Preliminary investigations at Spiers Farm have confirmed that the Saltford Shale is characterised by tough, grey, laminated mudstones enclosing nodules and bands of fine-grained limestone. Much of the member is sparsely fossiliferous, though body chambers of schlotheimiid ammonites, fragments of ammonite-rich scour-fills gutter casts and a nautiloid (*Cenoceras* sp.) have been collected. As elsewhere, the base of the Rugby Limestone is defined by the incoming of well-developed fine-grained shelly limestone beds alternating with mudstones - the typical 'Blue Lias' facies development (Ambrose, 2001).

Silty limestone scour-fill enclosing schlotheimiid ammonites. Specimen is 129 mm in length.

As in the adjacent quarry, the lowest few metres of the Rugby Limestone Member are highly fossiliferous, yielding especially oysters (*Liostrea* sp.), regular echinoid debris, oyster-encrusted nautiloids and some ammonites. Large, thin-shelled bivalves (*Plagiostoma giganteum* J. Sowerby and *Antiquilima antiquata* (J. Sowerby)), commonly oyster-encrusted, are common in certain limestone beds; some of which are quite coarsely bioclastic. Ichnofossils are similarly widespread within limestone beds in the lowest few metres, including *Kulindrichnus langi* Hallam and *Diplocraterion* isp.. Preliminary investigations of the succession suggest that some of the most intensely bioturbated and fossiliferous levels mark omission surfaces, *sensu* Sheppard *et al*. (2006).

Above, the remainder of the exposed Rugby Limestone is currently accessible via a series of benches and trench sections, and is revealing many of the marker beds detected in the adjacent disused quarry by Clements (1975; also Old *et al*., 1987; Ambrose, 2001 and Radley, 2002). These include the Rhynchonella Bed, characterised by abundant small rhynchonellid brachiopods (*Calcirhynchia calcaria* S.S. Buckman) and at least one conspicuous paper-shale. These higher strata, generally less bioturbated and poorer in fossils than the lower beds, have nevertheless revealed *Chondrites*-dominated ichnofabrics and large, poorly preserved ammonites, and additionally mark the appearance of gryphaeid oysters (*Gryphaea arcuata* Lamarck) in the local Rugby Limestone succession. The author hopes to maintain close observation on this site as quarrying proceeds, as it promises to replicate much of the palaeobiological and palaeoenvironmental interest of the adjacent Southam Quarry.

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MEMBERS' NIGHT, 2007

The first Members' Night was held on 17th March 2007, when five presentations were made. The instructions to the presenters were simple: *show us your interests and infect us with your enthusiasms*. It is hoped that other members, whether amateur or professional, will take up the baton for future years.

Rock around Orkney

Gerry Shaw

Orkney is largely a remnant of the Devonian Old Red Sandstone continent. While its geology has been studied and interpreted by many, the works of two Orcadians,Hugh Miller in the 19th Century and John Flett Brown in the 20th , are notable.

Hugh Miller was born at in the north of Scotland in 1802, and began life as a quarry worker. He studied fish fossils and recorded his experiences in *The Cruise of the Betsy*, published posthumously in 1858. His main life`s work was to propagate the message of the Free Church, and he edited its journal *The Witness*. Geology was his recreation and he saw the complexities of fossil fish as evidence of the work of a Creator. Moreover as these fossils had existed in ancient times he saw no need for evolution.

John Brown was educated at Stromness primary school, and after a doctorate at Oxford, taught in the USA, before working in oil exploration for BP. He led an Open University field trip to Orkney in summer 2006, which is the basis of this presentation.

The Orkney basin was a large lacustrine basin that developed within a graben after the closure of the Iapetus Ocean. Sediments derived from uplands of the Caledonian orogeny were deposited in the basin, with seasonally varved deposits in the succession above the basement along the Stromness shore; these indicate repeated lake cycles that were probably related to Milankovitch variations in the Earth's orbit. The sediments show evidence of lake conditions including algal stromatolites, with mudcracks as evidence of intermittent desiccation. Devonian lobe-finned and armored fish were preserved by being floated posthumously into deeper water, where they sank to cold, anoxic depths so that decay was inhibited.. The resulting fossils can now be seen in the Sandwick fish bed at Cruaday quarry. Radiometric dating of the sediments (379+/-10 Ma) is provided from a lava flow extruded over the Stromness Flagstones, which is now seen at the base of the Old Man of Hoy.

Gyroptychius*, a lobe-finned fish in Burray museum, Orkney.*

In contrast, the Yesnaby sandstones of the west coast of Orkney Mainland show massive cross-bedding of aeolian sand dunes. These are exposed well in the sea stack of Yesnaby Castle. The flagstones formed an excellent building material for our ancestors, and the houses of Skara Brae and the standing stones of the Ring of Brodgar are two examples of construction 5000 years ago. Moreover, they are a good reservoir rock, and may still contain extensive oil reserves for the modern world.

When Hugh Miller wrote *In the Footsteps of the Creator*, he saw fossils as the work of God. We have the advantages of radiometric chronology, plate tectonics, cladistics and molecular biology which allow us to relate the lobe-finned fishes to the evolution of land vertebrates by natural selection. However it is still marvellous to read such interesting and enthusiastic writing on geology as that produced by Hugh Miller, and to then to view, with a modern perspective, the outcrops on which he worked.

Sea stack of Yesnaby sandstones on Mainland's west coast.

Big Bend, Texas

Alan Filmer

The Big Bend region of south-west Texas, is in the northern part of the Chihuahuan desert and includes National and State Parks. The region is bounded to the south by the Rio Grande following the line of a fault in the Santa Elena limestone downthrown to the north forming spectacular cliffs. Much of the surface geology of the region consists of Cretaceous limestone, intruded by Tertiary rhyolite magmas during Basin and Range extension. They are exposed by faulting and erosion as seen in the rhyolite domes where they form the crests of the Chisos mountains. Tertiary basalts cap mesas and black basaltic dykes are readily seen crossing the desert as upstanding walls. The landscape is colourful with red and black volcanics contrasting with white limestone. Basement Palaeozoic rocks are seen near the north of the National Park, where steeply dipping beds of chert have been metamorphosed to gleaming white novaculite (see also *Mercian Geologist*, 2005, p133).

Besides geological features that are easily seen, the desert environment provides other attractions: for the botanist there are many species of cactus, lupins and daisies and after winter and spring rains the desert blooms; and for "twitchers" there are avian visitors to the desert from Mexico, and indeed the Road Runner, of cartoon fame, is the distinctive Park emblem.

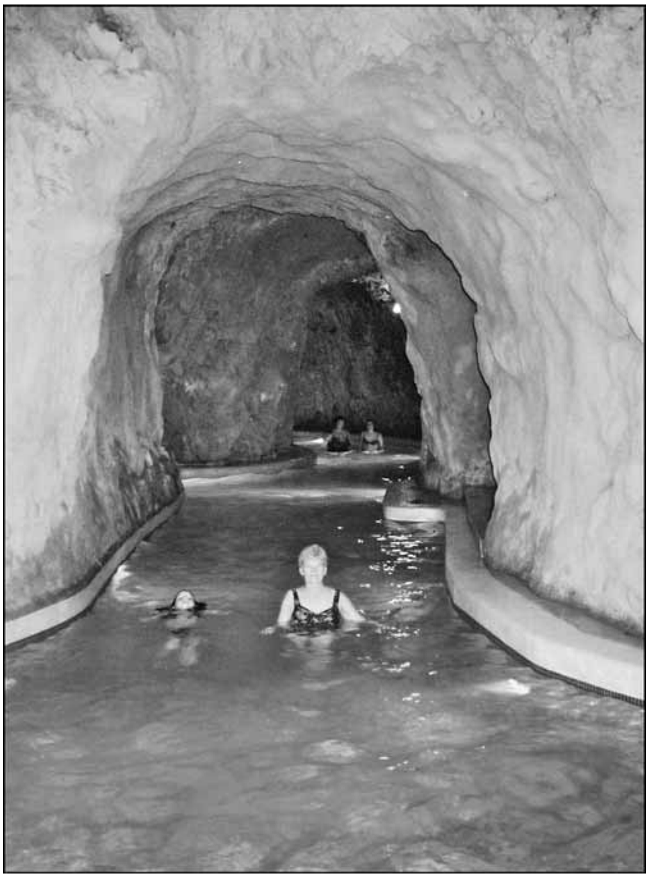
A Geological Visit to Hungary

Tony Morris

Hungary is located in the central part of the Pannonian Basin, surrounded by the Alps, the Carpathians and the Dinarides. It has three principal geomorphological divisions: lowlands consisting of the Great and the Little Hungarian Plains, the Transdanubian mountain range near to the border with Austria, and the North Hungarian Range bordering onto Slovakia. Our excursion with the Hertfordshire Geological Society enabled us to sample some of the complex geology, resultant developments (both social and industrial), and splendid Hungarian hospitality.

With widespread limestone areas, caves and karst scenery are prominent. The Crystal Caves, in Eocene limestone of the Pal Valley, have more than 20 km of passages, and thermal waters are used for public baths in nearby Budapest. The Baradla Cave in north Hungary is in a World Heritage Site of Triassic karst that extends into Slovakia and has more than 270 caves. It is an area of outstanding beauty which is augmented by the plentiful wildlife, particularly the butterflies. Perhaps the most pleasurable of the caves are the Tapolca cave baths on the edge of the Buuk Hills, where visitors swim through caverns half-filled with water that is comfortably warm at 22ºC. The temperature increases to 80ºC in the caves nearer to the thermal centre under the hills. It is not surprising that Hungary's caves and thermal waters have been used for medicinal purposes since the middle ages.

Noteworthy are the preservation of geological sites and quarries as outdoor geo-museums. Bauxite is Hungary's most important mineral, which formed in tropical humid soils which overlay Triassic dolomite, during the Cretaceous, Palaeocene and Eocene. At Gant, south of the Vertes Mountains, the bauxite quarry is preserved as an exhibition site, with laid-out geo-trails and a museum of mining artefacts. Similarly, in the Balaton Uplands National Park a quarry in Pliocene basalt has been used for displays of minerals and the history of quarrying. At nearby Urkut, a former manganese quarry is now maintained as a nature reserve, and a representative section of the exposed geological features has been preserved



Swimming in the Tapolca cave baths at 22º C.

Geological study has a long history in Hungary, and the Royal Geological Institute was founded in 1869. It is now housed in the Geological Institute in Budapest, a building with an exuberant, if not whimsical, architectural style, which alone is worth a visit without considering its contents!

Potable water from Derbyshire springs

Vanessa Banks

The scene is set with a drought in Derbyshire: *all through these warm August and September nights, from dusk until long after dawn, the queues of farm carts, each with its water barrel and its tired patient horse, have waited for hours by the few springs and wells which have not yet dried up* (Peach, 1933). Similar droughts occurred in 1921 and 1929.

Springs along the Wye valley increase in number towards the east between Buxton and Cressbrook Dale, and although declines can be accounted for by the large seasonal range of the groundwater, 30-50 m being recorded in some boreholes, the more numerous springs to the east are most susceptible to variation. Dewatering the White Peak's lead mine workings, by excavation of soughs, has reinforced the easterly and southeasterly hydraulic gradient of the region.

Key factors in the geology and hydrogeology of the limestone are formational differences and material response to stress. Development of permeability in the aquifers is explained by the inception hypothesis (Lowe & Gunn, 1997), which stresses formational differences. Based on water-tracing experiments, and geochemical and hydrograph analysis, it is suggested that the dominant flow paths in the Woo Dale Limestone are guided by faults and by stylolite-related inception horizons. In the Chee Tor Limestone Member of the Bee Low Limestone Formation there is little evidence for inception-horizon related flow; instead the brittle nature of this formation renders it more susceptible to jointing. Stress relief, where the Chee Tor Limestone is exposed at surface, results in a relatively high hydraulic conductivity, as indicated by dye-tracing experiments. However, at depth, where the joints are tight, the Chee Tor Limestone appears to act as an aquitard.

There is field evidence of inception horizons in the overlying Miller`s Dale Limestone Member (of the Bee Low Limestone Formation), in the Monsal Dale Limestone, and in the Eyam Limestone. Examination of thin sections has identified zones of dolomitization associated with micro-stylolites, and also poikilitic de-dolomitization. It maybe that the replacement calcite is more soluble, and likely to guide cave inception and thus development of the aquifer. Also, associated silicification of the underlying bed renders it an aquitard, with the potential to guide groundwater flow along the overlying inception horizon.

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This presentation is based on research in the Limestone Research Group, University of Huddersfield, supervised by Prof John Gunn, Dr Dave Lowe and Dr Alan Dykes; with the permission of the Executive Director of the British Geological Survey (NERC).

Oxford Clay's reptiles and fish

Alan Dawn

For over a hundred years the Oxford Clay around Peterborough and Bedford has been exploited for the manufacture of bricks. Quarrying operations have revealed a rich fauna of large marine reptiles and many fish. In the late 1800s and early 1900s, Charles and Alfred Leeds, farmers at Eye, made extensive collections of fossils, most of which are now in the British Museum of Natural History or the Hunterian Museum in Glasgow.

Peterborough did not then have a museum, and most of the local material has been collected over the last 25 years. Some of this was found by John Phillips soon after the Leeds brothers were active. It includes:

The ichthyosaur *Ophthalmosaurus* represented by an almost complete skeleton, now mounted three-dimensionally for display;

The plesiosaur *Cryptoclidus eurymerus* as an almost complete skeleton with the most complete skull known;

The formidable skull and jaws of Simulestes vorax.

Simolestes vorax, another plesiosaur, that is nearly complete, and with a very well preserved skull;

Pachycostasaurus dawnii, a newly identified species and genus of plesiosaur.

All these are on permanent display at Peterborough Museum together with a complete specimen of *Steneosaurus*, a marine crocodile found by Phillips in 1923. Less complete material that is in store includes *Peloneustes*, *Metriorhyncus*, and *Muraenosaurus*.

More recently a specimen of *Leedsichthys problematicus*, found in 2001, has been prepared in the museum laboratory. In October 2006, another fish was found, but has yet to be positively identified, though it is of particular interest because it includes skin impressions. Other fish include *Lepidotes*, *Leptolepis* and *Caturus*. Sharks are represented by an array of teeth and fin spines, but, because they are cartilaginous, no shark bones have been found. There is also a varied population of invertebrates, including ammonites and belemnites.

In addition to the Jurassic fauna, fossil remains of an extensive Pleistocene animal population are found in the overlying glacial deposits. Woolly mammoth and woolly rhinoceros are frequently found in the Devensian gravels, together with reindeer, horse, bison, aurochs and bear. Earlier remains, from the Ipswichian warm period, include the head and forequarters of *Palaeoloxodon antiquus*, the straight-tusked elephant, and also a hippopotamus.

Crytptochidus eurymeus *under assembly.*

Nottingham's Market Square

Britain's largest market square has been re-vamped. Modern, expensive, trendy, bleak, dramatic, sterile, futuristic, wasteful - different people each have their own views. But now that it's all finished, we can peruse the new geological delights of the city centre.

It is typical of Britain's modern stone industry that none of the four stone types used in the new Market Square is derived from quarries in this country. Portugal and China were the sources; press reports that it all came from China, or that some came from Donegal, were in error. But the natural stone does replace the concrete slabs that previously floored most of the Square (with just steps of Cornish granite and kerbs of Mountsorrel granodiorite).

The main stone used for the majority of the slabs in the square is a beautiful, light, coarse granite that is packed with large plagioclase feldspar crystals, up to 75 mm long, all embedded in a finer-grained matrix. Some of this stone is darker, almost to a grey colour. This was down to natural variation in the one quarry, and some of the darker stone has been used almost as a feature along step edges, but some appears incongruous as scattered darker slabs that indicate some lapse in quality control. Much better are the many fist-sized xenoliths of a dark and fine-grained material; some have well-defined margins, while others show varying degrees of absorption and porphyroblastic recrystallisation. The designers did not like these, but were persuaded by the suppliers that they were an unavoidable natural feature – fortunately, because they are excellent. About 1000 tonnes of this granite were used in the Square, and it all came from a new quarry in northern Portugal, where it was cut and finished on site, the quarry lies inland, but most of the stone was trucked to a port and then shipped to Felixstowe for another stage of road transport. This granite goes under the trade name of Crystal Azul, and was supplied by Charcon.

There is also a beige granite that makes up a large part of the water feature and some of the stone bench seating terraces. This is called Amarelo Mondim, also from Charcon and also from Portugal. It is more homogeneous and finer grained than the main granite; so less interesting but a good colour contrast.

Much of the fountains area, and more of the stone benching, is a conspicuously darker material. It is an olivine gabbro, almost black and difficult to see its texture except where green crystals of olivine are visible in some of the watered faces. This came from Fujian, a province on the southeast coast of China, and was provided by Marshalls under the exciting trade name of GRA921 – where they refer to it as a black granite (using trade terminology instead of geological description).

The new Square (photo: Dom Henry, www.domhenry.com).

The fourth rock type, used in some small areas and features, is an unusual white granite, finer-grained and very homogeneous. It looks almost like a quartzite, and not dissimilar to the Portland limestone of the Council House, but it is actually an albitised granite. One wonders whether it is hydrothermally altered, or if it is a type of late-stage aplite, but it does appear to have retained its durability. This stone came from Jiangxi, the Chinese province just inland of Fujian, and was also imported by Marshalls, under the name GRA926, as one of their newer granite materials.

Parts of the Square's new design are seen by some as almost polychromatic in the style of Fothergill Watson, the famous Nottingham architect, and such a link to the past has to be both pleasing and appropriate to the city's evolving heritage.

Neil Turner and Tony Waltham

The old Square (photo: Tony Waltham, www.geophotos.co.uk).

REPORT

Vein cavities on Dirtlow Rake

In the Carboniferous Limestone south of Castleton, Dirtlow Rake is a classic vein system with a long history of productive mining. This included a large open pit that was developed in the 1980s and now lies close to the high point on the new road skirting the much larger limestone quarry.

Fluorspar mining completed

The open pit was originally worked by a contractor for Laporte Minerals, after the orebody adjacent to the main rake was discovered in 1984. Mineral extraction continued under a series of planning permissions until the contractor went into receivership in 1996. In the following year a planning permission was issued which consolidated Dirtlow Rake with the adjacent Hollandtwine and Hazard Mine workings. With its prominent position on Bradwell Moor, in the centre of the Peak District National Park, controlling the impact of this mineral working on the landscape was always problematical. The approved working scheme was never carried out to its full extent and the proposed final restoration plan to achieve a long valley feature connecting all three sites could not be implemented.

Laporte ceased operations in 1999, and responsibility for restoration of the site could not easily be resolved among the various parties that had been involved. Eventually, after several years of negotiations, funds were provided for restoration work and a scheme was agreed with the landowner. Begun in late 2006, this involved backfilling the open pits with the remaining overburden material to leave a regraded landform sympathetic to the surrounding landscape with its history of mineral working along the rake over three to four centuries. The scheme maximises the area of restored grazing land available to the current landowner, while preserving for open view the geological features on the northern quarry face. The earthmoving work is due for completion by the summer of 2007, and the site will then begin to blend into the landscape as the field boundaries are rebuilt and the grass cover gradually returns.

This is a good example of geo-conservation and is consistent with the principles outlined in the recently-published geo-diversity guidelines (ODPM, 2005; Scott et al, 2007). It is hoped that the final dressing of topsoil will have a tolerably low concentration of lead, though retaining isolated areas of galena-contaminated soil that will encourage the development of metallophyte plant communities, adding to the local biodiversity.

The orebody, now completely removed from the pit, was a dome-shaped mass about 100 m in diameter and 30 m deep. It was roofed by limestone that was almost entirely un-mineralised, and its floor was on the Upper Miller's Dale Lava. It was slightly elongate with its south-eastern margin edge against Dirtlow Rake. A lower zone of altered limestone was capped by a breccia pile that appeared to represent extensive collapse of a Carboniferous cave chamber (Butcher and Hedges, 1987). It is unclear whether the dissolution and subsequent roof failure, by progressive stoping, of this chamber, pre-dated the mineralisation. Alternatively, both its enlargement and collapse may have been by the same hydrothermal activity that introduced the minerals. The main mineral of the domed orebody was fluorite, though the adjacent rake carries largely calcite and barite with lesser quantities of galena.

The two large pipe-shaped vein cavities exposed on the north wall of the Dirtlow workings, with remnants of smaller cavities recognisable by the ribs on their walls.

Backfilling the open pit in summer 2007. The tipper is on the fill at its intended level, which will finally reach a slope down to the foot of the face with the solution features.

Solution features preserved

With the orebody now removed, solution features are now exposed on the open north-western face. Most notable are the surviving halves of two large vertical pipe-shaped vein cavities, along with remnants of at least six more, smaller cavities. All lie within a zone of jointing, though they are not on a single well-defined joint. The two large features are each about 20 m high and 7 m wide. Their walls are stepped by sub-horizontal ribs. These could relate to variable dissolution on beds of contrasting lithologies; alternatively they could have been etched into the walls beside the tops of sediment banks that accumulated in stages while the roof migrated upward by stoping collapse. Scallops are large and poorly defined, and there is no vertical fluting that would indicate vadose origins by cave waterfalls.

Morphologies of these features are all consistent with a phreatic origin, by slowly moving water well below the contemporary water table. They are vein cavities comparable with many others known in the Castleton limestone (Ford, 1986, 2000). These by the Dirtlow Rake are shaped more like vertical shafts than many of the other features - which are more extensive in two dimensions along the planes of single rakes or joints; these could possibly have been linked by openings removed by mining where they lay in front of the plane of the cut face. Of the two large vertical features, that to the west is capped by a half-roof, while that to the east is now open to the sky above where it splits into two (only since a sediment plug fell out from each when it was all breached by the pit face). A low cave along a bedding plane, with its roof pitted by small phreatic domes, links the bases of the shafts. Like at most other nearby vein cavities, there are no large open cave passages leading in or out.

These vein cavities beside Dirtlow Rake are not mineralised. They are therefore much younger than the earlier stage of dissolution when the broad dome structure was formed, then partially collapsed during or before receiving its late Carboniferous

The eastern vein cavity with its ribbed wall.

The undercut bedding plane across the base of the vein cavities, with its roof pitted by phreatic domes.

hydrothermal mineralisation. They are probably roughly contemporary with the many other vein cavities in the area, including the nearby Titan Shaft (Waltham, 2000). Though initiation of the cavities may relate to early circulation by warm waters, their main enlargement dates from the mid-Tertiary, soon after the Upper Carboniferous cover was removed, thereby allowing accelerated groundwater circulation and dissolution (Ford, 1986). All these old phreatic cavities were drained when the Hope Valley was cut to levels beneath them. While most of these distinctive solution features lie far underground and are accessible only to cavers, these beside Dirtlow Rake are now available for all to see.

This report was compiled with generous assistance from John Hunter (Peak District National Park Authority).

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Tony Waltham

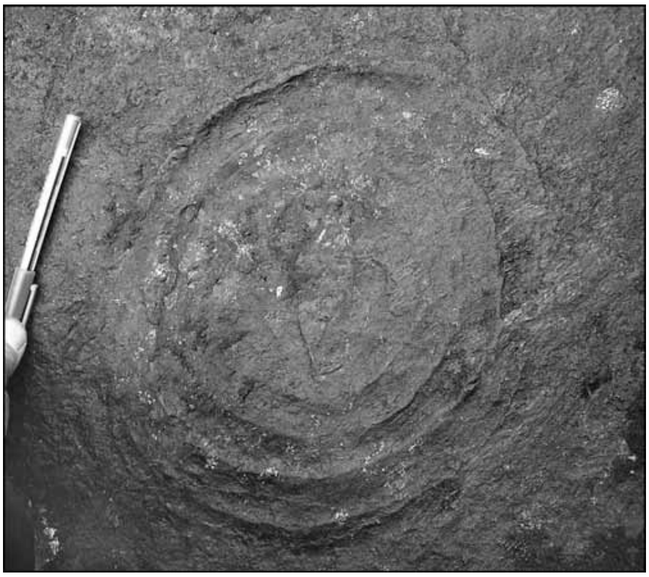
A new book, *The Rise and Fall of the Ediacaran Biota*, edited by P. Vickers-Rich and P. Komarower is published in October 2007 as Special Publication of the Geological Society of London, Number 286, with 464 pages (ISBN 978-1-86239-233-5).

REPORT

The *Charnia* Research Group

The *Charnia* Research Group was set up in the spring of 2006 after four discs had been illegally removed from a bedding plane in Charnwood. The aim of the Group is to record, and ensure the preservation of, the remaining Precambrian fossils in Charnwood Forest.

Three meetings have already been held at Leicester University and a steering committee has been formed to review detailed progress. The programme for the future is to clean, replicate (by taking moulds), photograph and possibly laser scan the fossils at key locations. A team from the BGS has already assisted David Williams (GeoEd) with cleaning the main fossiliferous bedding plane in The Outwoods. Moulds were subsequently taken, from which a series of replica casts were made by GeoEd. A set of these is now available for examination at the BGS Palaeontological Collections department.



Very large disc with four inner rings (photo: Ian Evans).

At the fossil locality in the grounds of Charnwood Forest Golf Club, the clearing of overhanging tree branches is now well under way, thanks to the support of staff from the golf club, Natural England, and willing volunteers such as Frank Ince, who is adept at the abseiling techniques needed to gain access to all parts of the quarry face. This work prepares the way for cleaning the bedding planes and recording the extensive fauna of *Bradgatia, Charnia masoni* and the many discs and fragmented colonies that are being revealed. Other fossiliferous bedding planes in Charnwood Forest will be likewise recorded, and moulds and casts will be taken.

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REPORT

Fossil aeolian features re-appear at Buddon Wood

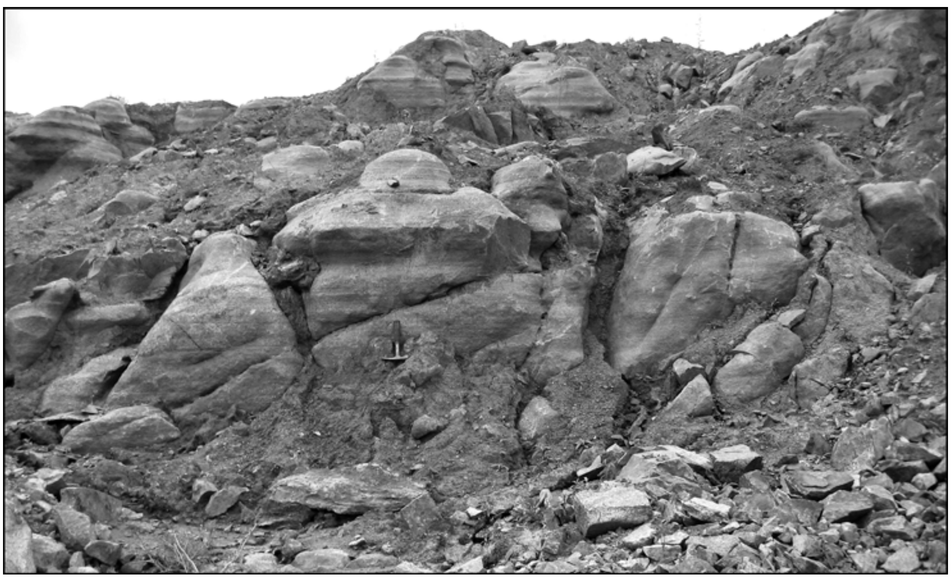
In his classic 1912 volume on the Triassic 'Keuper Marls' around Charnwood Forest, T. O. Bosworth took advantage of the rapid expansion in hard-rock quarrying to study the nature of the unconformity between Triassic, Mercia Mudstone strata and underlying Precambrian to Ordovician 'basement' rocks. This remarkably prescient work also incorporated detailed sedimentological information on the Mercia Mudstone, which included palaeoenvironmental interpretations and analysis of heavy mineral separates.

One of the most interesting illustrations, Fig. 21 in Bosworth's book (Bosworth, T.O. 1912. *The Keuper Marls around Charnwood.* Leicester Literary and Philosophical Society, 129pp.) depicted a 'tor' of Ordovician granodiorite, emerging from beneath the Mercia Mudstone overburden that was being quarried away in what subsequently became known as Castle Hill Quarry, just to the west of Mountsorrel village. In this photograph, the top of the tor forms smooth-surfaced, rounded masses, and its vertical sides are sculpted into horizontal flutes or grooves, which were called 'terraces'. The flutes had previously been seen by W. W. Watts in 1899, again in association with the Mountsorrel granodiorite. They were attributed to wind abrasion, and gave fresh impetus to the theory of a desert origin for the overlying Triassic strata.

Recent removals of Triassic overburden from Mountsorrel granodiorite in the easterly extension to the Buddon Wood 'Superquarry' have once again revealed wind-fluting. It is seen as horizontal, parallel grooves on the smooth, fresh granodiorite surface. On close examination, Mercia Mudstone still adhering to this surface is studded with angular, sand-sized grains of fresh feldspar and quartz; perfectly fresh biotite grains are also seen. This detrital component would have been derived from the arid-climate process of 'sanding', acting upon the granodiorite to make available the grains that would then have effectively sand-blasted the bare rock surface to form the flutes. Breccias with highly angular fragments of fresh granodiorite are also found in the adhering Mercia Mudstone. Some fragments are thin, with curved margins, suggesting that they are debris caused by exfoliation of the granodiorite surface, due to the extreme diurnal temperature variations typical of desert climatic regimes.

According to Bosworth, the occurrence of wind-fluted ridges is unique to surfaces on the Mountsorrel granodiorite, and this has been confirmed by observations made since. Thus in the similarly large quarry farther south at Croft, the diorite surface, though locally smooth and highly polished, is not significantly wind-fluted. It is possible that deeply penetrating erosion and weathering along major joint surfaces on the Mountsorrel granodiorite was a prerequisite to the formation of a dissected, gullied topography that would have funnelled the strong desert winds. The siltstone 'skerries' intercalated in the Mercia Mudstone were interpreted by Bosworth as the shallow-water deposits of ephemeral lakes or ponds, on the basis of features such as desiccation cracks and halite pseudomorphs. They also show small-scale ripple marks, which Bosworth suggested were generated from currents driven by winds blowing from a south-westerly direction. Was his theory correct or is more palaeo-environmental interpretation needed? This is exactly the opposite direction to that predicted by modern global wind patterns for a location 15-20º north of the Equator, which is where the East Midlands would have been in mid-Triassic times.

John Carney, BGS



Fluting on granodiorite tors attributed to Triassic wind erosion and re-exposed in Buddon Wood Quarry (photo: British Geological Survey).

VIEWPOINT

Global Warming

Climatic shifts, both worldwide and in so many separate regions, clearly indicate that global warming is upon us. Certainly its impacts on mankind are growing to unprecedented levels. But is this really the greatest of all geological events, or is it just a repeat of numerous climatic oscillations both in and before the Pleistocene? The latter option then raises the question of whether, or perhaps more truthfully, how much, global warming is natural or is man-induced.

It does seem perhaps a touch presumptuous, or even arrogant, to reckon that mankind can have a really major influence on the Earth's massive environmental systems. However, there is now plenty of clear evidence to show that some of man's activities are having an impact on global climates. But just how much remains open to debate - particularly by a geologist, who sees far greater environmental changes at many times in the past, when man was certainly not involved. The geological story seems to be rather overlooked in the rush to blame everything on man's current activities.

Effects and impacts

The effects of global warming will certainly be dramatic in the long term. They are already noticeable within lifetimes, and are likely to accelerate. On the small scale, there will be many notable weather changes. Britain will have wetter winters and warmer summers; the latter could be welcomed, but there will be more storms, and river flooding will increase. The worldwide retreat of glaciers will continue and may accelerate (Fig. 1). Half the Alpine ski resorts will be devoid of adequate snow. On the grander scale, ocean currents will shift, and there is a theoretical possibility of the Gulf Stream and North Atlantic Drift shutting down, with massive effect on our part of NW Europe.

Patterns of agriculture will shift, and cereal production will be greatly reduced or be forced to re-locate. Water shortages will become even more acute in some areas, and mass migrations of mankind may be driven by desperation. In the natural world, a third of animal species will face displacement or extinction. Some ice sheets will continue to diminish, particularly by break up of floating ice, though the Antarctica ice sheet may increase in mass due to increased snowfall. An ice-free Arctic Ocean by 2100 is a distinct possibility, perhaps bad news for polar bears (though they did seem to survive the far greater natural climatic changes in and since the Pleistocene).

Perhaps the greatest impact will be a rising sea-level - or to be precise a sea-level that continues to rise but at a greater rate. Only partly due to melting of the world's few remaining ice-caps, this is largely due to expansion of the sea-water as it is warmed. Sea-level rise within the next 100 years is expected to be about a metre (though there is a huge range in the predictions), compared too about 0.2 m in each of the last few centuries. Coastal flooding will occur, with notable impact in countries like Bangladesh, and in the huge number of coastal mega-cities around the world. Add to this, in some areas, the increased frequency of hurricanes and their resultant storm surges; New Orleans will not be the only one to suffer in a big way. Closer to home, the Thames Barrier is only designed to protect London until about 2030, and will need a major rebuild. Undoubtedly, sea-levels will rise, but the questions remain as to how much, and, more significantly - natural or man-made?

Man-made or natural?

Man's activity is undoubtedly part of the problem; the question is how big a part? On the grand scale, this question has been addressed by a succession of reports from the Intergovernmental Panel on Climate Change (IPCC), under the auspices of the World Meteorological Organisation and the United Nations. This panel is a very large group (of indeterminate size) of scientists who bring in a huge background of knowledge. There are however political undercurrents within the panel and in its report preparation, so that the group is discredited by various other groups of scientists. The facts gathered by IPCC are spectacular and undeniable, but the deductions from them are not all pure science. It is these deductions that are fed out

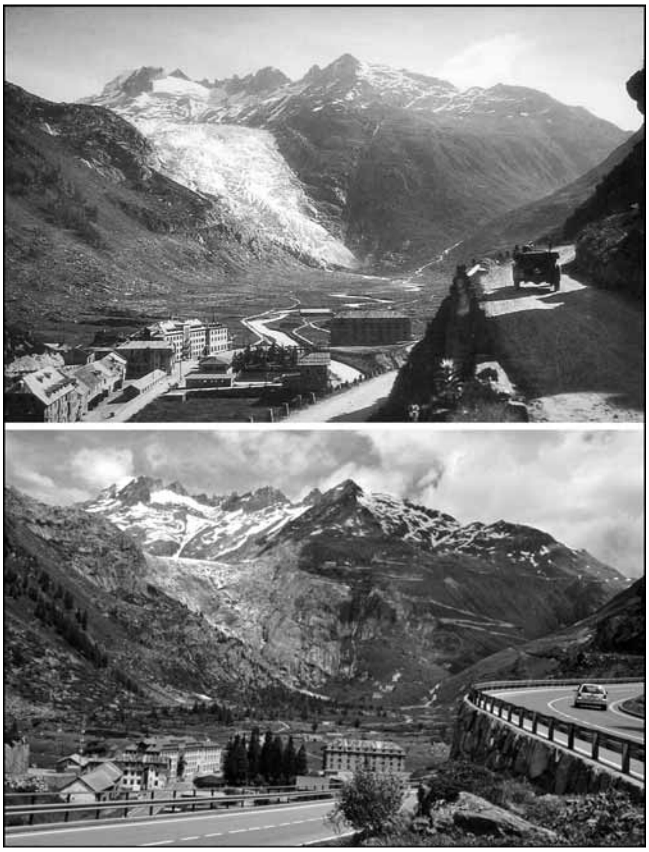


***Figure 1**. Retreat of the Rhone Glacier in Switzerland, seen in similar views from above Gletsch in 1932 and 2005.*

to the outside world, where the next link in the chain is the media - for whom a good story can be more important than real science.

In February 2007, publication of the IPCC Fourth Report produced a flurry of alarmist press headlines. In summarising that report, one respected newspaper stated that it was "unequivocal that climate change is happening and that humans are contributing". That was fine, but in the same newspaper the next day, this changed to "unequivocal that warming is almost certainly man-made". A rather different story, but environmental journalists have to hype their stories to keep their jobs. Another national newspaper said "the IPCC report says there is a >90% chance that mankind is to blame", whereas IPCC actually said only that there is a >90% chance that there is a link between man's activity and climate change. Again a significant distortion of the original.

The sceptic may also question the computer models from which the IPCC predictions are derived. Though these models are steadily increasing in capability, they are notorious for producing results so sensitive to their inputs that they have to be read with enormous margins of doubt; "junk in, junk out" is the old modellers' maxim. Memories might do well to reach back to *Limits to Growth*, the infamous doom-and-gloom publication of 1972 prepared by an independent group of scientists and thinkers known as the Club of Rome. They predicted, among many other things, when various mineral resources would run out - most conspicuously that the world's oil could be gone by 1990! They misjudged the scale of industrial development, totally under-estimated mineral exploration potential, and based their predictions on rather inadequate computer programmes. It was the best possible at that time. Its warning of resource depletion was sound in principle, but its predictions were so unreal as to earn a label of panic in the files of history. Comparisons with the global warming message may not be inappropriate.

The role of carbon dioxide

Much of global warming is based on carbon dioxide and the "greenhouse effect". This effect is created where there is an increase in atmospheric gases that are transparent to solar energy, which is therefore unabated as an input to the Earth system. While the same gases are barriers to terrestrially generated infra-red energy, which is therefore reduced as an output. Even though its total impact is far smaller than that of water vapour, carbon dioxide (CO_2) clearly has this effect. And CO_2 levels are rising at present. Bubbles extracted from ice cores, notably at Vostok in Antarctica, show CO_2 levels now far higher than at any time in the last 650,000 years. For most of that time, CO_2 levels have oscillated between about 180 and 300 ppm, but are now around 380 ppm; most of that rise is due to abnormal accumulation within the last 100 years (Fig. 2).

Isotopes of carbon show that the increased CO_2 is related to man's activities. Carbon-12 makes up the vast majority of carbon atoms, while carbon-13 makes up just over 1% of the atoms. Because some physical processes filter out the different isotopes, the hydrocarbons that make up wood, coal, oil and gas are depleted in carbon-13, in contrast to volcanic sources that are relatively rich in the heavier isotope. Tree-ring archives show that, since around 1850, the proportion of carbon-13 in the atmosphere has declined relative to carbon-12 (the decline in proportion is about 0.15%, which compares to a drop of only 0.03% during the post-Devensian glacial-to-interglacial warming). Over the same period, since 1850, the level of total atmospheric carbon dioxide has risen in a way that exceeds historical variability, and this coincides with mankind's increasing use of fossil fuels, firstly coal and then oil. Mankind does appear to account for a large part of the current rapid increase of atmospheric carbon dioxide.

There is however a word of caution. The Vostok ice cores do suggest a correlation between high CO_2 levels and high temperatures, but the CO_2 levels appear to have fluctuated with a lag of about 800 years behind the climatic changes. This suggests that the high CO_2 could be an effect of global warming, and not its cause. This is very reasonable, when it is known that warmer water can dissolve less CO_2 than cold water. Warm the oceans and they emit CO_2, and a few hundred years is required to establish any equilibrium across the enormous mass of ocean water. Though man-made carbon dioxide is cast as the ogre, the story may not be that simple.

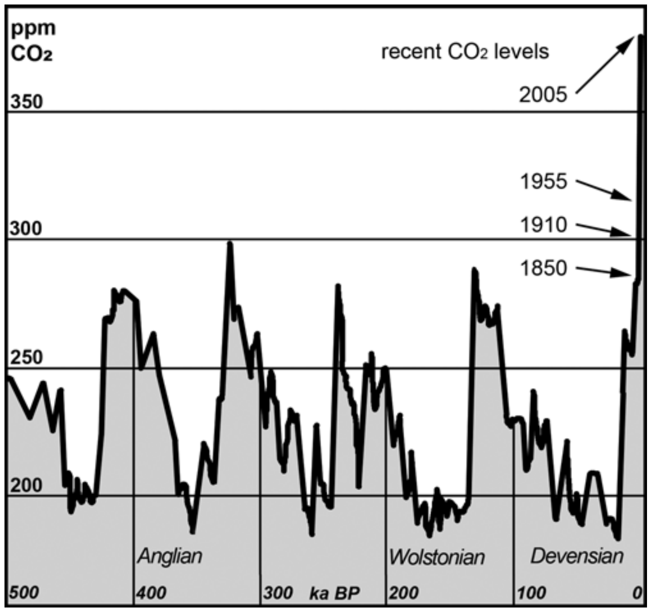


***Figure 2**. Variations in atmospheric carbon dioxide over the last 500,000 years, largely as recorded from bubbles within the ice cores at Vostok, Antarctica. The time scale is slightly distorted at the right where recent levels are dated on the steep graph (and go beyond 0 BP, which is 1950 AD).*

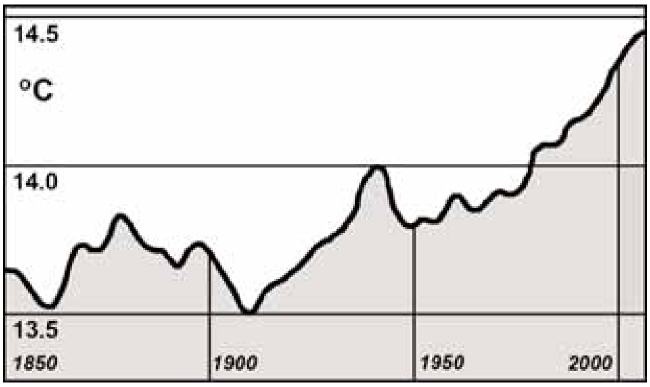


***Figure 3**. Rising mean global temperature from 1850 to 2006.*

The geological record

Global mean temperature has risen by about 1ºC within the last 100 years (Fig. 3). Its slight acceleration around 1970 heralded the phase of global warming that is now blamed on man's own activities. But, if the geological record, from any time before 1850 AD, can show climatic changes that equal or exceed the current events, then natural global warming must be accepted as a reality - because man was not there to be the cause. It pays to look back through time.

The "Little Ice Age" (also known as the Neoglacial) started around 1300 AD, really got going around 1550, lasted about 200 years, and was then followed by almost continuous warming from before 1800 (the timing varies slightly between different continents). It is well documented. For much of the cold spell, Frost Fairs were annual events held on the ice of frozen rivers - including both the Thames and the Trent. Their demise pre-dates man's major impact on climate (the river warming by power-station water was even later). In mountain regions around the world, alpine glaciers have been seen to be in steady retreat ever since then; neoglacial retreat moraines are well known everywhere, many because they impound very scenic pro-glacial lakes.

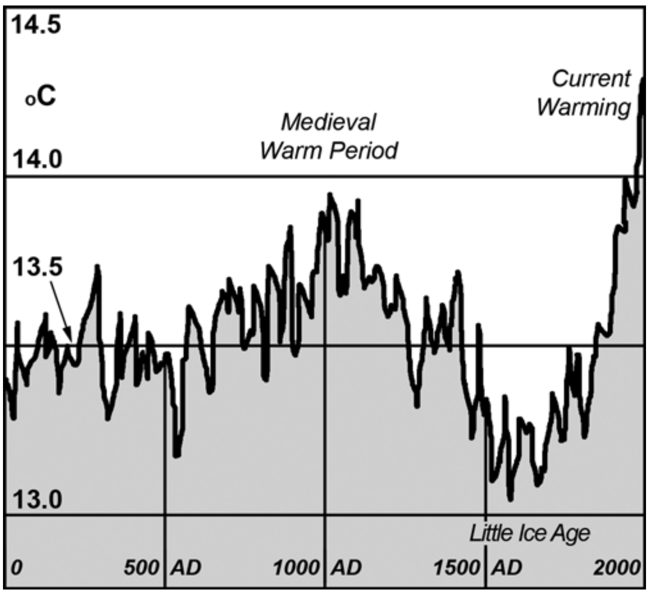


***Figure 4**. Mean global temperatures over the last 2000 years, spanning the Medieval Warm Period, the Little Ice Age and the current phase of warming.*

Before the Little Ice Age was the Medieval Warm Period, which peaked around 800 to 1200 AD. This was the time when Greenland was colonised as a green and pleasant land full of opportunity, and the warmer climates throughout Europe are well recorded. Today's phase of global warming does not look much different from the change into that earlier warm period (Fig. 4). Today's warming is a bit greater and a bit faster, so mankind may have made the difference by increasing the current processes. But that is rather different from claiming that man caused the modern change.

A bit earlier in time, the Holocene warm period (also known as the Atlantic period), from about 8000 to 6000 years ago, was both wetter and warmer in Britain, with comparable changes elsewhere. There was a much smaller area of permafrost then, and probably much less sea ice than there is now. But this was a minor change compared with the Pleistocene Ice Ages. In each of these, global temperatures dropped by up to about 10ºC, and then rose very rapidly by an equal amount at the end of each (Fig. 5). These were phases of massive global warming, far in excess of the current events, and clearly unrelated to man's "carbon footprints". Ice cores from Greenland record a temperature increase of about 8ºC within a few decades when the Loch Lomond cold stage ended around 11,600 years ago (Fig. 6). In each full Ice Age, worldwide sea-levels dropped by more than 100 m, due to huge amounts of water trapped in the continental icecaps of the higher latitudes. When the Devensian glaciers melted, sea-level rose at a rate of about 12.5 mm/year. Compare this with the current rise rate of about 2 mm/year and rates of 3 to 9 mm/year predicted for the next century. And the 12.5 rate was without any help from mankind.

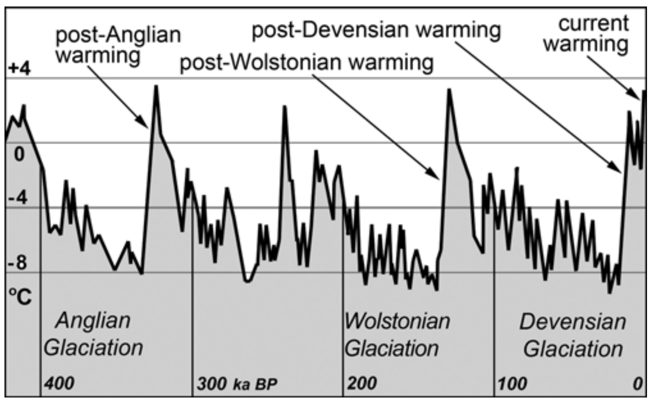


***Figure 5**. Variations in mean global temperatures, across an arbitrary datum, derived from ice core data, showing phases of rapid warming after each Ice Age.*

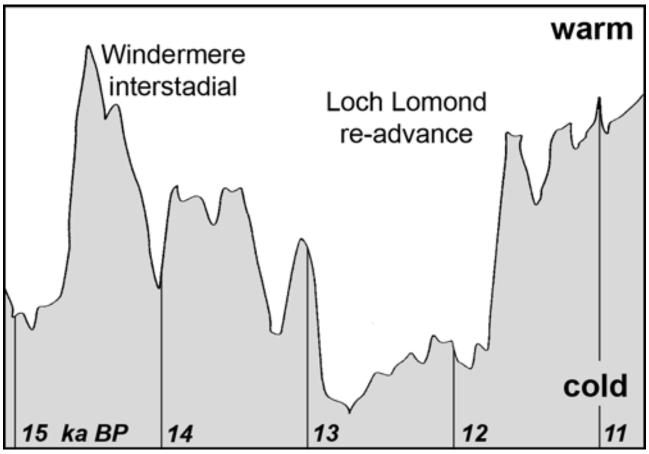


Figure 6. Global warming at the start of the Holocene, after the short-lived Loch Lomond re-advance (also known as the Younger Dryas). There is no absolute temperature scale on this ice core oxygen isotope interpretation, but it indicates a very rapid temperature rise of about 8ºC (from Peter Worsley's paper, Mercian Geologist, 2006, 16, 171).

On an even longer timescale, global climate changes were marked by extensive glaciations in the Carboniferous (the Gondwanan Glaciation) and in the Ordovician, with at least four more in the Precambrian. Each of these ended with massive global warming.

The natural causes of these pre-mankind climate changes are still not completely understood, which does allow some scope to those who blame modern global warming on man's activities. An Ice Age requires a large area of landmass at higher latitudes where icecaps can accumulate, and changes in the distribution of continents also influences the circulation of warmth by the ocean currents. But plate movements are too slow to account for the more rapid climatic oscillations within a cluster of Ice Ages, whether they are Gondwanan or Pleistocene.

The Milankovitch Cycles recognise three astronomical factors that influence the total amounts of solar radiation that reaches Earth. These factors are the variations in Earth orbit round the Sun, the changes in the Earth's axial tilt, and the precession of the Earth's axis of rotation. Each on its own is not enough to cause an Ice Age. But each has a different cycle length, and the different influences therefore coincide on longer and less regular cycles, which can account for the well-documented patterns of climate change within the Pleistocene.

On shorter time-scales, sunspot activity influences our dosage of solar energy, and this correlates very well with temperature change through the last few hundred years, notably the temperature decline through the 1940s that was in opposition to man's influence by the massive, post-war industrial growth. However, this data, often cited by sceptics, only correlates well with temperature up until about 1972 (when first recognised by Danish scientists), particularly when some of the temperature peaks are statistically smoothed out. Since about 1976, the trend of global warming has been opposite to that of solar activity (Fig. 7). Though solar activity appears to have been a contributory factor in the past, it is clearly not the primary cause of global warming. It is also well known that some temperature variations within the last 700 years have been due to volcanic eruptions that modified the atmosphere by their dust input. But, along with meteorite impacts, volcanoes are not cyclic, and belong in the list of smaller natural factors.

There is a mountain of "Further Reading" relevant to the understanding of global warming. On the web, the latest report from the IPCC is a free download from www.ipcc.ch/SPM2feb07.pdf , while an opposing view is at www.co2science.org/scripts/CO2ScienceB2C/Index.jsp . On paper, the geological factors are well expounded by Peter Fookes and Mark Lee in Geology Today (Climate variation - a simple geological perspective: v23, p66-73, 2007), while the IPCC conclusions are summarised and expanded in New Scientist (Climate change: v193, n2590, p6-9, 10 Feb 2007).

Ice Ages and lesser periods of cooling are not the only signs of climatic change held in the geological record. The stratigraphical record shows an abundance of sedimentary cycles, notably those of the Coal Measures, the Blue Lias, less conspicuous banding within limestones, and a host of others. The causes of these are not all understood, and climatic cycles vie with tectonic cycles as the more plausible for individual sequences. But they do record changes in the Earth's environment that are major and totally natural. The scale and power of these natural changes is rather overlooked in the heated debate on the current climatic shift - which is quite small in comparison with many in the geological record.

There remains the question of how important are "snowball effects", where a small event can trigger a chain of larger events. Computers are good at modelling these chain reactions, but only when the input data is totally sound, and that is not easy in modelling something as complex as the Earth's environment. Mass extinctions lie alongside Ice Ages

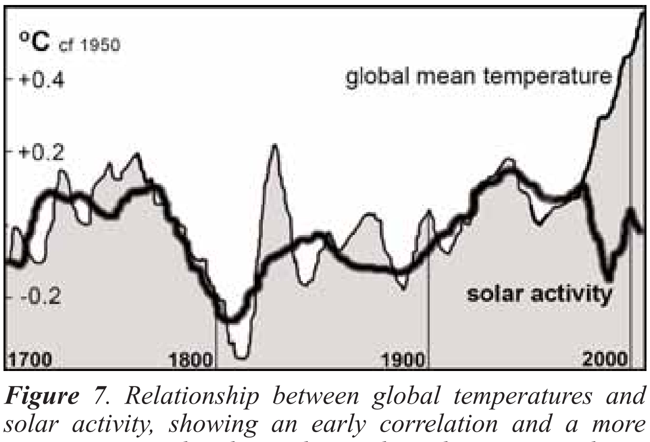


***Figure** 7. Relationship between global temperatures and solar activity, showing an early correlation and a more recent mis-match. The scale on the solar activity plot is arbitrary, as this graph is derived from various sources.*

as examples of the end-result. The trigger event could be the closing of a seaway between oceans, expansion of an icecap on a new mountain range, or a volcanic eruption. Or it could be man's input of a major dose of carbon dioxide. Significantly, man's contribution cannot be overlooked, but neither can the very large number of natural factors.

The way ahead

The geological record does show enormous and global changes in climate, including periods of very significant global warming. We are now in one of those warming phases, and have been for about the last 300 years (since the Little Ice Age) or for about the last 12,000 years (since the Loch Lomond retreat); and we now have an increased effect from the superimposition of the small-scale and large-scale cycles. There is also evidence of accelerated warming over the last 50 years or so, which does appear to correlate with environmental changes induced by mankind. It therefore appears that mankind is contributing to global warming. This is very different from saying that he is causing global warming. And the scale of the contribution remains open to debate.

As pointed out by the US Centre for Atmospheric Research, "no matter how much humanity reduces gas emissions, global warming and sea-level rise will continue for hundreds of years"; this is largely due to the slow response of thermal change in the oceans. So if sea-level rise is threatening a huge swathe of mankind, and is a geologically normal and unstoppable process, would it not be better to take more positive action to mitigate the damaging effects of this, rather than "reducing the carbon footprint" - which cripples industry in developing countries and enforces regulations on people everywhere (with everyone carefully side-stepping the nuclear option, which has to be the future in our resource-challenged world and has minimal carbon impact). The reductions in available space on dry land could be accommodated with ease if the effort that is going into the problem of global warming went into dismantling the religious and nationalistic barriers to population control. There are other direct impacts from global warming, notably on patterns of agriculture. But these are solvable, and there are far greater problems in disease pandemics and in the incessant warfare in Africa, to name but two. By focussing so heavily on global warming, mankind may be missing the point.

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Though this essay has been prepared by the Editor of Mercian Geologist, it is only a personal view, and is not presented as an authoritative editorial; it has been accepted by the Editorial Board as an interesting viewpoint that is a worthwhile contribution to the ongoing debate. Further contributions, debate and criticism will be welcome for the next issue of the journal.

REVIEWS

Fluorite, the Collectors Choice, edited by Jesse Fisher and others 2006. Lithographic LLC: Connecticut. ISBN 0-9715371-9-4, 128 pp. $30.
[*in UK from - Ian Bruce, PO#3967, Yeovil BA20 9AH (ian@crystalclassics.co.uk); Philip Taylor, Egis Lion House, Dyce Avenue, Dyce, Aberdeen AB21 0LQ; Paul Lowe, 3B United Downs Ind. Park, St Day, Redruth TR16 5HY (paul@lowestone.com)*].

This is a beautifully produced book with numerous fine coloured illustrations. It is number nine in an unspecified series. Aimed at the mineral collector it has been compiled by 33 contributors from countries around the world, only one British (Ian Jones, of Cardiff). Some entries were translated from other languages but it is not made clear which they were.

The book opens with one page on the classical banded myrrhine, which resembles Derbyshire's Blue John: a precis of its history is given but nothing is said about the original deposits generally thought to be in eastern Iran. An introductory chapter includes notes on atomic structure, crystallography, colour, commercial uses, fluorescence, luminescence and on the many variations of crystal habit from cubes with or without bevelled edges, through octahedra to highly complex forms some of which are almost spherical!

The main part of the book is divided into entries by continent and country. These are of a very varied standard, some give maps locating fluorite deposits, but most do not. Some outline the geological setting, but regrettably most do not. Instead emphasis is placed on the experiences of collectors. There are ten pages on British fluorites, including one page on Blue John, where the author was unaware of your reviewer's book on *Derbyshire Blue John* (Landmark, Ashbourne). Maps are given of Co. Durham and Cornwall but the Peak District gets short shrift. Other European countries with choice fluorites include Spain, France and Switzerland but are there no fluorites worth recording in the rest of Europe?

Numerous localities in USA, Canada and Mexico are noted in the chapter on the Americas, but the only country listed in South America is Peru. Asian countries include Russia, China, Pakistan and Japan. The Chinese equivalent of Blue John, now to be seen in many tourist shops throughout Europe in the form of carved animals and other ornaments is not mentioned. African fluorites seem to be restricted to Morocco and South Africa. Australia has no mention.

The book concludes with some useful short chapters on cutting facetted gemstones from fluorite, on fluid and gaseous inclusions, and on cleaning crystals. There is a two page list of references. From the attractive appearance of this book on Fluorite I expected a much more comprehensive treatment of *all* countries with fluorite deposits and of the geological setting of those deposits – I was disappointed.

Trevor Ford

Building Stones of Leicester – a Guided Walk, by the late John H. McD. Whitaker, 2006. East Midlands Geological Society, 32 pp, 39 photos. £5 (£3.50 to members).

From the original that was prepared in 1981, this guide has been edited and updated by Albert Horton, with assistance from members of the Society. With colour photographs and trail maps, it has been extended to cover more of the city, including shops and offices of the eastern precinct and the historic Roman and mediaeval buildings west of the civic centre. A total of 63 sites are identified and located on an excellent trail map which is colour-coded into the three areas of eastern, central and western Leicester. The complete trail length is 4.5 km and would take 3-4 hours to complete, but each area can be covered separately.

The guide is enhanced by a set of excellent colour photographs, allowing the reader readily to identify the rock types. Not quite so successful is, perhaps, the rather confusing collage of small photographs on the front cover and the patterned background of two pages of the civic centre section which makes reading the text difficult. However this is an excellent guide to any person with a geological interest who visits Leicester.

Helen Boynton

Exploring the landscape of Charnwood Forest and Mountsorrel by Keith Ambrose, John Carney, Graham Lott, Gill Weightman & Annette McGrath. 2007, British Geological Survey. Booklet, 52pp + map, ISBN 978-2085272570, £12.00. DVD video, 84 minutes, £5.00.

This booklet opens by describing the geological timescale from Precambrian to present in the context of the Charnwood Forest area, followed by descriptions of eleven geological walks, with annotated photographs of some of the localities. Another chapter briefly describes Charnwood's minerals, quarries and significant stone buildings.

The accompanying geological map is compiled from parts of the three local 1:50,000 sheets, simplified and scaled up to 1:25,000. All the walks are shown on the map with further enlargements for six of them. There are also some landscape photographs and the camera's location is usefully shown on the map. The key to the geological map includes brief descriptions of the rocks in each group or formation and is thus more user friendly than most geological map keys. Scales vary between the walk maps and no distance information is given in the text, so it is easy to over-shoot a locality.

When the reviewer road-tested Walk #1, it soon became apparent that although the way-finding instructions are quite good, the route marked on the geological map is inaccurate and misleading in places. This of course all adds to the challenge of a day out following a geological excursion. However, although the reviewer had never visited this area before, all eight localities were found, where the key rock features are easily seen and clearly described.

The booklet is in a style similar to the two earlier booklets, produced by the same team, that describe walks on Charnwood Forest (reviewed in the 2006 issue of *Mercian Geologist*), and this works well.

The video describes the geology of the Charnwood area chronologically in a series of chapters: Pre-Cambrian volcanoes and sediments, Dawn of life, Lower Paleozoic, Ordovician, Carboniferous and Triassic sediments, Mineralization & Quaternary. It plays on a TV or on computer with suitable software. With 84 minutes of concentrated information, it is important to be able to select individual chapters if concentration flags. There is no menu for this but the skip control can be used to step though chapters if this is available on the player.

Presentation in the video mainly takes the form of the viewer watching two geologists describing rock outcrops to each other. These conversations are interleaved by animations showing the tectonic processes and continental movements, videos of modern analogues (including Montserrat) and thin section close ups. There are visits to the laboratories at BGS Keyworth, including a description, that is well-explained, of how lead/uranium isotope dating is carried out using zircons recovered from rocks. Leicester Museum is also visited.

This all works very well; aimed at A-level students, the level is similar to that in an Open University programme, and is ideal for most Society members. One of the fascinations of geology is in the uncertainties in many hypothesis of the origin of formations. Commendably this is not avoided and where appropriate, alternative explanations are offered. Although there are talking heads, the camera stays mainly on the rocks while John Carney's pencil deftly points out the important features. The presenters are lucid and engaging without being intrusive. Locations are identified and most are easily accessible, many in and near Bradgate Country Park, and there are also descriptions of the rocks in working quarries not normally accessible including Brandon Hill, Whitwick, Longcliffe, Newhurst, Swithland Wood, Croft, New Cliffe Hill, and Mountsorrel.

The package of booklet, map and video is highly recommended for any Society member wishing to explore this geologically and scenically fascinating area.

Alan Filmer

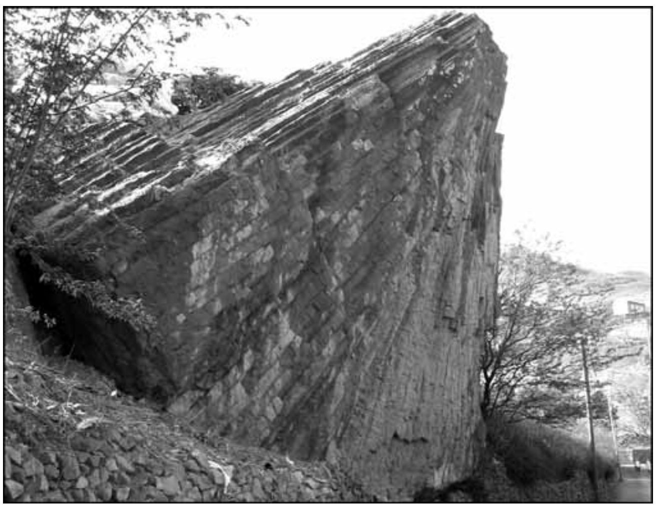
HOLIDAY GEOLOGY

Cape Verde Islands

The Islands stand in the Atlantic Ocean, 460 km west of Senegal and 1000 km south of the Canary Islands.

Early in the 20th Century, Alfred Wagner suggested that continents might have moved apart and created oceans between them. Although there was supporting palaeontological evidence, no mechanism was suggested, and the idea was widely dismissed. By the middle of the century advances in oceanography had revealed the spreading nature of the Mid-Atlantic Ridge. Matching paleo-magnetic reversals on each side of the ridge, and then the realisation that trenches were subduction zones, gave credence to the theory of Plate Tectonics. The mechanism however remained elusive. Some eminent speakers at Society meetings have favoured the concept of gravity pulling down the subducting plate, thus pulling it away from a spreading zone. Others have favoured gravity acting on the new ocean floor material on the sides of the ridge, pushing the plates along. Understanding improved when it was noticed that most volcanoes lie above the spreading and subduction zones. There remain a few isolated volcanoes, and the theory of mantle hot spots was proposed for these - it works well with the Hawaiian Islands whose chain aligns with the plate movement, with older islands further from the latest activity.

Limited data on the Atlantic islands make note of mantle hot spots. The geological museum on Lanzarote, Canaries, suggests that, as there is no subduction zone on the eastern side of the Atlantic Ocean, the eastward moving oceanic plate is actually an extension of the Africa plate; stresses in the oceanic section cause it to buckle and crack around the continental slab, thus allowing magma to rise from the mantle to form the Islands. This theory explains why the islands form a scatter, and why there is no obvious relationship between the individual locations and ages of the islands and the movement of the plate. It seems possible that the same theory could be applied to the Cape Verde Islands. Seismic studies have detected a swell under the islands. Perhaps this is over a hot spot, or it could be just a feature of the crustal buckling. Could it be that a future subduction zone might develop between these two island groups off Africa?



Fan of columns in an eroded dike in Ribiera Brava, Sao Nicolau

Of the Cape Verde Islands, Fogo is the youngest, with its oldest surface rocks dated to 100 ka. It is the only island with current volcanic activity; the last eruption was in 1995. The oldest island, Boa Vista, dates to 26 Ma. The group of islands shows a clear evolution among the individuals. They start mountainous and thus attract clouds and rainfall. This allows vegetation to develop, while runoff from torrential rainfall rapidly erodes dramatic gorges and valleys from the highest land to the sea. These are known as ribeiras, and today are cultivated throughout their length. As erosion progresses, the reduction in mountain height reduces rainfall until trees can no longer be sustained. This further reduces rainfall, yet increases erosion. Finally, dust-laden winds from the Sahara take over as the agents of erosion, and an island is slowly reduced to a barren plain.

The Windward Islands (Ilhas do Barlavento) form the northerly chain with Sal, Sao Vicente, Sao Nicolau and Santo Antao. Visitors arrive at the international airport on Sal, one of the older islands, a barren wind swept plain rising to only 400 m. Those looking for sun sand and sea head for the beach resort at the south of the island. Everyone else catches an inter-island flight to a more interesting island.

Sao Vicente is barren with some mountains rising to 750 m, but it has the second largest town in the Cape Verde Islands, Mindelo. This exists because of its magnificent natural harbour, in fact half of a collapsed caldera, which has long been used a transit point from Europe to the southern lands. From Mindelo there is a ferry to Santo Antao, the second highest island, reaching up to 1979 m. The journey from the port to the capital, Ribeira Grande, across the mountainous centre of the island is said be one of the most dramatic anywhere - particularly when sitting on a park bench in the back of a pickup truck. The plunging ribeiras and coastal cliffs give excellent cross sections though the volcanic pile. Successive basalt lava flows showing all the expected features, with ash layers and lahars, are stacked up and perfectly exposed. Later dikes radiate from the peaks and in many places form walls across the eroded landscape. Sao Nicolau is a little older and rises to 1312 m, revealing very similar volcanic features.

There are only a few roads on the islands, and these, together with most of the extensive path network, are paved with basalt sets, making it easy to explore on foot or by public transport. No rain is normal from January to July, but strong winds carry in Saharan dust. In January the mountains may be in cloud, but sunshine and 28ºC is normal elsewhere.

Alan Filmer

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