MERCIAN
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Front cover: Extraction of pure white calcite from a thick vertical vein in the Long Rake Mine, near Youlgreave, in the Derbyshire Peak District, has left this large open stope with ore-passes in its floor. See lecture report on page 211. Photo: Paul Deakin.

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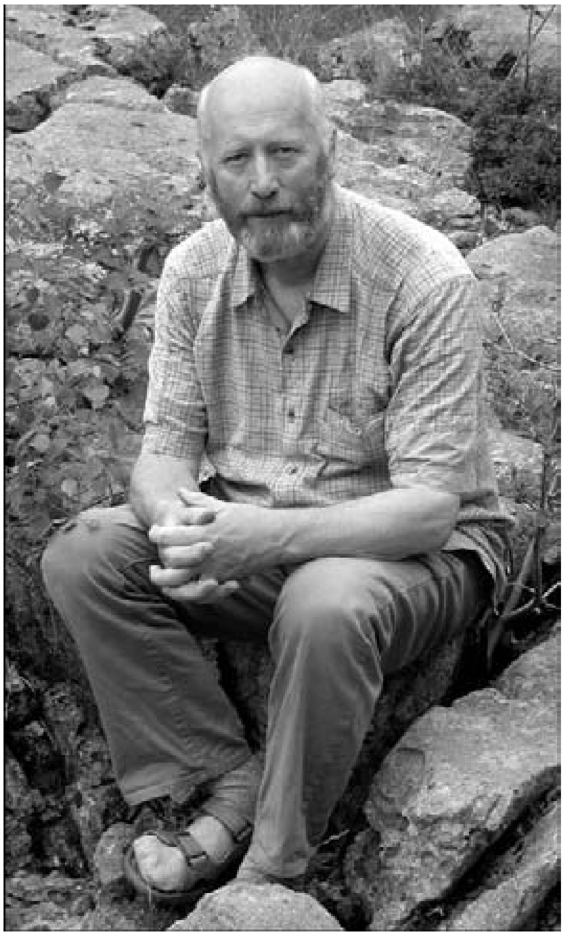
PROFILE

John Travis



I grew up in Nottingham near large clay quarries and smoky collieries that held a fascination in my young imagination, because the burning tips of coal waste looked and smelled like volcanoes. So started the road to becoming the Society's new president.

An early interest in landscape, geology and holes in the ground developed when an aunt took me walking in the Peak District, and I was intrigued by the minerals and crystals that we collected from lead mine dumps around open mine shafts. This interest in rocks, caves and mines was furthered on two school camps in the Peak District helped by the geography teacher Ron Disney, who had studied geology under H H Swinnerton at Nottingham University.

I started work on my 15th birthday for Boots, as an apprentice training in the chemical and pharmaceutical manufacturing departments. During my teenage years I spent hours reducing the family coal stocks to near-dust looking for fossils within the prized large lumps that were fashionable in those days of near-universal coal fires. Some lovely fossils were found, but they tended to be very friable and rarely survived long without treatment. Most of my geology was self-taught by reading until 1964, when I studied A-level geology at evening classes. In 1962, I moved to Nottingham University as a technician in the newly opened Chemical Engineering Department.

While working at Boots I met Josie, a keen and constant companion in the outdoor pursuits. We married in 1961, raising two daughters and a son. My walking, climbing and caving interests had meanwhile continued, first with the Scouts, and later with the newly-formed Four Ways Club (Caving, Climbing, Hiking and Camping). When the Derbyshire Caving Association was formed in 1960, I was elected as the representative for the Four Ways Club.

At the DCA I met people who helped to further my knowledge of geology and caves. Most notable was Trevor Ford, whom I assisted on some of the work on preparation for publication of the first edition of *Caves of Derbyshire*. I drove hundreds of miles on a scooter, checking locations and grid references, and correcting mismatches of old data and descriptions. I also joined Peak District Mines Historical Society in 1963, where I met Harold Sarjeant. He put me in touch with his son Bill in the Geology Department at Nottingham University. That friendship led, later that year to an invitation to a meeting to discuss the possible formation of a local geological society. From there the East Midlands Geological Society was born.

I served on the early council of the Society for two sessions, and on the editorial board for a spell. Josie was also active and supportive in the thankless tasks of those days such as regularly hand addressing hundreds of envelopes for the *Mercian*.

In 1973 I was head-hunted to work in Zürich for a researcher in chemical engineering going out from Nottingham University. For nearly two years, I was so busy at work that I saw little of the wonderful Alpine geology beyond some of the caves and karst.

In 1975 I returned to Britain, and immediately learned of a vacancy for a technician in the Geology Department at Nottingham University. With old friends still there, I was offered the job, and stayed for 11 enjoyable years, handling rocks from sources as diverse as meteorites and the deep-sea drilling project.

When the Geology Department closed, I returned to Chemical Engineering for another 11 years, and then jumped at a chance of early retirement. I had time to catch up on curating my mineral specimens, collecting ornaments made of stone and minerals, and pursuing interests in photography and natural history. Shortly after my retirement, Josie became seriously ill, but we managed a month's tour of Western Australia, visiting family and seeing some geology very different from that in Britain.

Among other trips overseas, NW USA was a highlight. The devastation by the Mt St Helen's 1980 eruption is unforgettable, and walking down a mile of lava cave was a novelty after 50 years of limestone caving.

My vision for the Society, like several of my predecessors, is to see younger members playing a greater role and moving us forward into the future.

FROM THE ARCHIVES

An archive photograph of East Midlands geology from the British Geological Survey collection

Ludlow Hill brick clay quarry

The clay pit lay close to the boundary between West Bridgford and Edwalton, adjacent to the former Nottingham to Melton railway line and is now accessible via Ludlow Hill Road, off the A606 Melton Road through West Bridgford. While it was being worked, the pit was photographed by the Geological Survey photographer T C Hall in 1908.

Excavation began around 1885, with the construction of a brickworks on the site by Messrs. Smart. Like numerous other brickworks in the area at this time, demand was fuelled by the rapid expansion of Nottingham's industry and population, and the need for construction materials for factories and dwellings. Smart's Brickworks mainly fed the demand for bricks for the growth of West Bridgford. Mudstones were initially exposed in the eastern wall of the railway cutting, and were then exploited by further excavation in an eastwards direction. Railway sidings were constructed in the quarry to load completed bricks for transport to West Bridgford and Nottingham, and to drop workers off at the brickworks, avoiding the walk from Edwalton Station 1 km to the south-east.

Brick clay in the Nottingham area has mainly been quarried either from the Permian Edlington Formation (formerly Middle Permian Marl) or the Triassic Mercia Mudstone Group. Much of the latter contains clays suitable for brick making, but the most commonly worked clays occur at two stratigraphical levels within the Gunthorpe Formation in the lower part of the Group. These beds were favoured mainly because of their association with overlying, resistant sandstone units (the Plains 'Skerry' and the Cotgrave Sandstone Member), which form prominent scarp slopes allowing the underlying clays to be quarried with ease. The Ludlow Hill Pit exploited the mudstones immediately below the Cotgrave Sandstone Member, a greenish-grey, calcareous and dolomitic sandstone, visible as a pale coloured series of beds towards the top of the quarry face in the photo. From its heyday in the mid to late 19th century, brick clay excavation in Nottingham has now declined to a single quarry at Dorket Head, Arnold, which exploits mudstone immediately below the Plains 'Skerry' sandstone bed.

Smart's Brickworks remained in production until its closure during the Second World War, supposedly to prevent the blackout being compromised by the glow from the open kilns. The site was sold and became an industrial estate; a warehouse on the site was used by the BGS in the 1980s as a store for core samples and publications prior to completion of purpose-built facilities at Keyworth. Parts of the site have recently been re-developed for residential use, but remnants of the quarry faces remain, including some very overgrown exposures of the Cotgrave Sandstone Member.

Andy Howard, British Geological Survey

Ludlow Hill brick clay quarry, in 1908 (BGS photograph # A00727 © NERC).

GEOBROWSER

Charnwood bricks for Eurohub

One of the most valuable UK brick contracts of the year has been awarded to the Charnwood Forest Brick Company. A national search for suitable matching materials has led to their quarry being chosen to supply the almost 700,000 bricks needed to restore the world-famous edifices of St Pancras station, and adjoining Midland Grand Hotel (at present known as St Pancras Chambers). This highly prestigious project is part of a massive redevelopment of the St Pancras and King's Cross stations, which will become the principal London terminus for Eurostar trains. The relatively unassuming brick pit nestles against the northern slopes of Charnwood Forest, close to Shepshed, and exploits Triassic 'red beds' of the Mercia Mudstone Group, just above the Precambrian unconformity surface. An historic cycle involving the movement of bricks from Nottinghamshire and Leicestershire to London has now come full-circle. It started back in the late nineteenth century, when the Midland Railway network to London was completed with the opening of St Pancras station in 1868 (only three years after the plans had been accepted!). All that remained was the construction of the Midland Grand Hotel, for which the stunning brick Gothic revival design of the architect George Gilbert Scott was chosen. Spurning the more local Oxford Clay resource, most of the bricks were manufactured from Mercia mudstones, from pits such as that at Mapperley, as well as Tucker's brickworks, which is now part of the Charnwood Water recreational area on the outskirts of Loughborough. That particular pit was opened immediately adjacent to the Midland Railway (later the Great Central Railway) line, not only ensuring the rapid and easy transport of bricks to the building site, but perhaps also safeguarding for the future the unique importance of this local resource.

St Pancras station frontage

Glaciers can melt rock

A valley or ice-cap glacier evokes pictures of a frozen wasteland with temperatures only occasionally rising above freezing point to form meltwater streams along the ice front. But the bases of glaciers are commonly 'armoured' by rock fragments, which grind against the underlying rock to produce the grooved and striated surfaces frequently seen in recently glaciated regions. These processes involve very significant friction, and when friction is present, heat is generated. We cannot directly observe it for modern glaciers, but observations on the basal contact of Precambrian (Marinoan) tillites in Norway (*Journal of the Geological Society,* 2006, p.417) have shown that where in contact with glacially-embedded rock fragments, the bedrock has developed a cataclastic foliation, with individual quartz grains 'healed' or sutured together – a type of fabric indicative of either melting or instantaneous recrystallization. In fact, the temperatures estimated for these rapidly transient, high friction episodes are around 2200ºC, which is well above the melting point of silica at around 1 kbar pressure. Computer modelling shows how stresses at the base of a glacier 1 km thick can be suddenly released, resulting in movements of 13 metres over 40 seconds, sufficient to cause the 'flash' temperatures demonstrated by the rock fabrics. Such 'stick-slip' events are analogous to those responsible for generating tectonic earthquakes and indeed 'glacial earthquakes' are commonly observed phenomena around the margins of the modern Greenland ice-cap.

More insights on K-T boundary extinction

The 'Great Chicxulub Debate' and its role in causing the extinction of dinosaurs 65 million years ago continues, and for those interested there is now a special website, www.geolsoc.org.uk/Chicxulub. The latest work, reviewed in *Geoscientist* (May, 2006, p.16), was carried out on spherules, or fragments of melted rock, ejected from the Yucatan Peninsula impact crater and it shows that the Chicxulub impactor struck the planet some time before dinosaur extinction. Thus the famous layer enriched in cosmically-sourced iridium – and the current marker for the K-T (Cretaceous/Tertiary) boundary – actually occurs above the spherule layer attributed to the Chicxulub strike. All of this points to a protracted, multicausal scenario of events, as noted in *Geobrowser* for 2004, with these themes emerging:

1. The Chicxulub impact was certainly catastrophic and can now be linked in time to the extinction of the ammonites, although this all happened 300,000 years before the dinosaurs died out.
2. As reviewed in *Geobrowser 2004*, the Chicxulub strike probably did not cause a significantly long 'impact winter', nor globally extensive wildfires (*Journal of the Geological Society*, 2005, p.591). It

could nevertheless have resulted in acid rains and high global sulphur dioxide contents, sufficient perhaps to seriously alter sea-water chemistry, thus affecting marine creatures such as ammonites.

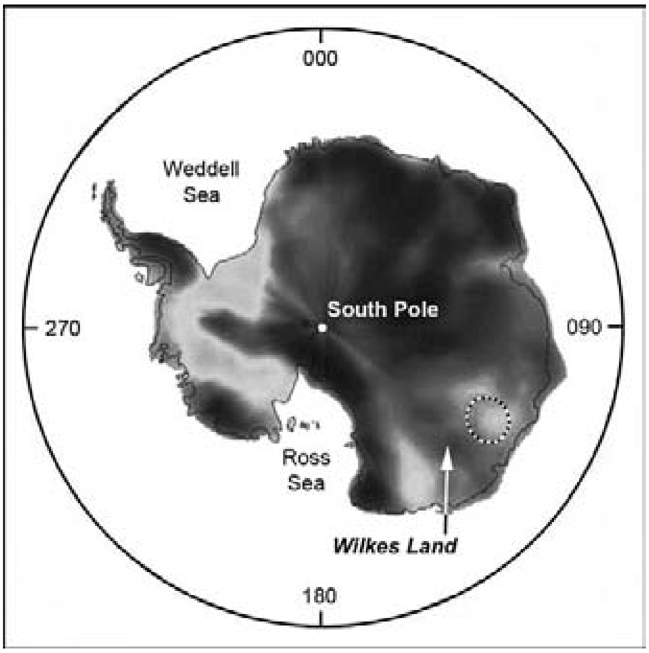
3. It now seems that the K-T boundary layer and the dinosaur death-beds probably do not reflect a single large impact, but point to a time when the Earth was passing through a layer of cosmic dust, laden with meteorites that broke up in the atmosphere and released iridium that was rained out and deposited in lakes and oceans. There is the intriguing possibility of other, as yet unknown, climatic consequences of this type of bombardment, which perhaps were exacerbated by the large amounts of carbon dioxide produced by the voluminous volcanic eruptions of that time (*Geobrowser*, 2001).

An even greater catastrophe

Theories implicating climatic factors, however caused, as the main trigger for mass extinctions have found support from a less well-known, but even more catastrophic episode than that defining the K-T boundary. About 250 million years ago, at the Permian-Triassic boundary, the biggest catastrophe to have affected the Earth killed off 96% of all marine creatures and 70% of land animals, possibly paving the way for the rise of the dinosaurs (*The Great Palaeozoic Crisis*; D H Erwin, Columbia University Press 1993). Up to now, little light has been thrown on the physical record of this event in terrestrial rock sequences, which are seldom greatly fossiliferous. However, these strata commonly contain fossil pollen, and a recent article in the *Journal of the Geological Society* (2005, p. 653) argues that pollen grains from two widely separated sequences straddling the Permian-Triassic boundary in China and Siberia show signs of stress. They exhibit significant defects, which could, it is argued, be attributable to the types of atmospheric pollution associated with acid rain and increased ultraviolet radiation. This in turn could be linked to voluminous basaltic eruptions that were occurring across Siberia and China at that time. The really big question, whether these effects were globally distributed, was not answered; however, a previous article (*Science, February 2005*), based on work done in the Karoo basin of South Africa, had presented evidence that the culprit for the end-Permian "Great Dying" was probably atmospheric warming due to greenhouse gas emissions from erupting volcanoes.

….And the world's largest impact?

The causes of the end-Permian disaster have been debated for some years, and as with the K-T boundary extinction a complex scenario of events has frequently been suggested - an unfortunate coincidence of several destructive factors such as volcanoes, climate change



Geophysical map of Antarctica showing crustal thickness based on gravity data, whereby dark equals thicker crust. The impact site in Wilkes Land shows as a pale area of thin crust, and the dotted circle traces the rim ridge mapped from radar profiles. (Image from Ohio State University)

caused by tectonic plate reorganizations and, perhaps inevitably, an asteroid impact. There has been little evidence for the extraterrestrial dimension to the problem, but this is set to change following the 'discovery' of a vast crater-like structure, possibly the 'scar' of a meteorite impact, concealed beneath the ice sheet in the Wilkes Land region of Antarctica (*New Scientist website*, 2006). This circular feature was revealed by a positive gravity anomaly on surveys by NASA satellites. It was then found to match a poorly defined circular ridge that could be seen on radar images of the rock surface beneath the ice. The feature is interpreted as a crater that overlies a post-impact upwelling of dense mantle material. It is estimated to be 500 km wide, and to have been caused by an impactor measuring 50 kilometres (30 miles) across, against which the Chicxulub body, with an estimated 9.5 km diameter, looks positively puny. So much for the hype, but there are still some serious points to be addressed: does the structure indeed have an impact origin or are other interpretations possible, and does the time of impact 'fit' that of the mass extinction? It seems unlikely that the researcher's wish to drill through the ice cap into this structure will readily be granted in such a region. Instead the evidence will probably have to come from studies of other less environmentally sensitive stratigraphical sections around the World. As some of these are already showing encouraging evidence for a discrete 'event layer', coinciding with the Permian-Triassic boundary extinction, we must expect many more articles, and much heated debate, in the forthcoming year.

Conservation of Nottingham's finest cave

The most spectacular of the many caves carved into the sandstone under Nottingham is Thomas Herbert's ornamental cave within The Park. Though rarely visited (as it lies beneath a private house) the life-size statues of "Daniel in the Lion's Den" are a treasured part of Nottingham's historical and geological heritage. They have however been suffering undue weathering, as their cave has open entrances in the hillside. Daily and seasonal changes in humidity and temperature break down the sandstone's weak clay cement, so that sand grains steadily fall away from the carved surfaces.

The features of the statues were slowly being lost, but the simple remedy was to build doors and shutters across the cave entrances, without damaging the rock structure. This was done, late in 2005, in a project funded entirely by the EMGS (appropriately enough, from income from sales of the Society's book, *Sandstone Caves of Nottingham*). This appears to have been very successful. Monitoring of the site is in progress, but preliminary results suggest that weathering of the cave walls has been reduced to less than 10% of its original decay rate; results will be reported in the next issue of *Mercian Geologist*.

Sandstone cave in Warwick

A cave carved into sandstone under Warwick is notably similar to the many that are well known under Nottingham. It was recently found beneath a public house, at the foot of a flight of stairs that reached deep enough to leave a solid rock roof over an almost traditional pub cellar, with barrel thralls along part of the walls. One section of roof is formed by masonry, but the rest is an almost flat surface cut in bedrock; masonry and brickwork of various structures and ages also form parts of the walls. The cave is cut into the Bromsgrove Sandstone Formation, slightly younger than the Nottingham Castle Sandstone, but also within the Sherwood Sandstone Group. It is a massive sandstone, buff and locally red in colour, with only widely spaced joints, and compares closely to the Nottingham rock as an ideal material for cave excavation.

Thank you to Patrick Mohan for this brief report.

Conservation of geological sites

The Department of the Environment, Food and Rural Affairs (Defra) has overall responsibility for the conservation of sites valuable to natural science and environmental diversity. It has now produced guidance to promote more transparent and consistent approaches in the operation of Local Sites systems across the country. This outlines the purposes of Local Sites systems, and proposes frameworks, standards and roles for their operation as well as for the selection, protection and management of the sites.

There are currently a number of different terms in use to describe sites of local importance, including Regionally Important Geological Sites (RIGS), and Defra recommends that the term Local Site should be used as a standard generic term, optionally distinguishing between Wildlife and Geological Sites.

Although no formal equivalent to Biodiversity Action Planning currently exists for geological sites, action for such sites is now being developed and promoted widely. Local Geodiversity Action Plans have been prepared in some areas, and these aim to set local objectives to deliver geological conservation that build on the nationally important Sites of Special Scientific Interest (SSSIs), the local RIGS and geology in the wider environment.

The Geological Conservation Review provides the documentation of the country's geological SSSIs. It has been developed for local application through the RIGS system, which also reflects the educational role of local geological sites. The Association of UKRIGS has produced a Field Record and Site Assessment form for recording site details for evaluation (available at www.ukrigs.org.uk).

Traditionally, partnerships supporting Local Sites systems have organised themselves in various ways. The new guidance draws together best practice from within existing systems. Its aim is to create a more consistent sense of the value and importance of Local Sites by securing broader awareness and support for their protection. The guidance is available on www.defra.gov.uk/wildlife-countryside/ewd/local-sites.pdf There are now more than 35,000 Local Sites in England, though geological sites are fewer than biological sites.

Geology Today

From its launch in 1985, *Geology Today* was intended to be the "popular" magazine for geologists both amateur and professional. Well illustrated and without heavy writing, it features up-to-date topics, explanatory series, overviews and locality reports. It was a great success for about 15 years, but then started to lose its edge. A new editor in 2003 generated its revival, and the magazine went into full colour printing at the start of 2006. It is now a really good geo-magazine. Published by Blackwells, along with their various academic journals, *Geology Today* does suffer from a rather high cover price. But starting in 2007, the subscription rate has been reduced for members of geological societies (including EMGS). Visit the website for subscriptions and for free downloads of various articles; "geology today" in Google (UK pages) is quicker than the cumbersome web address.

This may look a little like advertising, and the Editor of *Mercian Geologist* admits to being also on the Editorial Board of the magazine, but many members of EMGS could find the revamped *Geology Today* a very welcome resource of armchair geology.

VALE

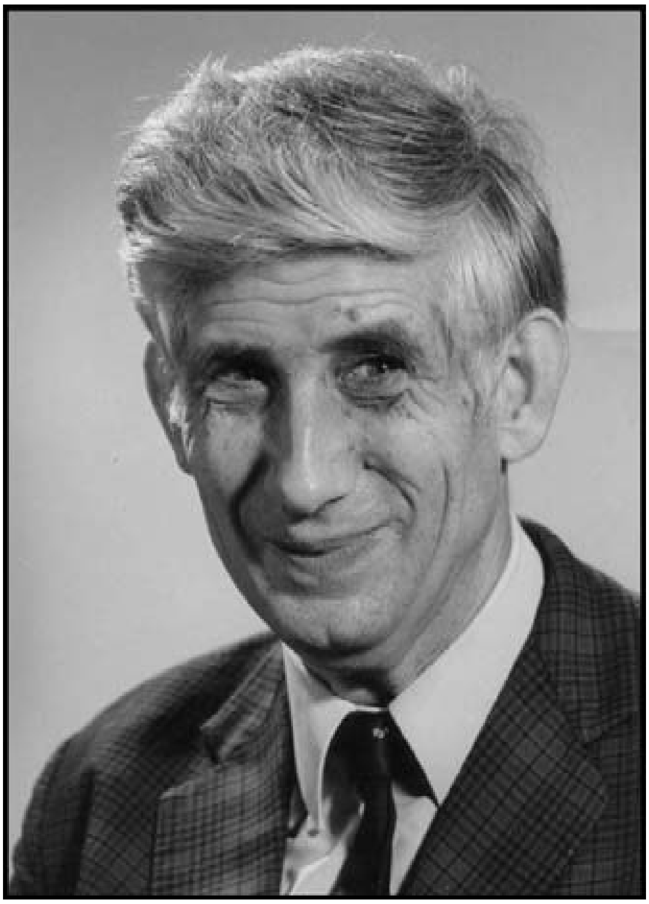
Ron Firman 1929-2005

Born in Norfolk as an only child, Ronald John Firman overcame the severe handicap of cerebral palsy, to lead a very full and fruitful life. His early years in rural Norfolk had a great influence, and he was never more at home than when he was in the field, for either his first love of geology or other aspects of natural history.

Between 1940 and 1947, he attended the City of Norwich School, which had a strong tradition in the teaching of geology. By the time Ron entered the sixth form he had already had a taste of the subject, which he then pursued with great and lasting enthusiasm. The degree to which Ron ignored his physical problems was reflected in him being made captain of the school hockey team, a status he later equalled at his college in Durham. At university in Durham, Ron continued his study of geology under the direction of such notables as Professor Lawrence Wager and Professor Sir Kingsley Dunham. It was Wager who expressed his doubt about Ron's ability to carry out geological fieldwork by leaving him out of a departmental field trip to the Lake District. Eric Robinson, one of Ron's contemporaries at Durham, reflects how Wager tended to favour the type of student who was a potential candidate for the 1953 Everest expedition or who could roll kayaks under the cliffs of the Skaergaard intrusion. Following an animated discussion, Ron was allowed to join the Lake District trip, and the obvious success of it was that he participated in all subsequent departmental trips. Eric and his contemporaries had great admiration for Ron who even in his student days had severe physical problems. During his time as a student he also made private trips to Skye, North Wales and the Malverns.

Kingsley Dunham was a major influence in Ron's developing interests. Following graduation, Ron embarked on a PhD research study on the "Metamorphism and metasomatism around the Shap and Eskdale granites". At this time he was particularly interested in the origin of granites, a topic that provoked considerable interest and controversy. Under the supervision of Frederick Stewart he completed his thesis in just over two years. Before his thesis was completed Ron led a number of field trips, including one for the Yorkshire Geological Society to the Lake District; this was attended by Prof W D Evans, who later appointed him to a lectureship at Nottingham.

Following award of his PhD in 1953, Ron became a research assistant to Professor Deer at Manchester University. Although his stay in Manchester was short, it was significant, as it was there that he met Pat, who he married in 1955 after he was appointed to a lectureship at Nottingham University. They had three children, Rosemary, Hugh and Alison. Ron and Pat had many interests in common, and in particular a love of the Lake District where Ron continued his research activities. It was in the Duddon Valley that Ian Sutton assisted in the mapping of joint patterns in the glorious summer of 1958 - with wonderful memories of Pat in harness, dragging the baby Hugh in a box with wheels over the rough fells, Rosemary with her face covered in bilberry stains - and Ron ceaselessly mapping joints.



Although Ron was very much a field geologist he excelled in academic work. He gave a course on metamorphism and metamorphic petrology to the final-year students in Nottingham. It reflected so much of Ron's attitude to the subject, and also the great care that he took in everything he did. The lectures were superbly prepared, very much up-to-date with many of the references to current publications. The students did not fail to recognise the high quality of Ron's presentations, and many owe a great deal to him. Ron genuinely cared for his students' needs, and Phil Doughty was just one of those for ever grateful because Ron took them on for research projects when few others showed much interest.

Ron also enjoyed his teaching to engineering students. For many years Ron paid a weekly visit to Sutton Bonnington, to deliver lectures on mineralogy and pedology. He caught the train at Beeston and took his bicycle with him; his students at Sutton Bonnington were in full admiration of Ron's cycle ride from Beeston - they were never disabused.

Ron's work was recognised nationally and internationally. He was a fellow of the Geological

Society and a member of the Institute of Mining and Metallurgy. His work in the Lake District earned him the award of the moiety of the Lyell Fund in 1964.

Ron also did extensive geological consultancy. He was in great demand in the location of hydrothermal mineral deposits in the Peak District, and became an authority on the gypsum deposits and alabaster of the East Midlands. Perhaps some of his most important consultancy work was for Manchester Corporation Waterworks in the Lake District, where he advised during the construction of the Wet Sleddale Dam near Shap; he was solely responsible for geological advice on renovation of tunnels leading from Thirlmere reservoir and on many other projects in the region.

Ron's well-merited promotion to senior lecturer at Nottingham was in 1968. By 1984, his worsening speech impediment had made lecturing into a less appropriate occupation, and he was awarded the post of Senior Research Fellow. On closure of the Geology Department in 1989, he retained that position in the Archaeology Department. Ron already had natural links with archaeology, particularly his interests in bricks and other building materials.

A most important aspect of Ron's interest in geology was his desire to bring the subject to the non-geological world. This he did by offering and teaching a number of adult education courses, and also by being a very strong supporter of the EMGS. He was a major contributor to the health of the Society, being a founder member, a member of Council and for a long period Editor of the Mercian Geologist. These were only some among many diverse activities within and outside the geological world.

Ron was fully involved with the Spastics Society (now Scope), and in 1962 he helped to found the '62 Club as a social club run entirely by people with cerebral palsy. He was successively the Chairman, Secretary and President of the Nottingham '62 Club, and from 1973 to 1979 was President of the National Association of '62 Clubs. He was also directly involved in the establishment of the Portland Club for the disabled, for which he was the first President and Chairman. Ron inaugurated the Nottingham University society for disabled adults.

In spite of all his physical problems Ron was very much a happy man – he enjoyed life and he had a very strong sense of humour. In a most delightful way the humour was that of a rascal, but he was also quite happy to be the butt of some of his humour. Some will recall his story of him going to a meeting straight from field work at Manchester Corporation offices to be told by the lift attendant that if he wanted the job he should dress more appropriately.

Ron was a man of great dignity, of compassion and was a colleague held in high esteem. Mercia has lost one of its specialist geologists and one who perhaps was not given enough credit during his life in geology.

Jens Esmark, Vassryggen and early glacial theory in Britain

Peter Worsley

Abstract. An end moraine (Vassryggen) and associated sandur, described by Jens Esmark as early as 1824, was the first pre-Neoglacial glacigenic landform association to be recognised as such. It forms the most important element of a range of evidence used by Esmark in support of his continental-scale glaciation hypothesis. The career of Esmark, who became a foundation professor of the Royal Frederick University in Christiania (Oslo) is outlined, and his influence on the development of the glacial theory in Britain is appraised, as is the role of his associate Robert Jameson in Edinburgh. A sketch of the glacial geology of the Forsand area of southwest Norway examines Vassryggen and its allied landforms in the context of deglaciation and sea-level change at the close of the Younger Dryas stadial.

In south west Norway, some 25 km ESE of Stavanger, a magnificent glacial end moraine marks the maximum extent of a now-vanished valley glacier. This cuts across and blocks the floor of a glacial trough eroded into Precambrian gneiss. Locally it is known as Vassryggen (the lake ridge) but internationally it is also known as the Esmark Moraine, named after Jens Esmark, who, in 1824, was the first geologist to describe and interpret it as an ice-marginal geomorphological feature (Fig. 1). The lake of Haukalivatn lies at the foot of the proximal slope, while on the distal side there is a sandur - a gently sloping outwash plain. (*Note:* -et *and* -en *are suffixes that mean the in Norwegian, and context determines whether they do or do not appear on the ends of place names.*) The feature dates from the final stadial (Younger Dryas) of the Last Glacial (Weichselian) stage. There are strong historical grounds for claiming that this landform couplet, many kilometres from the nearest modern glacier, was the first ever to be recognised as having a genetic relationship to a former active glacier margin (Fig. 2).

In 1824, Esmark promulgated the concept of an extensive glaciation of mainland Europe, citing a range of field evidence that he had observed whilst travelling in the Alps, Denmark, the north German Plain and Norway. Esmark's paper is now universally regarded as a classic of the glacial literature, but sadly is not as well known as it deserves to be. The objectives here are (a) to review the historical context of Esmark's pioneering glacial geological research, (b) to examine its impact on the application of the glacial theory in Britain and (c) to assess the end moraine in the context of the last deglaciation and the modern landscape.

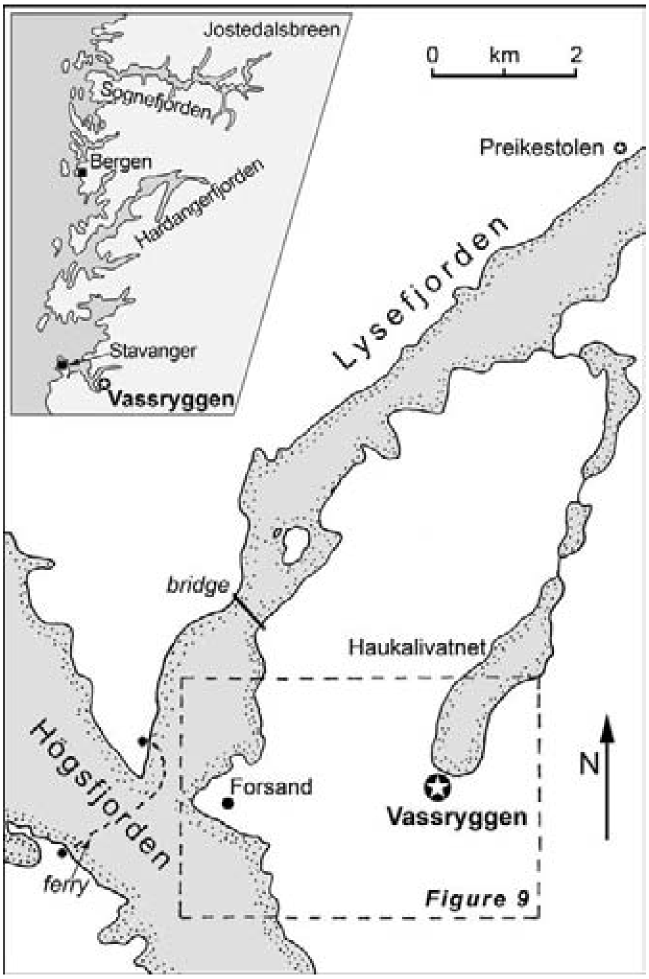


Figure 1. Location of Forsand and the Jøtunheimen area within south-west Norway.

Background

In the eighteenth century, during the Age of Enlightenment, many savants appreciated the ability of modern glaciers to transport sediment, and some realised that glacial debris found far beyond current glacier limits indicated that glaciers had once been more extensive than at present (Rudwick, 2005). As Charlesworth (1957: p623) was to observe, *The glacial theory, like many other scientific theories of note, occurred to several people at roughly the same time if not in quite identical form*. Among these was the alleged father of modern geology, James Hutton, who, in his classic treatise of 1795, suggested that Alpine glaciers had been considerably more extensive (to account for the granite erratics scattered over the limestone Juras), but omitted to apply this concept to Britain (Davies, 1968). Although Menzies (2002) claims that Hutton's promoter, John Playfair (1802), in his *Illustrations of the Huttonian Theory of the Earth*, proposed that Scotland had been glaciated, this is not the case. Interestingly, Sissons (1967: p29), in his splendid book on the evolution of Scotland's scenery, attributes to Esmark the role of catalyst in the recognition of Scottish glaciation, although Price (1983), in his detailed review of the last 30,000 years in Scotland, makes no mention of him.

From a specifically British perspective, the key event in the acceptance of the idea of glaciation in these islands was undoubtedly Louis Agassiz's journey through Britain and Ireland in 1840. Six years earlier, Agassiz had made the first of his several visits to Britain while researching his initial specialism, the study of fossil fish. During his stay he was chaperoned by William Buckland, then Reader in Geology and Mineralogy at the University of Oxford. Four years later, Buckland, accompanied by his wife, made a reciprocal visit to Agassiz in his home country of Switzerland. By that time Agassiz was devoting all of his spare time to developing a glacial theory in the context of the Alps. It is therefore not surprising that he demonstrated to Buckland the field evidence on which his crystallising glacial theory depended.

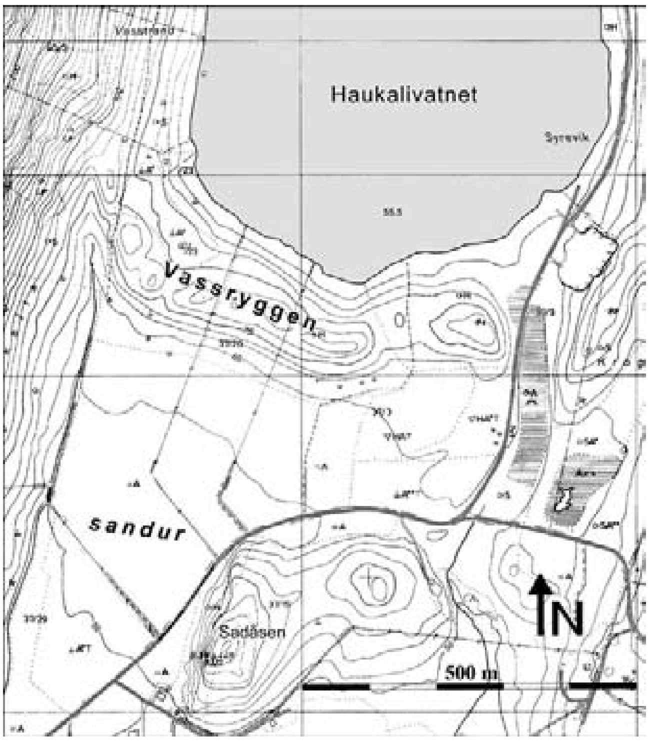


***Figure 2**. Map showing the morphology of the Vassryggen end moraine (the Esmark Moraine). Contour interval: 5m.*

Apparently Buckland expressed support for his interpretation, but also went on to describe to Agassiz some British geomorphological features that he believed were analogous to the glacial landforms they were examining in Switzerland. They resolved that they would jointly investigate this topic further when Agassiz next visited Britain (Agassiz, 1876).

In his presidential address to the Geological Society of London on 21st February 1840, Buckland (1840: p261) commented on Esmark's 1824 paper as follows - *the most important portion of this paper …. show(s) that the greater part of Norway has, at some period, been covered with ice, and that the granite blocks, so abundant in that country, have been brought to their present place by glaciers.* Just over half a year later, at the annual meeting of the British Association for the Advancement of Science, which fortuitously was held in Glasgow in the midst of a drumlin field, Agassiz presented his hypothesis that the landscapes of Britain and Ireland bore the imprint of past glacial processes (Agassiz, 1840-1). During a joint field excursion immediately after the Glasgow meeting, Buckland declared that he had been fully won over by Agassiz's reasoning (Boylan, 1998). This led to a major paradigm shift, for, as the palaeontologist Edward Forbes commented in a letter of 1841 to Louis Agassiz, *you have made all the geologists glacier-mad here, and they are turning Great Britain into an ice-house* (Agassiz, 1885). For instance, on October 16th 1841, Buckland was to write the following note in the visitor's book at the Goat Hotel, Beddgelert, in Gwynedd, north Wales - *Notice to geologists – At Pont-aber-glass-llyn, 100 yards below the bridge ... see a good example of the furrows, flutings, and striae on rounded and polished surfaces of the rock, which Agassiz refers to the action of glaciers. See many similar effects on the left, or south-west, side of the pass of Llanberis.* (Davies, 1969: p263). This entry was subsequently framed and displayed at the hotel, but, following a change in ownership, its present whereabouts is unknown. Nevertheless, despite the glacial euphoria, the general acceptance of the glacial land ice theory was to be delayed by several decades until officers of the British Geological Survey commenced serious mapping of superficial sediments and landforms.

Jens Esmark (1763-1839)

Summaries of Esmark's life have been compiled by Buckland (1840), Rózsa *et al* (2003), Rørdam (1890), Schetelig (1926), Kettner (1964) and S.A. Andersen (1980). He was born in the hamlet of Houlbjerg (Hovlbjaerg), some 30 km west of Aarhus in Denmark, the son of the local parson. Perhaps fittingly, Houlbjerg is situated in the middle of the Danish 'Younger Morainic' landscape produced by the Last Glaciation in eastern Jutland, and lies just south of a major incised sub-glacial meltwater tunnel valley. After attending the local high school in the town of

Randers, his senior studies were undertaken at the university in Copenhagen, and these included natural history, theology and medicine. For a short period, Esmark was employed at a hospital, but soon he embarked upon an in-depth training in mineralogy and geology. This involved him attending the mining school at Kongsberg (founded in 1757) in southern Norway, close to the important silver-mining area. At that time Norway was a province of Denmark. He then returned to Copenhagen University as a student in law and geometry, after which he was awarded a six-year travelling scholarship.

During 1791 and 1792 he attended the famous Bergakademie in Freiberg, Saxony, close to the Erzgebirge Mountains, where his contemporaries included Leopold von Buch and Alexander Humboldt. This academy was directed by the inspirational Saxon geologist Abraham Gottlob Werner, and not surprisingly, during his stay there he acquired the strong Wernerian (Neptunian) sympathies which he maintained for the rest of his life. Essentially, the Neptunist view was that all rocks had been precipitated from a primordial ocean. At that time a furious debate was in progress over the origin of rocks, with the main alternative being Hutton's ideas of Vulcanism which involved the internal heat of the Earth. Esmark then moved to the German mining centre of Schemnitz (Hungarian Selmec, and now Banska Stiavnica in Slovakia) for training in mineral analysis, and in 1794 toured Hungary, western Romania and southern Poland visiting mines, before spending some months in Chemnitz (Rózsa *et al* 2003). On his return to Freiberg he published an account of his journey with the title 'Short description of a mineralogical tour through Hungary, Transylvania and the Banat' (Esmark 1798, 1799). This work established him as a geologist and mineralogist of European repute (Fig. 3).

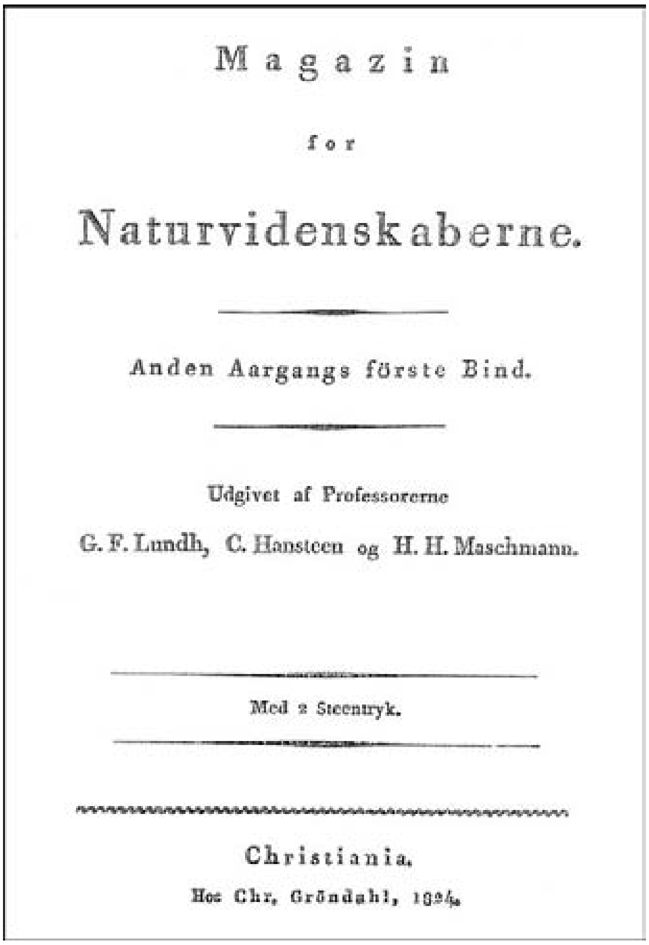
Late in 1797, Esmark settled permanently in Norway, first returning to the Kongsberg Mining School as a chief mining inspector and later (1802) as a lecturer and supervisor in mineralogy, chemistry and physics. While working at Kongsberg he travelled extensively in southern Norway and indulged in mountaineering; he made the first ascent of Snøhetta on Dovrefjell in 1798. This activity brought him face-to-face with modern glaciers and their immediate environs, an experience which was to manifest itself later in his benchmark paper of 1824. In Kongsberg, in the same year, he married Vibeke Thrane Brünnich, who hailed from Copenhagen. They had two sons, H. Morten Esmark, later a vicar and well-known mineralogist, and Lauritz M. Esmark who became Professor of Zoology at the University in Christiania.

Following pressure from the *Selskabet for Norges Vel* (Society for the good of Norway) in 1811, the Danish king agreed to support the foundation of a new Kongelige Frederiks Universitet (The Royal Frederick University). Originally, the intention was to locate the

Figure 3. *Portrait of Jens Esmark (from Schiffuer, 1935: p19)*

new institution in Kongsberg, but soon this was changed in favour of Christiania. From the beginning (1813), it was planned that the new university would include applied subjects within its curriculum, and to support this objective, the mining school was transferred from Kongsberg (Popperwell, 1972). So, when in 1814 a Chair of Bergverkvitenskap (Mining Science) was created in the new Faculty of Philosophy, Esmark was elected to occupy it. Despite the inclusion of sciences, Latin remained the official language of the university until 1845 (it was renamed University of Oslo as late as 1939).

Internationally, 1814 was a critical and politically complex year in the aftermath of the Napoleonic wars in Europe. At the Treaty of Kiel, Denmark, as an ally of France, was obliged to cede its province of Norway to Sweden, following 400 years of sovereignty (ironically, the former Norwegian territories of Færoe Islands, Greenland and Iceland were overlooked, and these remained as part of Denmark). Latent Norwegian nationalism was triggered by this change, and as a consequence a new constitution was declared at Eidsvoll, and a parliament (known as the Storting) established. Effectively Norway was an independent nation for a few months, until the will of the victorious powers was able to assert itself. Following union, the Swedish crown showed sensible pragmatism and permitted effective Norwegian home rule, and then in return, the Storting voted in favour of a combined


Magazin

for

Naturvidenskaberne.

Anden Aargangs förste Bind.

Udgivet af Professorerne

G. F. Lundh, C. Hansteen og H. H. Maschmann.

Med 2 Steentryk.

Christiania.

Hos Chr. Gröndahl, 1824.

Figure 4*. Title page of the second year issue of the Magazin for Naturvidenskarberne (1824).*

kingdom. Ironically, the national language remained Danish and it could be argued that technically Esmark became a Swedish citizen (Norwegian misgivings being acknowledged!).

Esmark remained in this post at the university until he died early in 1839 after an illness which had lasted several years. From 1816 to 1838 he was responsible for maintaining a series of meteorological observations which are the oldest pertaining to the capital (Christiania became Kristiania in 1897, and finally Oslo in 1925). He also published a book (in Danish and German editions) concerning a geological circular journey in 1827 (anticlockwise) from the capital up to central Norway and into Værdal, during which he paid special attention to establishing the heights and plotting a relief profile (Esmark, 1829a, 1829b). According to William Buckland, he was an excellent chess player.

Esmark was probably one of the founding foreign members of the Wernerian Natural History Society in Edinburgh (he was a member at least by 1811). This link was to become significant for British glacial geological history. In the summer of 1815, he made a scientific study visit to England, and read a short mineralogical paper before the Geological Society of London on June 18th, (Esmark, 1816). He was elected as only the third Foreign Member of the society. A good indication of his international eminence at that time can be gauged from the fact that in the society's list of foreign members he was senior to such distinguished geologists as Georges Cuvier, his mentor Abraham Werner, and Alexander von Humboldt.

Esmark's classic paper of 1824

It should first be emphasised that this paper by Esmark dates from well *before* Agassiz became involved with modern and ancient glaciation in his native Switzerland, and sixteen years prior to his pivotal visit to Britain. The paper appeared in the Christiania-published journal *Magazin for Naturvidenskaberne*, then in its second year (Fig. 4). This new journal's content resembled the Memoirs of the Wernerian Natural History Society, and the issue containing Esmark's paper included another (in Danish) by the English seafarer Captain Scoresby on the rediscovery of parts of eastern Greenland, and a report on an English scientific expedition to the polar seas. The only extant copies in Britain are at the British Library and in the library of the Royal Society of London.

Esmark's paper (also written in Danish) is not wholly devoted to his glacial hypothesis, and the first half concerns a discourse on the formation of the Earth with Wernerian undertones (Fig. 5). It is in the second part where he argues that his adopted country, Norway, had once been covered by *immense masses of ice* which reached *down to sea level*.

The evidence from the Norwegian landscape, which he considered gave support to his glacial hypothesis, included:-

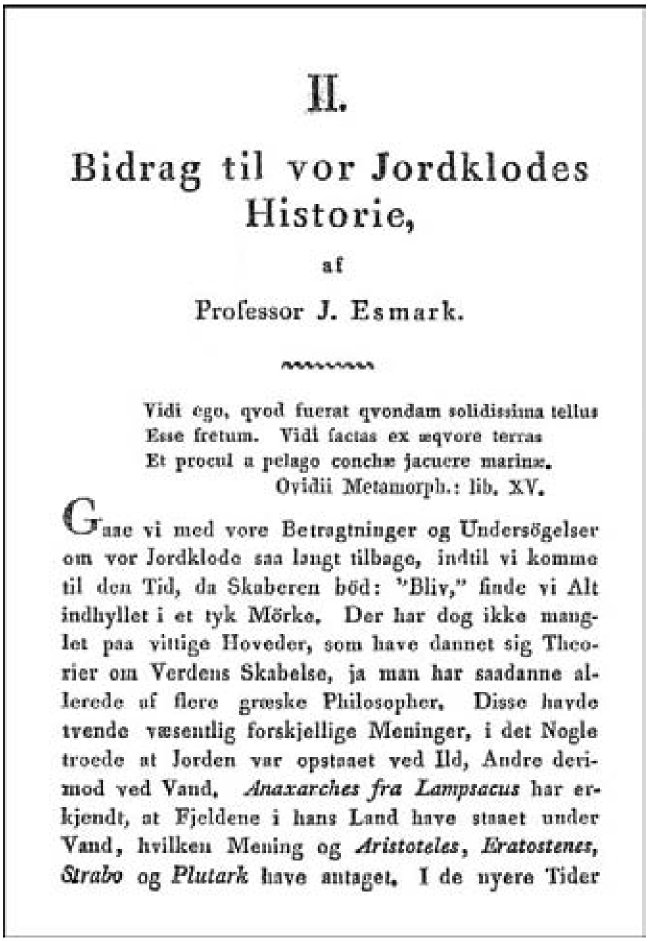
(a) Scattered boulder-sized blocks, often of a different composition to the rock beneath, some even occurring on mountain summits.

(b) A widespread sediment cover consisting of poorly-sorted admixture of large-sized material in a finer matrix, which was inconsistent with attribution to fluvial action, i.e. boulder clay or till.

(c) Steep-sided flat bottomed valleys (U-shaped cross profiles). He wrote - *Ice or glaciers, by their immense expanding powers must beyond doubt have produced this change in their original form from this circumstance, that they were continually sliding downwards from the higher mountains to the lower districts and by progressive motion carried with them the masses of stone which they had torn from the mountains.*

(d) Fluted, smoothed and scoured bedrock surfaces, including conglomerates which appeared to have been *cut across by a sharp knife.*

(e) A ridge (Vassryggen), which completely crosses a U-shaped valley from one side to the other. Here he made his most dramatic landform insight since he interpreted this as an end moraine produced by a



II.

Bidrag til vor Jordklodes Historie,

af

Professor J. Esmark.

Vidi ego, qvod fuerat qvondam solidissima tellus
Esse fretum. Vidi factas ex æqvore terras
Et procul a pelago conchæ jacuere marinæ.
Ovidii Metamorph.: lib. XV.

Gaae vi med vore Betragtninger og Undersögelser om vor Jordklode saa langt tilbage, indtil vi komme til den Tid, da Skaberen böd: "Bliv," finde vi Alt indhyllet i et tyk Mörke. Der har dog ikke manglet paa vittige Hoveder, som have dannet sig Theorier om Verdens Skabelse, ja man har saadanne allerede af flere græske Philosopher. Disse havde trende væsentlig forskjellige Meninger, i det Nogle troede at Jorden var opstaaet ved Ild, Andre derimod ved Vand. *Anaxarches fra Lampsacus* har erkjendt, at Fjeldene i hans Land have staaet under Vand, hvilken Mening og *Aristoteles*, *Eratostenes*, *Strabo* og *Plutark* have antaget. I de nyere Tider

***Figure 5**. First page of Esmark's paper in the Magazine for Naturvidenskarberne 1824.*

glacier which had subsequently vanished. In the original he referred to this as a *gletcher vold* (glacial rampart) and regarded it as *his strongest proof* that glaciers had been much more extensive in the past.

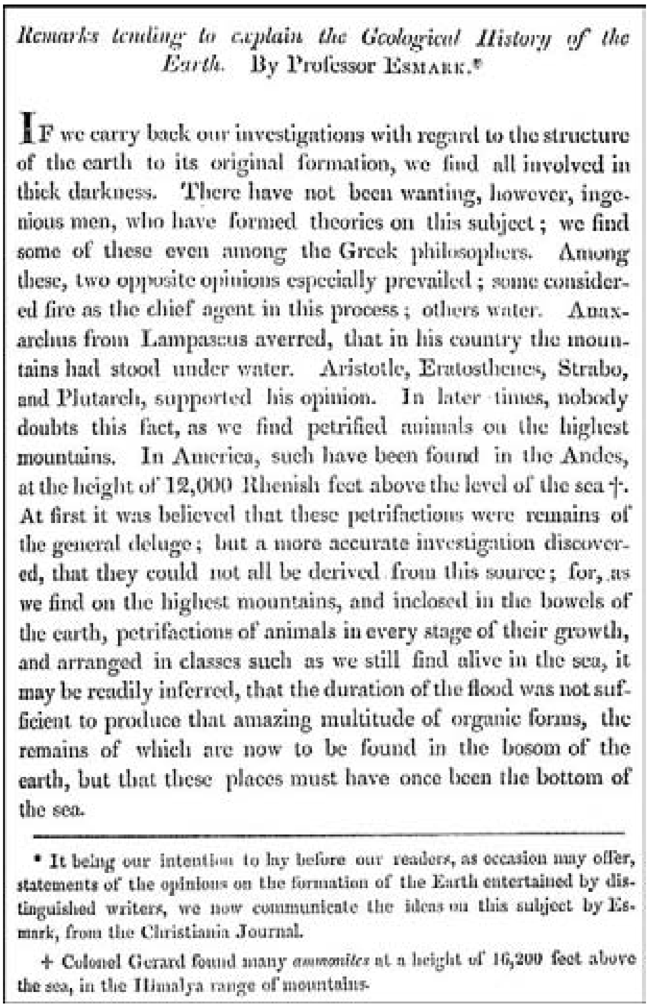
(f) A plain distal to the ridge (i.e. an outwash plain or sandur).

But he was not quite finished. Next he utilised current geomorphological and sedimentological methodologies to infer the nature of former geological processes by making comparisons with modern depositional environments, the so-called actualistic approach. Esmark clearly realised that the depositional environments of modern Norwegian glaciers displayed striking parallels with the much older landform assemblage that he had identified near Stavanger. He drew independent support from Mr O. Tank, a young mineralogist who accompanied him during the examination of Vassryggen and later the modern ice margins between Londfjord and Lomb. He reported that when Tank encountered the modern glacier environments for the first time he did not require any prompting before immediately making a genetic connection between the two. Sadly, progress in British glacial geology during the first half of the twentieth century was often retarded by an absence of such an actualistic approach.

Esmark's paper in English translation

Remarkably, within two years, a complete English translation of Esmark's paper was published in Edinburgh (Esmark, 1826) (Fig. 6). However, the unidentified translator indulged in some fanciful language such that the original title *Bidrag til vor jordklodes historie,* that translates as *Contribution to the history of our Earth,* became *Remarks tending to explain the geological history of the Earth.*

The rationale of undertaking the translation is of special relevance to the historical development of the glacial theory in Britain. It arose through the initiative of Robert Jameson (1774-1854), who occupied the chair of Regius Professor of Natural History in the University of Edinburgh from 1804 to 1854 (Fig. 7). Jameson, like Esmark, had attended classes given by Abraham Werner at the Freiberg Mining Academy. In his case it was from 1800 only to 1802, when the death of his father forced his return to Scotland. During his time at Freiberg he was converted *into Neptunism's most devoted and ardent disciple* (Davis, 1969: p147). On March 3rd 1808 he formed the Wernerian Natural History Society of Edinburgh, just two months after



Remarks tending to explain the Geological History of the Earth. By Professor ESMARK.*

IF we carry back our investigations with regard to the structure of the earth to its original formation, we find all involved in thick darkness. There have not been wanting, however, ingenious men, who have formed theories on this subject; we find some of these even among the Greek philosophers. Among these, two opposite opinions especially prevailed; some considered fire as the chief agent in this process; others water. Anaxarchus from Lampascus averred, that in his country the mountains had stood under water. Aristotle, Eratosthenes, Strabo, and Plutarch, supported his opinion. In later times, nobody doubts this fact, as we find petrified animals on the highest mountains. In America, such have been found in the Andes, at the height of 12,000 Rhenish feet above the level of the sea †. At first it was believed that these petrifactions were remains of the general deluge; but a more accurate investigation discovered, that they could not all be derived from this source; for, as we find on the highest mountains, and inclosed in the bowels of the earth, petrifactions of animals in every stage of their growth, and arranged in classes such as we still find alive in the sea, it may be readily inferred, that the duration of the flood was not sufficient to produce that amazing multitude of organic forms, the remains of which are now to be found in the bosom of the earth, but that these places must have once been the bottom of the sea.

* It being our intention to lay before our readers, as occasion may offer, statements of the opinions on the formation of the Earth entertained by distinguished writers, we now communicate the ideas on this subject by Esmark, from the Christiania Journal.

† Colonel Gerard found many *ammonites* at a height of 16,200 feet above the sea, in the Himalya range of mountains.

***Figure 6**. First page of Esmark's translated paper in the Edinburgh New Philosophical Journal in 1826.*

the founding of the Geological Society of London, and thereafter was re-elected annually as president for the rest of his life! Geikie (1909: p5) described Edinburgh as *the headquarters of the Neptunists in this country with a policy of active propaganda of Wernerian doctrines.* Esmark, as we have seen, was an early member of the Society, and this almost certainly arose through his friendship with Jameson and their shared Neptunist views derived from their common Freiburg heritage. The oral proceedings of the Wernerian Natural History Society are recorded as an appendix (History of the Society) in the last pages of each memoir. These reveal that during the February and March meetings of 1826, Jameson had read out instalments of Esmark's paper. It is reasonable to assume that the second instalment, presented during the March 11th session, featured Esmark's glacial geological hypothesis. Unfortunately, there is no report of Jameson's personal views at that time, although it is highly likely that he favoured the hypothesis, since otherwise he would have been unlikely to promote its reading.

From 1819 to 1824, Jameson was the founder, and initially co-editor with David Brewster, of the *The Edinburgh Philosophical Journal*. Following a disagreement with Brewster, he started, as sole editor, *The **New** Edinburgh Philosophical Journal*, a post which he held for the following 30 years, with a specific policy of *exhibiting a view of the progressive improvements and discoveries in the sciences and the arts*. This publication is frequently referred to as *Jameson's Journal* such was his domination of it.

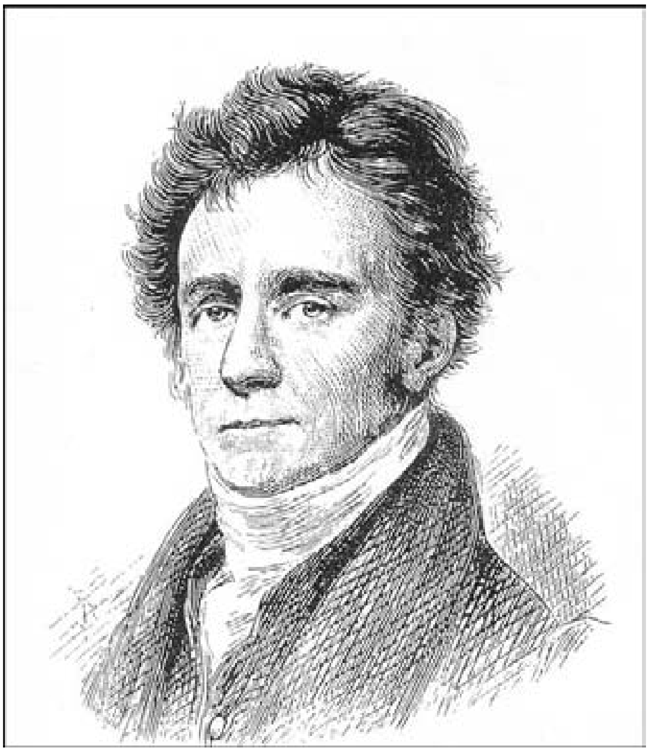


***Figure** 7. Portrait of Robert Jameson (from a miniature).*

Jameson regarded himself as *conductor* rather than editor of the journal, and during his tenure he published a wide range of manuscripts. Some of these related to cold environments; in the quarterly issue (October-December 1826) which contained Esmark's paper, there was one on Arctic seas and allied ice. He developed a policy of using his journal to keep British geologists abreast of scientific developments by instigating a *Scientific Intelligence* section that consisted of summaries of new findings.

Jameson's role in the concept of Scottish glaciation

Gordon Herries Davies has chronicled how Jameson was probably the first person to publicly declare that glacial processes had contributed to the character of the British landscape (Davies, 1969). As a student at Edinburgh University, the celebrated Scottish glaciologist J. D. Forbes (1809-1868), attended a natural history course given by Jameson in 1827-28. This had a syllabus covering zoology, botany, palaeontology, geology, mineralogy, the philosophy of zoology and practical work both in the museum and the field. Lectures were given five days a week for a period of five months and the emphasis was on mineralogy and geology. Secord (1991) describes the course as *one of the leading natural history courses in the world*. Crucially, Forbes's lecture notes from Jameson's lecture 12 on 27th November 1827 survive, and these state - *Moraine is the name for stones, fragments and deposits by the motion of the glacier on its borders which have accumulated in great masses. In Norway and in Scotland such appearances are observed which are considered proofs of formerly existent glaciers* (Cunningham, 1990: p15).

In the previous session, 1826-27, among the over 200 attendees taking this course was a seventeen year old second-year undergraduate called Charles Darwin, who attended as an extracurricular activity. He records that Jameson came across as an *old brown dry stick* and further added with respect to the lectures (probably at a particularly cynical moment) *The sole effect they produced on me was the determination never as long as I lived to read a book on geology, or in way any to study the science* (Barlow, 1958: p52-3; Browne, 1995). Nevertheless, despite his unflattering impression of Jameson, Darwin assiduously attended the course and thereby gained a thorough grounding in the basics of geology. He personally owned the course text-book which, unsurprisingly, was Jameson's latest book (Jameson, 1821), and his copy survives in the Darwin archive of Cambridge University Library. The many hand-written annotations it contains reveal that he must have studied it carefully (Herbert, 2005). Jameson in 1826 was undoubtedly fired by the implications of Esmark's glacial theory, and his teaching of the elements of glacial geology and their significance with respect to Scotland reflected this. It is very plausible that Darwin witnessed Jameson's first glacial exposition, but apparently its implications did not register with him at the time, and it was not until

1842 that he adopted much of the newly defined glacial theory.

Four years after leaving Edinburgh, in 1831, Darwin spent at least a week in North Wales with Adam Sedgwick, in order to become better acquainted in field geology. This venture had been arranged by his Cambridge tutor J. S. Henslow who, although a Professor of Botany, was originally a Professor of Mineralogy at Cambridge. Years later Darwin recalled that they totally missed seeing the abundant evidence of glaciation - *on this tour I had a striking instance how easy it is to overlook phenomena, however conspicuous, before they have been observed by anyone .... neither of us saw a trace of the wonderful glacial phenomena all around us, we did not notice the plainly scored rocks, the perched boulders, the lateral and terminal moraines.*

Another astonishing paper included in the first part of Jameson's journal in 1827 was by G Bohr (1773-1832) a teacher from Bergen. It is unknown whether this had been specially translated into English but was almost certainly derived from Bohr (1820). It records actualistic observations made on a journey to Jostedalen, on the eastern side of the Josterdalsbreen ice cap (the largest in Europe) in southern Norway. Among others, the now well-known glaciers of Berset, Nigaard and Lodal are described. It is very clear from the narrative that Bohr appreciated that these glaciers were subject to size variations and referred to the *encroachments of the glaciers and of the mischief occasioned by them* (Bohr, 1827: p257). Further, he notes that a peasant called Claus Elvekragen had earlier recalled seeing the roof of a house buried in a moraine. From today's perspective, this observation suggests that, during the culmination of the Late Neoglacial Little Ice Age around 1750AD, an advancing glacier must have almost completely enveloped a building. The term *moraine* is noted as being a Swiss word for *masses of gravel, and sand and stone*. Bohr notes Esmark's work on establishing the heights of various Norwegian summits, and it is clear that he must have visited Jostedal and was familiar with its glaciers.

The delayed impact of Esmark's hypothesis

Despite the availability of an English translation of Esmark's paper, and an extended French summary (Esmark, 1827), it appears to have had little impact on the British geological community. The reasons behind the delayed acceptance of the glacial theory have attracted the attention of science historians. Rudwick (1969), in a review arising from the publication of an English translation of Agassiz's *Studies on Glaciers* monograph of 1840, points out that the diluvial theory, which invoked a universal deluge linked to the Mosaic testimony, was very persuasive. He argued that this was especially so when viewed in the context of a clearly anomalous recent Earth history. Support was strengthened by an awareness of the tsunami generated by the 1755 Lisbon earthquake and its coastal impact. Further, there was considerable conceptual difficulty in reconciling the huge areas of northern and central Europe (hypothetically affected by glaciation) with the comparatively limited areas occupied by modern glaciers. Even Professor B. M. Keilhau (1797-1858), a younger geological colleague of Esmark at the University of Christiania, advocated the flood hypothesis until 1840, even though he had experience of the Jotunheimen glaciated region, north Norway and Svalbard (Keilhau, 1831; Andersen, 2000). Keilhau joined the Wernerian Natural History Society in 1836, and became the seventh member from Norway. In opposing such deeply embedded conventional wisdom, Esmark's perception is truly remarkable. Although Rudwick cites Esmark's paper, he did not convey the full nature of its content, and in particular made no mention of what Esmark regarded as the strongest proof - the end moraine of Vassryggen.

Unfortunately, Esmark's paper has on occasion escaped the attention of some major historians of glacial geology and glaciology. Inexplicably, Esmark is not mentioned at all in the authoritative two-part Norwegian tome on glacial matters published by the Norwegian Polar Institute (Hoel & Werenskiold, 1962; and Hoel & Norvik, 1962). James Geikie, who was long associated with Edinburgh and glacial geology, appears never to have discussed or cited it in his voluminous writings. Yet he was a friend of Helland, who was the first Norwegian geologist to investigate and publish on Vassryggen after Esmark (Helland, 1875), and cites this latter paper in his book *Prehistoric Europe* (Geikie, 1881). Even more surprisingly, North (1943) is silent in his very detailed review of the glacial theory marking the centenary of Agassiz's 1840 visit to Britain, despite the paper's subtitle *notes on manuscripts and publications relating to its origin, development and its introduction into Britain*. Chorley *et al*. (1964), in the first volume of their masterful history of global geomorphology, appear to be unaware of the contents of Esmark's paper, and make no specific reference to him in their chapter reviewing the development of the glacial theory. Yet, in their informative index, there is an entry for *Esmarch* (Esmarck). This simply records that this worker is noted to have expressed the view that the Norwegian glaciers were once much more extensive. Paradoxically, in their main text they include a quotation from Sir Roderick Murchison's paper of 1835-1836. This reveals that even though Murchison remained unconvinced, he was clearly aware of 'Esmarck's' interpretations and attendant implications (p205). Probably this citation accounts for the index entry. Hansen (1970) focussed on the role of Agassiz and Lyell, apparently unaware of the existence of Esmark's paper and the activities of Jameson. Bill Sarjeant (1980: v2, p968-9), in his massive multi-volume history, has a brief entry on 'Esmarch' as a mineralogist, but sadly omits any mention of his landmark glacial paper.

The reawakening

Following the founding of the British Glaciological Society in 1946, the *Journal of Glaciology* was launched, and it soon commenced a series of articles on the theme of *Early discoverers.* The fourth of these, *Esmark on glaciation*, was communicated by Kaare Strøm, the distinguished Norwegian Professor of Geography and Limnology in the University of Oslo. This paper consisted of an extract from the Esmark translation of 1826 of that part relating to the glaciation of Norway. Apart from tinkering with the spelling of some geographical names, he somewhat disappointingly makes virtually no comment on the significance of the text (Strøm, 1950). Changing geographical names remains a continuing problem in Norway, in part because of the existence of two official languages, Riksmål and Nynorsk, with their range of dialects and spelling reforms.

Finally *Boreas*, which is an international Quaternary research journal, later initiated a series called *Boreas Pioneers* with a similar objective to the Early discoverers just mentioned. From a Norwegian standpoint, Bjørn Andersen (1992) contributed a comprehensive analysis and review of the significance of Esmark's paper. Both Andersen and Borns (1994) in their attractive textbook and Andersen (2000) in his popular book on *The Ice Age in Norway* briefly cover the work of Esmark, and Vassryggen in particular. Unfortunately, as of 2005, this latter book was not available in any British library.

The glacial geology of the Forsand area

Vassryggen end moraine lies in Forsand Kommune (district). In the earlier literature Forsand is spelt Fossand. Forsand is an extended village stretching from the coast inland along the featureless valley floor towards the end moraine. It lies at the eastern margin of the mouth of Lysefjorden, a magnificent classic glacial trough flooded by the sea (Ahlmann, 1919; Andersen, 2000). At one very accessible overlook called Preikestolen (the priest's pulpit), the fjord wall drops vertically for 600m (Fig. 8). The bathymetry of the fjord was investigated by Kaare Strøm, who established that the maximum water depth is 457m (Strøm, 1936). Towards the lower end of the main Lysefjord trough, at a low elevation on the east shore, a narrow valley diverges to run roughly parallel with the master feature. Southwards this widens into a valley occupied by the lake known as Haukalivatnet. The north slope of the Vassryggen end moraine forms the southern shore of this lake, which now drains out to the north, against the direction of former ice flow.

Following Esmark, four Norwegian geologists have contributed to a growing understanding of the area's glacial history. First, Helland (1875) discussed the genesis of moraines and terraces bordering the lower ends of lakes, since landform associations of this character are widespread in southern Norway. He highlighted Esmark's description and added that the moraine crest is 35m above the lake. He inferred a local relative sea level some 35m above that of the present at the time of formation.

Second, Reusch (1901), with the aid of a sketch map, briefly commented on the occurrence of the sandars extending between Vassryggen and the eastern segment of the Lysefjorden end moraine at Forsand (Fossan) and appreciated that they were contemporary.

Third, Hansen (1913) in a long paper on the theme of the Ice Age in the Sørlandet region, recognised that an end moraine and raised shoreline system that had been named Ra (ra is an old Norwegian term for ridge) was extensive; he incorporated the observations of Esmark, Helland and Reusch in his discussion.

Finally, Andersen (1954), on the basis of geomorphological mapping of ice-marginal morainic features, was able to accurately reconstruct the dimensions of the last (Younger Dryas) Lysefjord glacier. He demonstrated that it was an outlet glacier extending from an inland ice source for about 30 km to the sea, with a maximum ice thickness of 1300m and a surface slope towards its terminus of 75 m/km. Inland, the gradient was reduced to 20 m/km. At the mouth of Lysefjorden, beyond the confining valley walls, the glacier terminus was seen to have expanded to form a lobate foot extending into Høgsfjorden. Today, the main frontal end moraine remains submerged below sea level at a depth between 10 and 15 m, but its lateral margins are emergent as two separate arcuate ridges on each side of the fjord mouth.

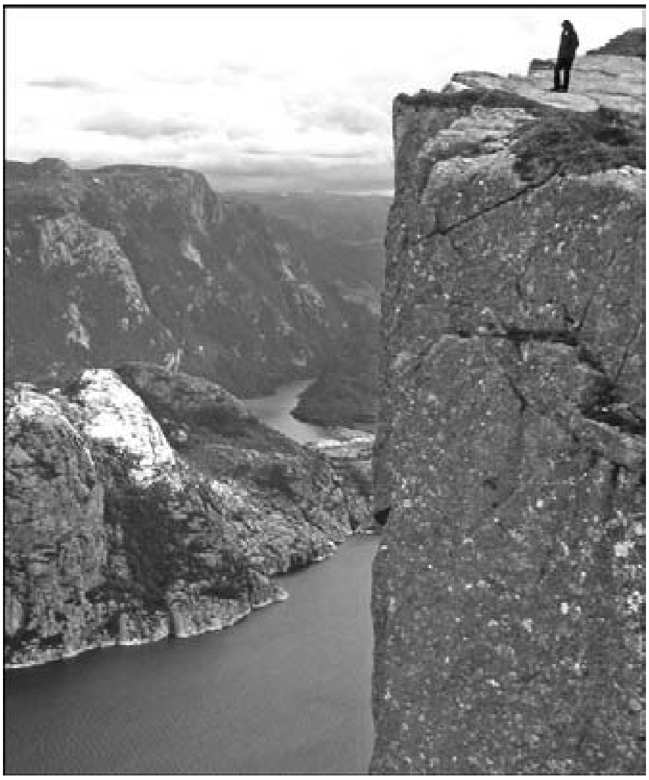


***Figure 8**. The view south past Preiteskolen, the rock ledge 600m above Lysefjorden, with the first lake just visible in the glaciated trough that continues to Haukalivatn.*

Andersen's model shows how a distributary of the Lysefjord glacier entered the sub-trough now occupied by Haukalivatnet lying at 53-54m above sea level, to form Vassryggen at its southern terminus. Unlike the main trunk glacier, this branch ended above the contemporary sea level, and rather than forming a calving ice margin, it produced a typical sub-aerial end moraine with a sandur extending from the glacier margin towards the sea which at that time was some 40m above that of present. Although partially covered in forest today, the Vassryggen ridge is about 800m long forming a prominent arcuate landform rising to 20-30m above its surroundings (Fig. 9). The proximal slope is steep and descends below the lake level to a maximum depth of 30m. In contrast, the distal slope is shallower and abruptly terminates at the head of the southward-sloping palaeosandur surface known locally as Fossanmoen (Fig. 10). The sandur splits around the till-plastered bedrock hill of Sadåsen (Figs. 2 and 9).

In composition, the moraine surface is typical of glacial ridges in the Norwegian mountains, consisting of a bimodal mixture of mainly sub-rounded large cobble and boulder-sized clasts, set within a sandy gravely matrix. Close to the eastern end of Vassryggen, there is a breach in the ridge where a glacial meltwater river discharged. Since this channel is incised a little into the sandur surface extending across the valley floor, it is likely that it was active for a short period after the ice had withdrawn from the maximum limit. Interestingly, Esmark was clearly aware of the significance of this feature.

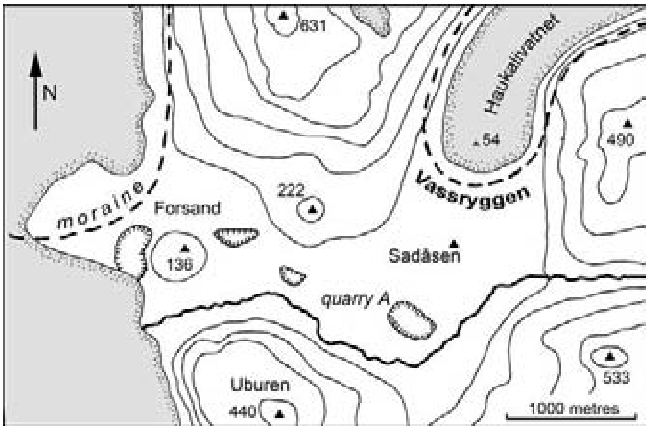


***Figure 9**. Forsand area with Vassryggen and the Younger Dryas ice limit after Andersen. (Base map from Statens Kartverk M711 Series Sheet 1212 1 Høle. 1:50,000, 1991)*

Recently in connection with a ground water study, seismic data, ground penetrating radar and boreholes have substantially augmented the Quaternary geological data base of the area immediately around Vassryggen (Eckholdt & Wahl, 2002). Two water abstraction wells sunk close to the intake of the former meltwater breach in the end moraine attained depths of 26m and 32m. These reveal a variable succession of sand, sandy gravels, gravels and till. The geophysical measurements suggest that the bedrock beneath the sandur is overlain by 40-50m of sediment infill.

During the readvance maximum, the eastern side of the lobate foot of the trunk Lysefjord glacier built an end moraine that blocked the former exit of the east-west trending Forsand valley, thereby obliging the

***Figure 10**. Vassryggen, from the distal side looking north from the hill of Sadåsen, with part of the lake of Haukalivatn visible beyond the moraine ridge.*

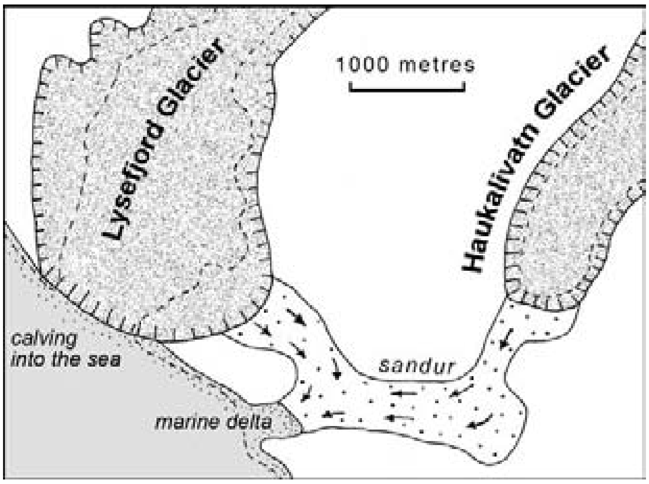


***Figure 11**. Palaeogeographical reconstruction of the Forsand area when the Vassrygg moraine was being formed at the Younger Dryas maximum, 12,700 - 11,400 cal yr BP.*

meltwater issuing from it to build a sandur sloping to the south east. This meltwater merged with another westward directed flow originating from Vassryggen, and the combined river went around the southern side of the bedrock hill of Åslund (136m). In the process, an extending delta was created where it entered the sea (Fig. 11). Post-glacially the modern Forsandåna (Fossanåna) river system has incised into the delta-sandar surface as it adjusted its bed in response to an overall lowering of sea level due to isostatic uplift.

These sandur and allied deltaic sediments are economically important sources of aggregate and sand. A factory on the shore at Forsand processes the sand to produce a dry ready-mix mortar that is transported by ship.

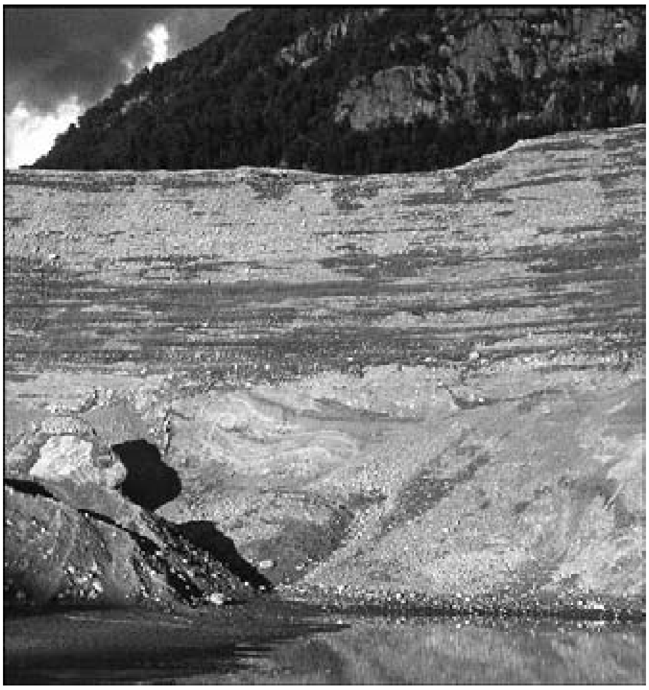


***Figure 12**. Section through the sandur deposits in Quarry A, showing the characteristic horizontal stratification.*

Where quarrying has occurred, sections reveal an earlier lower valley infill consisting of till and outwash sediments with giant erratics, which probably date from the main Weichselian deglaciation. The upper fill consists of the Younger Dryas sandur and delta deposits above a paraconformity that separates the two sequences. Typically they consist of sandy gravels, 3-6m thick, dominated by near-horizontal stratification (Fig. 12). On the coast just east of Forsand, huge volumes of sediment have been quarried, exposing the once-buried bedrock. A prominent horizontal line on the hillside marks the former upper surface of the aggradation, related to the marine limit in Høgsfjorden at the time of deposition. Several abandoned quarries line the east side of the road leading from Forsand towards Vassryggen. In the second of these, the main succession was seen to be characterised by large scale cross-bedded sets, signifying the progressive extension of a delta into the sea. On top of these, up to 5m of horizontal strata represented the extension of the sandur deposits across the former delta, the unusual thickness possibly due to a rising sea level at the time of aggradation (Andersen, pers. com. 2006; Rose *et al*, 1977: Lohne *et al*, 2004).

Regional context of Vassryggen

Andersen (1954) mapped the pattern of deglaciation in the Ryfylke region of Rogaland County, southwest Norway (including Forsand), and identified two concentric end moraine systems produced by distinct glacier readvances during the wastage of the main Norwegian ice sheet. These systems he attributed to what he termed the Lysefjord and the Trollgaren Stadials. The outer of the glacial limits attributed to the Lysefjord Stadial incorporated Vassryggen. Later, Andersen was able to demonstrate that eastwards this limit could be traced into the Younger Dryas Ra moraines of Sørlandet and Oslo fjord. Ultimately, landforms associated with the Younger Dryas ice margins could be traced throughout Fennoscandia. These landforms are interpreted as signifying a glacial re-advance induced by the dramatic climatic deterioration during the Younger Dryas (known as the Loch Lomond Stadial in Britain) with an absolute age of 12.8 - 11.6 ka BP. A Younger Dryas readvance of at least 40 km to the Herdla moraine can be demonstrated in the area north of Bergen (Mangerud, 2000).

It is important to appreciate that the Younger Dryas glacial readvance was superimposed on an overall pattern of ice retreat from the Last Glacial Maximum ice border that lay off-shore in southwest Norway. Hence, outside the Younger Dryas maximum limit, the landscape contains abundant evidence of both erosional and depositional glacial processes. It is often difficult to differentiate these slightly older features from the slightly younger landforms and deposits, since they were formed by the same processes. Also it has to be recognised that glacial erosional forms in bedrock represent the end products of repeated Quaternary glaciations.

Conclusions

The glacial depositional landforms in the Forsand area are of special significance in the development of ideas concerning global climatic change. Jens Esmark was clearly a scientist of exceptional merit, since he had the perception to identify and interpret a range of evidence occurring across much of northern Europe in terms of a now-vanished phase of extensive glaciation. Specifically at Vassryggen, some distance from modern glaciers, he had the ability to see that this end moraine landform was essentially identical to those which had been produced by modern glaciers. Unfortunately, his contemporaries were mostly unable to comprehend the importance of his hypothesis, although Robert Jameson did appreciate that it provided an innovative explanation for features in Scotland that had previously been attributed to a deluge. Even though Jameson was not himself a specialist worker in the field, he attempted to bring Esmark's hypothesis to a wider audience by having it translated into English and by featuring it in his lecture course. Of equal importance was his pioneering attempt to apply the hypothesis to the interpretation of Scotland's scenery.

These days, the public at large is almost daily being reminded by the media that much of the modern world's glacial ice is potentially unstable due to feedback processes arising from anthropogenic atmospheric pollution. Doomsday scenarios predict imminent catastrophic glacier collapse and awful effects on coastlines and their populations. It is appropriate to recall the lessons from the investigation of recent Earth history, particularly the Younger Dryas climatic deterioration. This was both preceded and followed by abrupt climate change, as is clearly apparent in the isotope stratigraphy of the Greenland ice-sheet (Fig. 13). Rapid global change is not a new phenomenon, although the Younger Dryas shifts were only experienced by small human populations unlike those confronting any imminent future change.

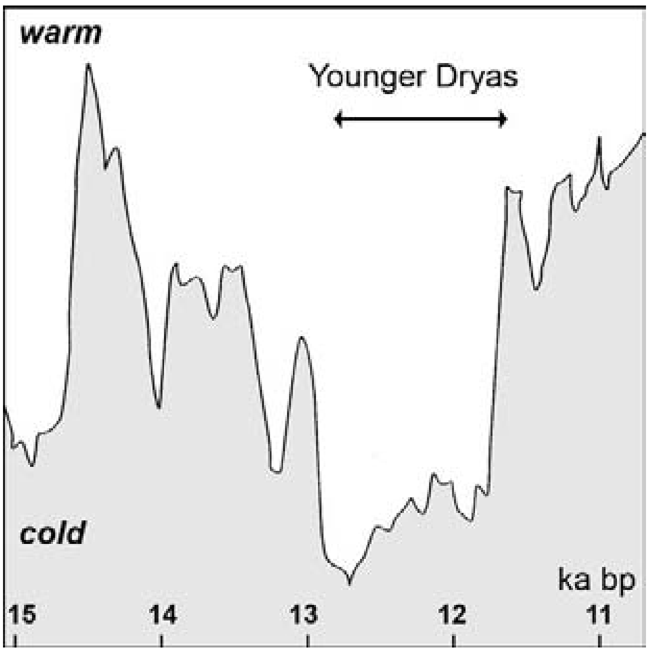


Figure 13. The signal of the Younger Dryas climatic deterioration, as expressed by oxygen isotope variations in a central Greenland ice core (after Grootes and Stuiver, 1997). The time scale is in thousands of years before present ("present" is 1950AD); 11,600 years ago, the temperature increased by about 8ºC within no more than a few decades.

From the perspective of both prehistoric rapid climatic change and the conceptual development of the glacial theory, it is suggested that the Forsand glacial geology warrants listing as a candidate for World Heritage Site status. This would have the merit of bringing the pioneering work of Esmark and his key site to the attention of a much greater lay and professional audience than hitherto. It would also help to ensure that any future quarry developments would be in areas that would not jeopardise this largely pristine landscape.

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Mineral Dusts are Dangerous: Asbestos and Disease

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Abstract. Asbestos minerals have been used from prehistoric times because of their strength, durability and resistance to heat. Widespread use was brought about by the need for insulation in the Steam Age, coupled with the opportune discovery of large mineral deposits in Africa, Russia and America. The main asbestos minerals are chrysotile (white asbestos) and amphiboles (including crocidolite, blue asbestos), which offer the greater health hazard. Initially, environmental control of asbestos dust was poor, and workers in mining and manufacturing industries exposed to high levels of the dusts for many years developed fibrosis of the lungs - asbestosis - leading to respiratory and cardiac failure. Recognition of this sequence led to stringent environmental controls in industries where the risk of asbestos was perceived. Lesser degrees of exposure may be carcinogenic, but only after a prolonged latent period. It was only recognised after decades of use that exposure to asbestos was associated with an increase in lung carcinoma (cancer) and mesothelioma, a highly malignant tumour of the pleura. These tumours occurred in workers not in occupations where the asbestos risk was apparent (and guarded against) but in maintenance workers, plumbers and electricians exposed incidentally to asbestos in their work. It has been estimated that between 1968 and 2050 about 90,000 deaths from mesothelioma will have occurred in Britain; 65,000 of these will be after 2001. Asbestos fibres occur normally in the atmosphere in the western world, but in very small amounts, which are not dangerous. In some Mediterranean countries with ophiolite at outcrop, tremolite occurs in dust, and the cumulative retention of these fibres in the lung is comparable to that in persons occupationally exposed in N W Europe. In these populations, carcinomas and mesotheliomas occur with increased frequency. In Anatolia in three villages, 50% of deaths are attributed to mesothelioma produced by exposure to dust containing erionite, a fibrous zeolite which develops in weathered tuffs.

Asbestos in history

Asbestos is named from the Greek *asbeston*, meaning inextinguishable or unquenchable, and describes not a single mineral, but a number of silicates distinguished by their fibrous structure, flexibility, strength and high resistance to heat and chemicals. These properties ensured the minerals' use from the earliest times. Archaeologists have identified asbestos as a strengthener in earthenware from East Finland aged about 4.5ka. There is evidence of asbestos use in Cyprus during the classical period, for the manufacture of cremation cloths, lamp wicks, hats and shoes. The Egyptians used asbestos as embalming cloths, and the Romans for cremation wrappings.

In early times, there was difficulty in deciding whether asbestos was a stone or vegetable. The geographer Strabo (64BC - 21AD) described quarries on the Greek island of Euboea where *there is found in the earth a stone which is combed like wool, and woven, so that napkins, which when soiled are thrown into the fire and cleaned as in the washing of linen*, and Pliny (77AD) described it as *linus vivum* - durable linen. In post-classical times and throughout the Middle Ages, its origin provoked much speculation and alchemists claimed that asbestos was the hair of a fire resistant salamander (Ross & Nolan, 2003).

Commercial use began in the Ural region of Russia in the early eighteenth century, where the fibres were woven into cloth for gloves, aprons and hats in high-temperature metallurgical shops. In the nineteenth century, Jean Aldini, professor of physics at Bologna University, tailored asbestos cloth into a suit to protect against fire. He exhibited his suit in European capitals, including at the Royal Institution in London, and was commended by Michael Faraday (Murray, 1990).

Asbestiform mineralogy

The word *asbestos* gives rise to confusion for it is often misused as a mineralogical term, whereas it is a commercial-industrial term to describe a mineral habit - *asbestiform* - with distinctive physical properties. In this paper *asbestos* is used as a simple generic term to describe any minerals with the asbestiform habit. To add to the confusion, these belong to two completely separate groups of silicate minerals - serpentine and amphibole; there is a plethora of alternative common and proper names for the individual minerals (Table 1).

Asbestos minerals readily separate into long, thin fibres that are flexible enough to be woven (Fig. 1). They are heat-resistant, chemically inert and good electrical insulators. Properties that distinguish them from non-asbestiform polymorphs include -

- Fibre-like morphology, and dimensions with very small crystal diameter, large aspect ratio and smooth and parallel longitudinal faces:

- Enhanced strength and flexibility; the tensile strength of commercial quality asbestos is about 20-50 times greater than that of the same non-asbestiform minerals:
- Diameter-dependant strength; longitudinally, the unit strength of the fibre increases as its diameter decreases:
- Increased physical and chemical durability compared to non-asbestiform polymorphs (CNHAF, 1984).

Historically the definition of asbestos was based primarily on appearance, but is now augmented with a statement of properties to exclude fibrous minerals (such as the quartz pseudomorphs, including tiger's eye) that break into irregular fragments unrelated to the fibrous structure and which do not have the physical properties of asbestos.

The asbestos minerals

Chrysotile is a member of the serpentine group, and is typically pale green, but is normally white in its fibrous form, which provides its common name as white asbestos. It is a phyllosilicate, recognisable in its formula by the 2:5 ratio of its silicon and oxygen atoms (Table 1). This has a sheet atomic structure, in which a silica layer is joined to a brucite (MgOH) layer. There is an inherent misfit between the octahedral brucite layer and the tetrahedral silica sheet, with consequent mismatching and strain on the crystal lattice. This is partly compensated by tight concentric or spiral curling of the layers and by elongation along the crystallographic *a*-axis - hence creating a fibrous habit from a sheet atomic structure. Each individual chrysotile fibre has an external diameter of 20-40 nm (20-40 x 10^{-9} m), with a central "capillary" space about 2-4 nm in diameter (Roggli & Coin, 2003). Chrysotile fibres may exceed 100 µm in length, and have a curved and curly morphology with splayed ends because of separation of the fibrillar units (Fig. 2). It should not be confused with chrysolite, which is an old name for olivine, and is sometimes still ascribed to yellowish varieties of peridot, the gem-quality olivine.

Asbestos mineral within the serpentine group		
Chrysotile	$Mg_3[Si_2O_5](OH)_4$	***White Asbestos***
Asbestos minerals of the Amphibole group		
Crocidolite	$Na_2Fe_3Fe_2[Si_8O_{22}](OH)_2$	***Blue Asbestos***
Amosite	$(Fe,Mg)_7[Si_8O_{22}](OH)_2$	***Brown Asbestos***
Anthophyllite	$(Mg,Fe)_7[Si_8O_{22}](OH,F)_2$	white, brown
Minor asbestiform minerals in amphibole group		
Fluor-edenite	$NaCa_2Mg_5[AlSi_7O_{22}](F)_2$	white
Tremolite	$Ca_2Mg_5[Si_8O_{22}](OH)_2$	white, pale green
Actinolite	$Ca_2(Mg,Fe)_5[Si_8O_{22}](OH)_2$	dark green

Table 1. *Asbestos mineralogy*

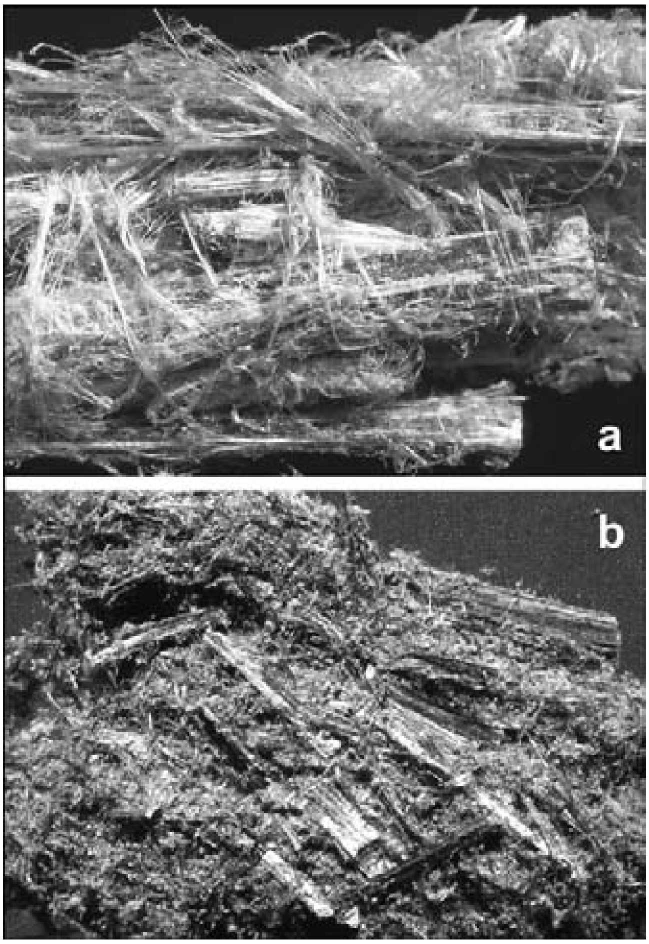

Figure 1. *Asbestos minerals in hand specimens:* ***a*** *- chrysotile:* ***b*** *- crocidolite*

Amphiboles are a large group of inosilicates, with linked double chains of silica tetrahedra, recognisable in their formulae by the ratio 4:11 of the silicon and oxygen atoms (with or without one atom of silicon substituted by aluminium). The chains are separated and bonded to each other by planes of cations. The amphibole structure permits extensive ionic replacement, to produce a wide range of chemical compositions. Most non-asbestiform amphiboles occur as elongate prismatic crystals. The asbestiform habit results from a strongly preferred mineral growth along the *c*-crystallographic axis, but only some amphiboles exhibit this habit and only three occur in commercially viable quantities (Table 1).

Crocidolite is the dominant amphibole asbestos, and its distinctive blue colour provides its common name as blue asbestos. It is the fibrous variety of riebeckite, the most widespread alkali amphibole, with sodium and both ferrous and ferric iron.

Amosite is a brown, iron-rich, fibrous variety of grunerite, a monoclinic amphibole containing neither calcium nor alkali. It was named after the acronym of the Asbestos Mines of South Africa, and is also known as brown asbestos.

Anthophyllite is one of the few orthorhombic amphiboles, and is grey or greenish in colour.

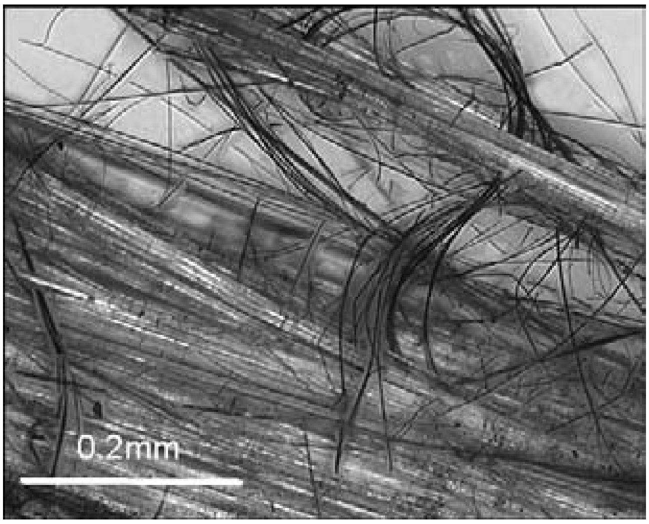

Figure 2. *Curled fibres and fibrils of chrysotile, seen under an optical microscope (Photo: Barbara Cressey)*

Fluor-edenite has only recently been found to constitute some of the amphibole asbestos. Edenite is a member of the complex hornblende group, and has one extra sodium atom to compensate for the one aluminium substitution, and the fluor-edenite has fluorine in place of its hydroxyl.

Tremolite and ***actinolite*** are members of the non-sodic, calcium amphiboles, and occur only rarely in asbestiform habit.

Amphibole asbestos fibre lengths and diameters are widely variable. Amosite fibres generally have lengths >200 µm and diameters <1 µm; crocidolite generally has the finest fibres, and the non-commercial amphiboles the coarsest. Amphibole asbestos fibres are straight, with parallel sides, and may show longitudinal grooving; they do not have the splayed ends or show the longitudinal splitting seen in chrysotile (Fig. 3).

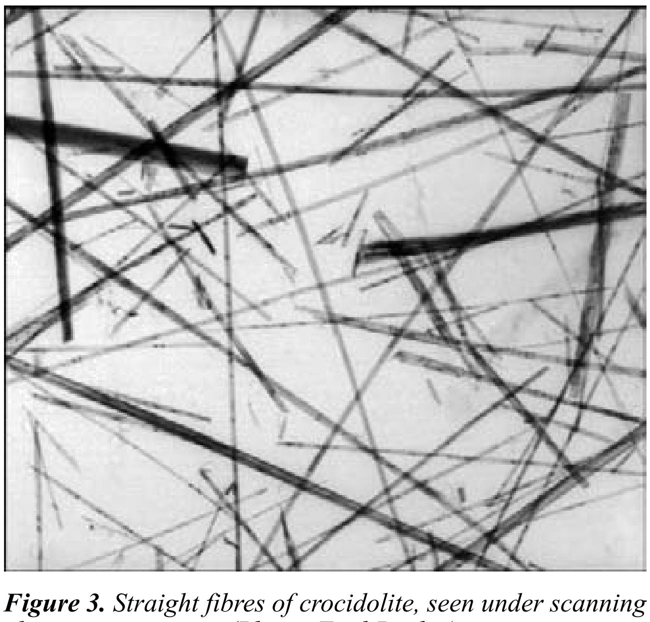

Figure 3. *Straight fibres of crocidolite, seen under scanning electron microscope (Photo: Fred Pooley)*

The commercial value of asbestos fibres depended almost wholly on their ability to be spun, with high grade minerals having long silky fibres. The heat resistance of all fibre types is about the same, but the differing chemical and physical structures give different properties. Thus, chrysotile is decomposed by hydrochloric acid, so that amosite and crocidolite were sometimes preferred for their acid resisting properties. Importantly, from a health viewpoint amphibole asbestos is more biopersistent when introduced into tissues, and the hazards differ significantly between chrysotile and amphiboles - though this is often overlooked when authorities consider asbestos risks. Crocidolite amphibole (blue asbestos) is far more dangerous than chrysotile (white asbestos).

Occurrence

Amphibole and serpentine minerals are widely distributed in the Earth's crust, and both can occur as massive, non-asbestiform deposits under conditions of moderate temperature and pressure. Subsequent asbestiform recrystallisation occurs within environments undergoing deformation by folding, faulting, shearing and dilatation, commonly accompanied by magmatic intrusion of sills and dykes (Ross & Nolan, 2003; Roggli & Coin, 2003).

Chrysotile is the least abundant of the serpentine minerals, but has accounted for more than 95% of the world asbestos trade. It occurs as large veins or masses in highly tectonised serpentinites associated with ophiolite complexes, and formed during late stage hydrothermal activity. Most reserves are found in southern Africa, Canada, China and the Ural Mountains, but deposits have been worked in more than 40 countries. Altered carbonate rocks also host serpentine minerals and chrysotile asbestos deposits that have been worked in South Africa and Arizona (Veblen & Wylie, 1993).

The major world deposits of amphibole asbestos, crocidolite and amosite, are within Precambrian banded ironstone terranes in western Australia and southern Africa. The mineral occurs as seams up to 300 mm thick, aggregated into "reefs" tens of metres thick, which may be traced over many kilometres. Deposition of the African banded ironstones was at about 2200-2500 Ma, with asbestos mineral seams growing during diagenesis under an extensional stress regime and low grade metamorphism at low pressures. Higher temperatures in the contact aureole of the Bushveldt intrusion (2100 Ma) induced the formation of amosite rather than the low-temperature crocidolite. Anthophyllite, has been extracted from an ophiolite complex in East Finland (Gibbons, 2000).

Mining and modern use of asbestos

The uses for asbestos burgeoned in the early and mid-nineteenth century with the requirement of insulation for the developing steam industry. This led to the rejuvenation of old mines in the Italian Alps. Then, in the mid-1800s, large chrysotile deposits were discovered in Quebec and in the Urals. In South Africa, crocidolite was found in the Northern Cape in 1812, but mining development did not develop for a further 90 years. Amosite asbestos was discovered in the Transvaal in 1906, and commercial mining began in 1916 (Alleman & Mossman, 1997).

By the early 20th Century a boom was well underway, with asbestos being used in many diverse applications that reflected its inert properties. New manufacturing techniques allowed fabrication of asbestos threads, ropes, spun products and heat insulating boards. Asbestos was the basis of many building materials, including insulation, textured paints, wallboards, roofing tiles and concrete pipes. It was laminated as paper, woven into cloth, used as filter material and made into friction products such as motor car brake pads.

It has been estimated that, from the time of the first use of asbestos by Stone Age man to 1900, the total world production was around 250,000 tonnes of asbestos. By contrast the total world production between 1931 and 1999 was 166M tonnes, of which about 95% was chrysotile. About 3M tonnes each of amosite and crocidolite have been mined worldwide, together with about 350,000 tonnes of anthophyllite in east Finland. There has been little commercial production of tremolite and actinolite asbestos, but they are present as contaminants in other mined materials such as vermiculite. At present the major asbestos producing countries are Russia, China, Canada, Brazil, Zimbabwe and Kazakhstan (Ross & Nolan, 2003).

Exposure to asbestos

Ambient background

Geological weathering and erosional processes are responsible for the large amounts of natural dusts that enter the hydrosphere and atmosphere, but there are few quantitative studies of the mineralogical contents. One study from Japan reported an ambient average background level for globally distributed chrysotile fibres as 14.1 fibres/litre (Klein, 1993). This may originate from local soils and rock exposures, or by long-distance aeolian transport. Superimposed on this background is anthropogenic dust arising from industrial sources.

Evidence of exposure to asbestos in urban air can be found in the lungs of those livng in industrialised countries. Thomson *et al* (1963) reported that 25% of lungs, without evidence of pulmonary disease, examined at post mortem in Cape Town contained "asbestos bodies" - asbestos fibres coated with an iron-protein-mucopolysacharide material (Fig. 4). Subsequent quantitative studies confirmed the appreciable numbers of fibres found in the lungs. In Vancouver, Churg and Wiggs (1986) analysed the asbestos fibre content of the lungs of general members of the population coming to post mortem (Table 2), and Churg (1993) calculated that the lung of an urban

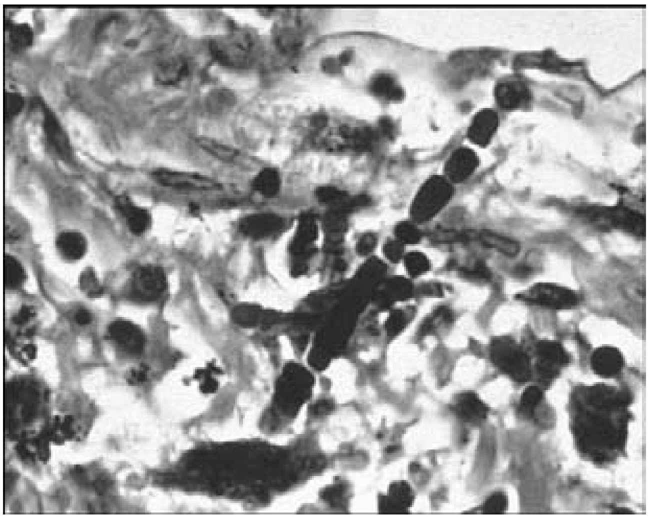

Figure 4. *An asbestos body from a human lung, with its characteristic segmented shape (and golden brown colour) ; these are generally 10 to 50 µm long. (Photo: Paolo Domizio)*

dweller there might contain as many as 40,000,000 each of chrysotile and tremolite fibres and 400,000 fibres of crocidolite and amosite. Such fibre burdens were without any evidence of associated disease.

Similar studies were made in mining towns in Quebec where the ambient fibre content of the air is several hundred times that of North American urban areas. Individuals resident for long periods in the towns (but never employed in the mining or milling processes) had lung fibre burdens five to ten times greater than dwellers in other urban areas. There is no evidence that such individuals suffer an increased frequency of mesothelioma or carcinoma (cancer) of the lung (Churg, 1986; McDonald,1985).

Excessive exposure to asbestos dust can arise in several ways. It may be by direct industrial exposure, or by peripheral exposure - including wives washing their husbands' heavily contaminated work clothes. Exposure may occur around asbestos mines, dumps and factories, or in buildings where there is a source of asbestos dust (Gibbons, 2000; Attanoos & Gibbs, 2003). Ambient non-industrial exposure arising from asbestos minerals in soil or outcrops may also occur, as in the Mediterranean region (see below).

Lung defences against dust

Inhaled particles follow the air into the lungs, and the depth to which they penetrate depends on particle size, shape, density and aerodynamic properties. When a particle comes into contact with an airway or the terminal alveolar airspace it is deposited. Large, dense

fibre type	million fibres/gram of dried lung	
	mean	*median*
Chrysotile	0.3	0.2
Tremolite	0.4	0.2
Amosite + crocidolite	0.001	0

Table 2*. Asbestos fibre contents of the lungs of the general population of Vancouver, Canada (after Churg, 1993)*

or compact particles deposited in the more proximal airways and surrounded by mucus are actively transported upwards by ciliated surface cells (the mucociliary escalator) and swallowed or expectorated. Fibres, such as asbestos, with high aspect ratios and fibre diameter <1.0 µm, may be carried axially in the airstream until they reach the smallest airways, where they collide with the walls of the respiratory and terminal bronchioles. In this way, amphibole asbestos fibres up to 200 µm long have been found in the periphery of the lungs of shipyard workers. The regularity of fibre shape also influences deposition, and the curled fibres of chrysotile are intercepted earlier in the airways than are the straight stiff fibres of amphiboles (Parkes, 1996).

Distally deposited particles are partially cleared by pulmonary macrophages (mobile scavenger cells) which phagocytose (engulf) and transport them to the mucociliary escalator. Short fibres (<5 µm) are easily engulfed, but this process fails with longer fibres. These fibres reach the interstitial tissue of the lung by direct transport across the alveolar walls, and are phagocytosed by macrophages within the tissue surrounding small airways and blood vessels. Heavy and prolonged dust burdens overload this macrophage dust clearance system, and particles then accumulate to provoke a chronic inflammatory response.

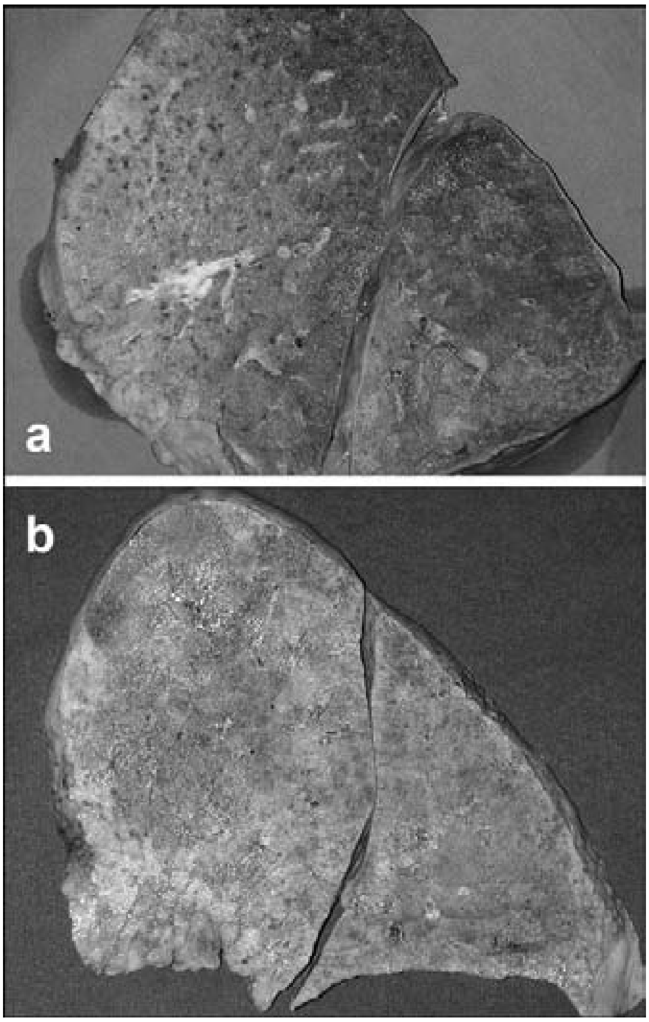

Figure 5. Slices through human lungs; a - a normal lung, with the thin pleural layer that covers the lung surface; b - lung with asbestosis, with extensive paler fibrotic tissue beneath the pleura. (Photos: Allen Gibbs)

There is a marked difference between amphibole and chrysotile fibre persistence in the tissues. Continued exposure to amphiboles leads to persistent and increasing fibre levels within the lungs, with an estimated amphibole half-life measured in decades. By contrast, there is a negligible increase in the lung fibre burden with continued exposure to chrysotile. Chrysotile is rapidly cleared, and its half-life is only weeks to months.

The difference is in part due to the solublity of chrysotile in acid solutions, with leaching of magnesium from its surface. Chrysotile fibres are extremely fragile in the lung environment, and they tend to break transversely into short segments that are easily engulfed and removed, in part by acid dissolution within macrophages. Asbestiform amphiboles show no elemental loss, and their fibres do not break down, so their lengths remain too great to be engulfed by macrophages. As a consequence, persons with prolonged exposure to mixed dusts exhibit a relative increase in amphibole fibres (compared to chrysotile fibres) that remain in the lung for many years. The lungs of former Quebec chrysotile miners and millers, at post mortem, contain up to 80% tremolite fibres and only about 20% chrysotile, though the initial contamination from the chrysotile ore had only a tiny proportion of tremolite (Churg, 1993). Fibre durability in the lungs may underlie perceived differences in amphibole and chrysotile hazard.

Diseases produced by asbestos exposure

When the asbestos load is sufficient to overcome the respiratory defences, pulmonary disease follows. Various aspects of asbestos fibres are important in the cause of pulmonary disease. The geometry and dimensions of the minerals govern their deposition, clearance, biologic activity and dissolution in the lung. This gave rise to the Stanton hypothesis based on animal models (Stanton *et al*, 1977), which implied that the carcinogenicity of inorganic fibres depended principally on their size and shape. However, other factors include chemical and surface properties (absorbtion, oxidation/reduction reactions and surface charge), and these also play major and important roles in biopersistence, cellular responses and disease development (Veblen & Wylie, 1993; Hochella, 1993).

Chronic inflammation and repair

Continuing injury to tissues produces chronic inflammation with repair by fibrosis. In lungs, damaged by exposure to prolonged high concentrations of asbestos dust, this response is modulated by macrophages which in addition to their primary phagocytic function (engulfing) have a major role in the production of chemical inflammatory mediators. These are released when asbestos fibres are phagocytosed by macrophages, and especially when phagocytosis is frustrated and ineffective on long asbestos fibres (Mossman & Churg, 1998). Fibrous scarring, as the end-result of chronic inflammation and repair, is seen in the lung and its coverings.

In the lungs, fibrous repair results in bilateral interstitial fibrosis, known as asbestosis. It occurs initially about the smallest airways, and then extends proximally to larger airways and distally to the air spaces of the alveolar ducts and alveoli. The walls of the latter are slowly and progressively thickened, with eventual obliteration of the alveolar spaces (Fig. 5). There is a loss of lung elasticity and impairment of respiratory gas exchange across the thickened alveolar walls (Fig. 6). Respiratory failure and cardiac failure, secondary to respiratory disease, eventually supervene.

Recognition of pulmonary fibrosis associated with inhalation of asbestos dust came in the 19th and early 20th centuries, in countries involved in mining and milling asbestos (Simson, 1928), as well as in importing countries (Seiler, 1928). Evidence was initially anecdotal, exemplified by a report in 1906, which described a case of pulmonary fibrosis to a government committee on compensation for industrial disease. The patient, an asbestos carder from Barking, described how he alone of ten men working in the card-room was the only one still alive. All the others died at about the age of 30 (Murray, 1990). Unfortunately, the committee did not allow compensation for any occupational pulmonary disease because of the confounding effects of tuberculosis, which was common at that time.

The association between diffuse fibrosis of the lungs and exposure to asbestos in the United Kingdom was firmly established by Merewether & Price (1930), who found pulmonary fibrosis in 25% of workers in an east London asbestos textile factory. They correlated the development of fibrosis with the intensity and duration of asbestos exposure, and described a latent period of 7-25 years between initial exposure and the development of asbestosis. Their observations led in

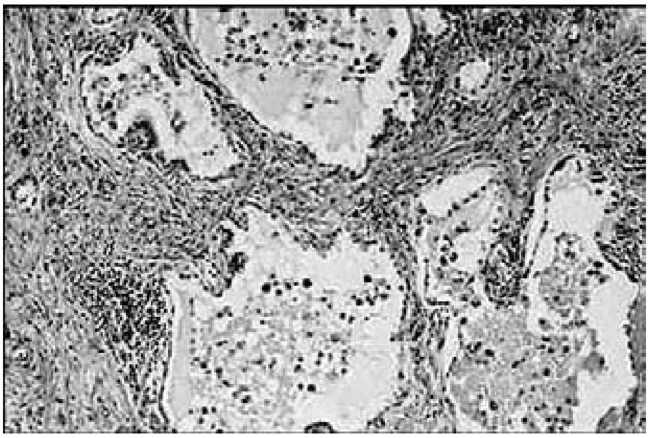

***Figure 6**. Asbestosis, showing gross fibrosis and thickening of the alveolar walls (around the pale annualar air spaces), which provides an impediment to gas exchange. (Photo: Paolo Domizio)*

period	exposure in years	
	range	*average*
1913 - 1940	1.5 - 19.0	7.0
1940 - 1950	—	10.0
1950 - 1960	3 - 32	14.5
1960 -	4 - 35	17.5

***Table 3**. Duration of exposure to asbestos prior to certification of asbestosis, in employees of an east London factory (after Smither, 1965)*

1933 to the introduction of the Asbestos Industry Regulations, which reduced the burden of dust exposure. These regulations progressively tightened so that exposures of >100 f/ml encountered in the 1930s were reduced to ~1f/ml in 1980.

Asbestosis only develops in workers heavily exposed to asbestos dust, over and above a threshold of about 25-100 fibres/ml/year, below which asbestosis is not seen. Asbestosis was first recognised in workers with prolonged high exposure, notably miners, asbestos millers, asbestos textile workers and insulators. However, during World War II asbestosis occurred in shipyard workers exposed to very high levels for relatively short periods (Mossman & Churg, 1998), which emphasised that the time from initial exposure to first signs or symptoms of the disease, is inversely proportional to the exposure level. In the 1930s, before dust control regulations took effect, the average time of exposure before onset of certified asbestosis was seven years. More recently, the latent period has responded to stricter controls in the workplace (Table 3), and it is now uncommon to see patients with asbestosis who are very short of breath and with marked active changes on chest X-ray.

In the pleura (the thin layer of tissue lined with mesothelium that covers the surface of the lungs and lines the chest walls), repair occurs as thickened fibrous plaques that are often calcified. Pleural plaques cause no symptoms, and are frequently incidental findings on routine chest radiographs that provide a means of screening populations at risk of damage due to asbestos dust (Constantopoulos *et al*, 1987; Manda-Stachouli *et al*, 2004). The exposure levels to induce pleural plaques are an order less than those to produce asbestosis.

Malignant tumours

Malignant tumours arise with increased frequency in those exposed to asbestos, and may arise with or without asbestosis. Doll (1955) established that cancer of the lung arising from the bronchial mucosa is a hazard to asbestos workers, and that the risk among men employed in the industry for more than 20 years was ten times that of the general population. The risk lessened as the duration of employment under the old dusty conditions decreased, following the Asbestos Regulations. It is disputed whether the increase in lung cancer is due to any exposure to asbestos, to levels of exposure sufficiently high to have the potential to produce asbestosis, or only occurs when some degree of pulmonary fibrosis has already been induced (Attanoos & Gibbs, 2003). There is synergism between asbestos exposure and tobacco; smokers who are heavily exposed to asbestos have a much greater risk of developing lung cancer than do those more lightly exposed to asbestos (Selikoff *et al*, 1964; Hammond & Selikoff, 1979).

Mesotheliomas are highly malignant tumours arising from the layer of cells which covers the lungs and lines the pleural cavities. The tumour grows rapidly and spreads to surround the lungs and heart (Fig. 7). It was regarded as rare until the 1960s, when the orthodox view was that most pleural tumours were secondary spread from undetected primary carcinomas of the lung or abdominal organs. Wagner *et al,* (1960) described 33 cases of mesothelioma in patients from the N W Cape Province of South Africa. Most had worked in asbestos mines or had been involved in asbestos transport with exposure to crocidolite, and in many of these patients their disease had been regarded as tuberculous pleurisy. They established the long latent period between initial exposure to asbestos and the diagnosis of mesothelioma, which averaged 44 years in their patients, and noted that several patients had never worked in the asbestos industry but had lived close to milling plants or waste dumps on which they had played as children. This report was criticised because only four cases came to autopsy and the pathology details were inadequate (Willis, 1967). However, it withstood the criticism, and was seminal in drawing attention to the linkage of asbestos exposure and mesothelioma. It became the most cited paper in industrial medicine (Wagner, 1991).

Increased mesothelioma in industrialised nations

With heightened awareness, it became apparent that mesothelioma was increasingly common in the industrial western nations, and in 1968 the UK Health and Safety Executive established a register of deaths due to mesothelioma. Since that time, there has been an epidemic of mesothelioma in Britain and Europe (Peto *et al*, 1995, 1999). The annual number of mesothelioma deaths in Great Britain has risen from 153 in 1968 to 1848 in 2001, and is predicted to peak at up to 2450 deaths each year between 2011 and 2015, with a rapid decline thereafter. The eventual death toll will depend on any residual asbestos exposure, but it is estimated that between 1968 and 2050 there will have been about 90,000 deaths from mesothelioma in Great Britain, 65,000 of which will occur after 2001 (Hodgson *et al*, 2005). Similar figures are predicted for Western Europe, with about 250,000 deaths over the next 30 years.

Risks of asbestos fibres as a carcinogen

Most epidemiologists agree that all forms of asbestos can cause both cancer of the lung and mesothelioma, but there is controversy on the relative contribution of chrysotile and the amphiboles to the overall incidences

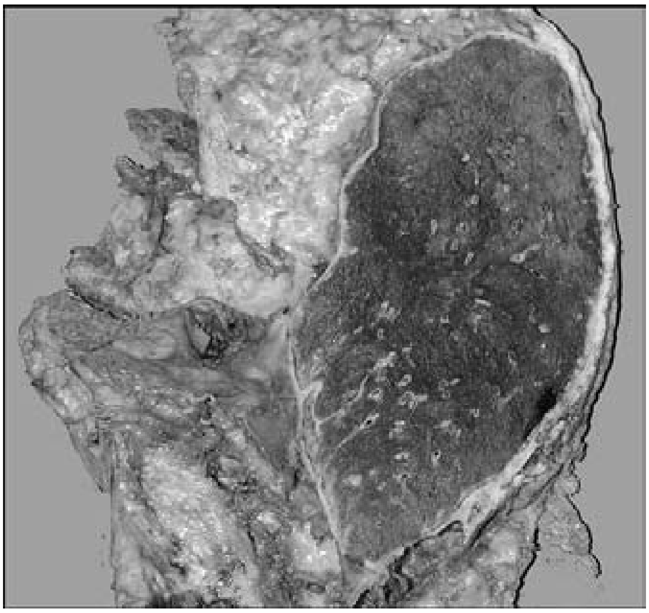

***Figure** 7. White tumour tissue of mesothelioma that has encased and compressed the lung; the tumour grew from the mesothelial layer of cells that cover the lungs. (Photo: Allen Gibbs)*

of these tumours (Peto *et al*, 1998; Liddell, 1997). A recent study found that the relative risks for the development of mesothelioma for the various fibre types at occupational exposure levels were chrysotile ~1, amosite ~100 and crocidolite ~500; for lung carcinoma the risk differential between chrysotile and amphibole fibres was less, between 1:10 and 1:50 (Hodgson & Darnton, 2000). Others have claimed chrystotile as the principal cause (Smith & Wright, 1996); Cullen (1998) suggests that, although less dangerous than the amphiboles, chrysotile is used far more widely worldwide, and is probably the main cause of mesothelioma. These reports have been questioned, as they arose from potentially biased sources involved in litigation. By contrast, studies of Quebec asbestos miners and millers for more than thirty years, showed that very few mesotheliomas are caused by pure chrysotile, and most are attributed to contaminant tremolite (McDonald *et al*, 1996, 1997). The problem is not easily resolved, for few workers are exposed to chrysotile alone. Most exposure measurements in the past were of "asbestos" particles, rather than of specific fibre types. Moreover, the interpretation of lung burden studies in humans, in contrast to those on experimental animals (Elmes, 1991), is vitiated by the relatively rapid pulmonary clearance of chrysotile compared to amphibole fibres, and also to the prolonged latent period between initial exposure and tumour development.

Other tumours ascribed to asbestos exposure include carcinoma of the larynx, stomach and colon, but social class, alcohol intake and smoking act as confusing factors, and these linkages are not proven (Attanoos & Gibbs, 2003).

Failure of industrial practice and control

Human costs

Excessive exposure to asbestos has occurred, despite regulations of workers' time, in mines, mills and industrial plants, and also in the surrounding environment. In the producer countries, some of this has been due to negligence and disregard of regulations, and some has been, allegedly, due to concealment of health risks. Gross examples have occurred in South Africa, Australia and the USA.

- In 1949, a doctor at the Penge amosite mine in the Transvaal reported: "Exposures were crude and unchecked. I found young children, completely included in large shipping bags, trampling down fluffy amosite asbestos, which all day long came down cascading over their heads. They were kept stepping lively by a burly supervisor with a hefty whip. I believe these children to have had the ultimate asbestos exposure. X-ray revealed several to have radiologic asbestosis, with heart failure before the age of 12." (Meeran, 2003).
- The surrounding environment of mine and adjacent homes were not spared. Also in South Africa, 2000 miners at Prieska began a legal action against Cape plc in 1998. Their representative, whose job had been sorting and packing asbestos with bare hands, was never provided with a mask or gloves. Now suffering from asbestosis, he related that his wife, parents and brothers had been killed by asbestos-induced disease. He said: "The dust was everywhere. It lay up to an inch thick. There were no warnings, nothing. Children played in it. I lived half a kilometre from the factory but in order to drink I had to scrape a layer of asbestos off the top of my water jar." (Talbot, 1999). A cohort study of 399 whites born in Prieska between 1932 and 1936 showed that 9% of the deaths up until 1990 were due to mesothelioma (Reid *et al*, 1990). The health damage to Africans is not known because of poor records but is probably worse (Gibbons, 2000).
- In Australia, despite the introduction of Federal regulations from 1945, asbestos was widely abused in the thermal power station industry, and power stations became virtual mountains of asbestos. This was crudely swept up and spread by workers boots, or was more widely disseminated by blasting with compressed air, so that the entire area of each power station was continuously blanketed by clouds of fibres (Gibbons 2000).
- In the United States in 2005, a federal grand jury indicted current and former executives of the W R Grace Company for endangering the inhabitants of Libby, Montana, by concealing information about its vermiculite mine (Spadaro, 2005). Libby residents have an increased incidence of asbestos-related diseases, including carcinoma of the lung which is 30% higher than expected compared to other areas of Montana and the U.S. It is alleged that since 1970, W R Grace and its executives hid the fact that tremolite was present as a contaminant in the vermiculite, and allowed vermiculite to be widely distributed throughout Libby. Workers left the plant covered in dust; residents were allowed to take vermiculite for their gardens, and vermiculite tailings were given to Libby schools for use as foundations for running tracks and an outdoor ice skating rink. The mine closed in 1990, and it is alleged that W R Grace sold contaminated properties without disclosing the nature or extent of contamination.

In user countries such as the United Kingdom, initial reports of asbestos-related disease concerned workers in asbestos factories and metal plate workers (including shipyard workers, and railway carriage builders where large amounts of amphibole asbestos were used) and exposures were intense. It was in these areas that regulations were most stringently applied because of the perceived risk of asbestosis. However, the worst carcinogenic effects of asbestos have been experienced by the generation who began work in the mid-1960s, after the health hazards from asbestos were well recognised. They worked in occupations where the risk from asbestos was not appreciated - in the construction and power generating industries, and as maintenance workers such as electricians and plumbers (Attanoos & Gibbs, 2003). At that time, amosite insulation boards and tiles were widely used in buildings; chrysotile was imported for incorporation into asbestos cement and floor tiles, but monitoring and exposure control was limited.

An example in the East Midlands concerns exposure to a mixture of asbestos fibre types. Mr R D, suffering from mesothelioma, alleged at the County Court that he was exposed to asbestos dust at work. Trackside cable troughs, which run alongside the railway, contain either mechanical or electrical cabling. During the relevant period of his exposure, most troughs were made of concrete, but some were asbestos concrete, as on the main line south of Chesterfield. The asbestos content was mainly chrysotile, but small quantities of crocidolite were present in older troughs. He was involved in their removal by smashing and breaking up the troughs. He related an occasion when a supervisor, asked if it was safe to deal with asbestos troughing, replied that white asbestos was safe. He also worked in signal boxes where ceiling tiles and wall boards contained amosite. At times he was engaged in pushing cabling through holes in the ceiling with inevitable chafing on the edges resulting in the release of asbestos dust. The court found for the claimant; he died in 2001 from mesothelioma (Sheffield County Court, 2000).

Costs to industry

The Faculty and Institute of Actuaries forecasts that the total future UK cost of asbestos-related diseases is £8-20bn. The UK insurance industry is expected to face a bill of £4-10bn. More than half of this sum will be for mesothelioma claims, which will continue to rise for the next ten years. By contrast, claims for asbestosis will fall due to the declining use of asbestos in the UK since the 1970s. The future cost represents 80,000-200,000 new insurance claims over about the next 30 years (Asbestos Working Party, 2004).

Asbestos hazard in buildings?

The lung can tolerate greater burdens of chrysotile and tremolite asbestos than is found in the lungs of urban dwellers. Churg and Wiggs (1986) provided re-assurance about the innocuous effects of the general background level of asbestos, and also about the effects of low levels of chrysotile release inside public buildings such as schools, where internal levels are close to the levels of ambient air. Nevertheless, public awareness of the perceived dangers of asbestos brought about near-panic in many parts of the Western world, and billions of dollars were spent in America removing asbestos from the structure of schools and public buildings.

A cold douche of common sense and hard data was needed to curtail the asbestos panic, which was founded on fear rather than evidence. Mossman *et al* (1990) gave very low risk estimates for children attending classes in schools built with asbestos-containing material. Data from HELAR (1991) and Wilson *et al,* (1994) showed that the average concentration of asbestos measured in 219 American schools was 0.00022 f/ml. Using this figure, Ross & Nolan (2003) calculated that in the worst-case calculated prediction, the risk for residing in the classroom for six hours a day, five days a week for 14 years is one excess cancer death per million lifetimes. Further evidence is provided from Quebec mining towns, where Camus *et al*, (1998) reported that ambient asbestos levels exceeded 1f/ml before the introduction of modern dust control procedures in the 1970s. Ross & Nolan (2003) calculated that the ambient asbestos dust levels in these towns varied from 230 to 23,000 times the average levels found in schools with asbestos insulation. Yet a mortality study of women who lived in these towns at that time (but did not work in the asbestos industry) showed that their health was unaffected by the very high, lifetime exposure to asbestos dust (Siemiatycki, 1982).

Most of the asbestos imported into Britain between 1960 and 1980 is still in place in buildings, but airborne levels are very low during normal use, and the material is not an immediate health risk to the general public. The danger now lies in the work of maintenance men (carpenters, electricians and plumbers) and demolition workers who may be unknowingly exposed to asbestos in their duties; this applies especially those working in small firms where they may be inadequately monitored. Since the 1980s, asbestos removal has become a specialised industry, and this new and initially inadequately regulated industry may well have increased the future burden of occupational asbestos disease (Peto *et al*, 1995).

Continuing use of asbestos

There are calls for a worldwide ban on the use of asbestos (Cullen, 1998; Collegium Ramazzini, 2001; Guidotti, 2001). These have now achieved some governments` support, and have led to country by country bans. Such calls are opposed by asbestos-producing countries. The Canadian asbestos industry is the world's second-largest producer of chrysotile, and more than 90% is exported. In 1991, the Canadian asbestos lobby successfully challenged the U.S. Environmental Protection Agency's ban on asbestos products. Since 1991, members of the European Union have individually banned asbestos on the grounds that there is no safe exposure level. Fearing global expansion of the ban, Canada challenged France (its largest European customer) at the World Trade Organization (WTO) in 1998 to repeal its unilateral ban on asbestos. The WTO found that all levels of asbestos posed some cancer risk, that safer substitute products were available, and that there was no such thing as "controlled use". The failure of the challenge allowed other countries to ban asbestos; a European Union asbestos-ban deadline of January 1st, 2005 was met by all member countries. E U directive 1999/77/EC bans placing, marketing and use of products that contain asbestos after 2005; directive 2003/18/EC prohibits all activities in which workers are exposed to asbestos fibres in asbestos mining or in production and processing of asbestos products, with effect from 2006.

There is, however, an inherent fallacy in the proscription of all asbestos minerals as a single coherent health risk. All agree that asbestiform amphiboles should be banned because of their undoubted toxic effects and their long persistence in the human lung, but the banning of chrysotile asbestos is on much less firm ground. The Canadian challenge is based on epidemiological studies over thirty years in Quebec asbestos mines and mills, which show that with strict controls chrysotile usage is essentially innocuous, and the probability is that tremolite contamination is responsible for most cases of mesothelioma associated with heavy chrysotile exposure (McDonald *et al* 1996, 1997; Liddell, 1997).

In response to falling markets in the industrial nations, the Canadian asbestos industry has progressively transferred its commercial activities to the Third World. Country by country bans have shifted rather than eliminated the use of asbestos. Southeastern Asia has been targeted as an export market, where asbestos is used to make piping, roofing and flooring material. It is argued that to deny a developing country the use of asbestos cement is to deny it adequate housing, drainage and water, with loss of protection against catastrophic waterborne diseases (Liddell, 1997). The Canadian Government and industry promote a concept called "safe use", with good ventilation, protective equipment, embedding the fibres and wetting the material when it is being handled. In practice the reality may be far from that. The poor countries of Southeastern Asia do not have good occupational health and safety regulations or good industry controls, and statistics on asbestos diseases are lacking. In Canada, rigorous controls may work. In Third World environments, there may be no such thing as safe use, but it may be a matter of balancing public health risks.

Non-industrial exposure to fibrous minerals

Asbestos

Pulmonary diseases including pulmonary fibrosis, pleural plaques, carcinomas of the lung and mesotheliomas have been reported to occur with increased frequency in inhabitants of the Mediterranean region, and have been attributed to environmental exposure to asbestos and other fibrous minerals present in local rocks and soils (Table 4). Many cases are found in areas on or near ophiolite outcrops, and are associated with exposure to tremolite (Ross & Nolan, 2003). Such exposure appears not to be related to quarrying or industrial use, but mainly to the use of white *luto* soils, that are contaminated with the amphibole, as an interior and exterior whitewash for house walls and floors. Langer *et al* (1987) report that in some parts of Turkey the whitewash consists of almost pure asbestiform tremolite (Fig. 8). In the Metsovo area of N W Greece, where the high prevalence of mesothelioma has been recognised for more than 20 years and the whitewash has not been used since 1985, a decrease in the number of cases of pleural plaques and of mesothelioma is reported (Manda-Stachouli *et al*, 2004). It has been estimated that about 16,000,000 people living in rural Anatolia have been exposed to asbestos mineral dusts, and in these the cumulative retention of fibres in the lung is comparable to that found in patients occupationally exposed to asbestos in northwest Europe (Dumortier *et al*, 1998).

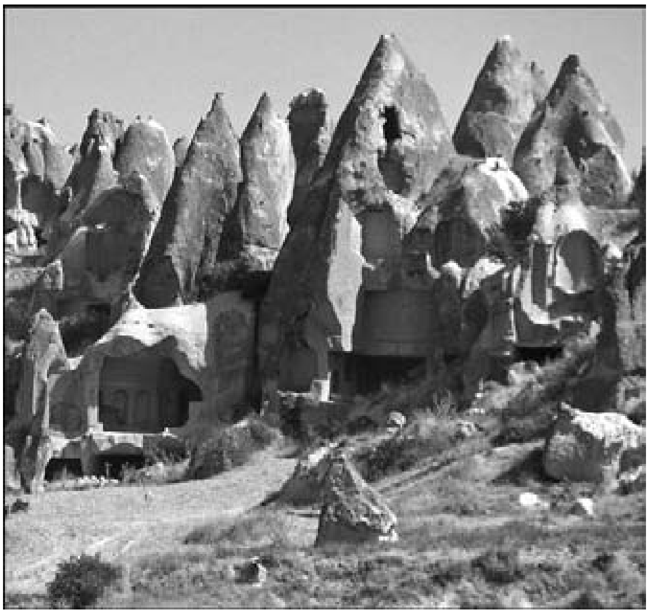

Figure 8. *Anatolian landscape where the volcanic tuffs have been gullied and weathered to leave the cones and pinnacles of Cappadocia; many cones have had artificial caves cut into their soft rock.*

Zeolites

Parts of the Anatolian plateau, in southeastern Asian Turkey, are covered with tuffs from the two volcanoes of Ercives and Hasandag. The weathered tuffs form the dramatic landscape of conical and hive-shaped landforms that are well known in Cappadoccia (Fig. 9). These tuffs are soft and easily excavated or quarried, and have provided cave dwellings or building materials for churches, houses and byres from ancient times. Weathering of the tuffs produces a variety of minerals in the clay and zeolite groups. Zeolites (from the Greek for *boiling stone*) are hydrated tectosilicates that give off water on heating. They typically occur in amygdales, cavities and pore-spaces in basic volcanic rocks, and as alteration products of feldspars, feldspathoids and volcanic glass. They have open, wide-meshed, 3-D atomic framework structures that can lose water or undergo cationic exchange while retaining their crystal shape. They have therefore been used commercially as molecular sieves and petroleum cracking catalysts (Bish & Guthrie, 1993). The zeolite group includes erionite (from the Greek for *wool*), a fibrous variety of the more widespread thomsonite, which in aggregate looks and feels like felt or wool.

Location	Mineral	Environmental factors	Pleural plaques, pulmonary fibrosis	Carcinoma of lung	Mesothelioma	Source
S E Turkey Madnen ophiolite	Tremolite	Stucco whitewash	◆	◆	◆	Yazicioglu *et al*, 1980 Senyisit *et al*, 2000
Turkey Anatolia	Tremolite Actinolite	Stucco whitewash	◆		◆	Zeren *et al*, 2000
Turkey Cappadoccia tuffs	Erionite	Cave dwelling	◆	◆	◆	Rohl *et al*,1982 Baris *et al*,1987
N W Greece Pindos ophiolite	Tremolite	Stucco whitewash	◆		◆	Sakellariou *et al*,1996 Constantopoulos *et al*, 1987 Langer *et al*, 1987 Manda-Stachouli *et al*, 2004
Cyprus Troodos ophiolite	Tremolite Chrysotile	Fibres in dust, domestic and environmental			◆	McConnachie *et al*, 1987
Corsica Cap Corse ophiolite	Tremolite Chrysotile	Asbestos outcrops	◆		◆	Rey *et al*, 1994
Eastern Sicily Etna volcanics	Flour-edenite	Contaminant of building blocks			◆	Gianfagna *et al*, 2003

Table 4. *Reports of pulmonary disease attributed to fibrous minerals in the Mediterranean area; ◆ indicates lesions reported.*

The incidence of mesothelioma in Anatolia has been estimated to be 45 per million inhabitants, and in some reports is linked to environmental exposure to tremolite. However, in three villages in central Anatolia the estimated incidence is even greater - 996 per 100,000 inhabitants - with more than 50% of deaths due to mesothelioma. A cohort of 162 Turkish emigrants from one of these villages to Sweden was followed: 18 deaths occurred between 1965 and 1997, and 14 of these were due to mesothelioma. Compared to the general Swedish population, the standardised incidence rates for mesothelioma were 135 times higher among men and 1336 times higher among women (Metintas *et al*, 1999). The three villages with the highest rates of pleural and peritoneal mesothelioma have raised environmental levels of erionite, compared to adjacent villages. Erionite fibres were a major part of airborne dust, and their source was identified as a poorly consolidated tuff that crops out naturally, and still forms the walls of caves used as utility rooms and animal quarters (Wagner *et al*, 1985).

Measurement of fibres taken from the Anatolian village environments showed erionite to approach the dimensions of asbestos, with fibres up to 50 µm long and 0.5-1.5 µm in diameter. Small amounts of chrysotile and tremolite were also found. In tissues from the lung and pleura of mesothelioma patients, 90% of the fibres were erionite, although there was a smaller amount of tremolite (Rohl *et al*, 1982).

Experimental studies of rats exposed to erionite, by inhalation or by injection, showed that erionite from the Turkish villages has a potential to produce mesotheliomas enhanced in comparison to crocidolite (Wagner *et al*, 1985). This may be due to its tectosilicate structure, which gives a greater internal surface area with enhanced surface effects, and its ability to facilitate ion exchange and catalyse biological reactions (Bish & Guthrie, 1993). However, the causes of mesothelioma in the villagers appear to be more than simple dust exposure; families in adjacent houses in the same village have very different incidences of the tumour, despite apparently similar exposure. In a genetic and epidemiological study of a group of 526 related persons (Hammady *et al*, 2001), susceptibility to mesothelioma appeared to be inherited.

A caution for the future

The debate over health hazards from fibrous mineral dusts is not yet over. There is still a need for substances with the industrial properties of asbestos, and substitutes are actively sought, but such replacement fibres may have a similar biological potential to that of asbestos. Animal models are of little use because of interspecies variability and because of the discrepancy between animal lifespan and the lengthy latent period in human asbestos-induced diseases. Awareness of the *possible* hazards in fibrous dusts must lead to active preventative measures by authority, employers and workers alike, from the period of initial use, if another asbestos-like industrial catastrophe is to be avoided.

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Ancient Quarrying of Rare *in situ* Palaeogene Hertfordshire Puddingstone

Bryan Lovell and Jane Tubb

Abstract: Previously elusive *in situ* siliceous concretions of the conglomerate commonly known as Hertfordshire Puddingstone are identified at two locations as patches of puddingstone in the lowermost few metres of the marine and nonmarine Palaeogene sequence that overlies Chalk in the Colliers End outlier, Hertfordshire. The siliceous concretions of puddingstone consist of rounded flint pebbles and cobbles set in a matrix of fine sand and silica cement. It is suggested that silica diagenesis took place soon after deposition of the lowermost Palaeogene, beneath the surface of a Hertfordshire landscape that enjoyed an unusually warm climate around 55 Ma. A Neolithic quern-stone, made from puddingstone, is recorded from a site that was evidently used as a flint and puddingstone quarry in Neolithic times and as a puddingstone quarry and factory by the Romans.

Key words: Hertfordshire Puddingstone, siliceous concretions, Palaeogene, Neolithic implement, Roman quern-stone.

Hertfordshire Puddingstone is a conglomeratic siliceous concretion consisting of rounded flint pebbles and cobbles set in a matrix of fine sand and silica cement (Fig. 1) (Page, 1859; Holmes, 1928; Milner, 1940). Its origin has been discussed for well over a century, from Hopkinson (1884) to Hepworth (1998) and Catt & Hepworth (2000). The report of Hopkinson (1884) on the Geologists' Association excursion to Radlett, Hertfordshire, on 12th July 1884, is a matchless combination of fine prose, field observation and early interpretation of 'the Hertfordshire conglomerate' as a 'shore-deposit…the shingle-bed of flint-pebbles consolidated by the infiltration of silica'.

This silica infiltration of the 'shingle-bed' has formed a cement that is as hard as the flint pebbles themselves. The processes involved are part of a continuing debate on the formation of silcretes at or near the surface of present-day southern England (Hepworth, 1998; Ullyott *et al.*, 2004). Hepworth (1998) provided an introduction to puddingstone literature, drawing comparisons between English and Australian silcretes. Catt (2000) adopted a more cautious approach, suggesting that 'silcretes form in a wide range of surface and subsurface environments'. Climatic control of silicification is detailed by Thiry *et al.* (2006). All this lends considerable current scientific interest to the puddingstone, already renowned for centuries for its extreme hardness and its long role in Hertfordshire folklore.

Yet Hertfordshire Puddingstone is elusive in two respects, one geological and one archaeological. Geologically, it is 'an elusive material to find *in situ*, although it occurs widely as loose blocks across parts of the London Basin' (Robinson, 1994, 77). As for archaeology, '[Roman]…quern manufacture…must have left significant traces. Production sites are little known and outcrops of Hertfordshire Puddingstone would certainly repay study' (Glazebrook, 1997, 41); querns are ancient corn grinders that incorporated large blocks of strong stone in their construction.

Progress has recently been made on the fronts of both geology and archaeology, thanks to the stoical behaviour of the local farmers. They discover the largest specimens of puddingstone at the cost of broken ploughs, yet retain their enthusiasm for its study. In 2005-2006 they helped to recover specimens for public display in Hertford and Bishop's Stortford. Members of a farming family, whose land has recently been sliced by construction of the A10 High Cross and

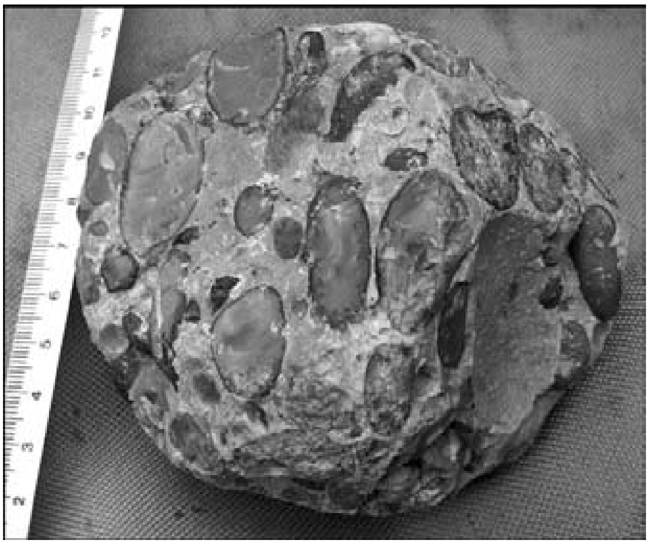

***Figure 1**. The upper face of the Neolithic quern-stone made from Hertfordshire Puddingstone, found in 2005 by Jane Tubb at the site of the ancient quarry south of Puckeridge. It measures 102 mm long by 95 mm wide and 72 mm high, and weighs 857 g. Specimen is now on loan to Hertford Museum.*

Colliers End bypass (Fig. 2), have recovered most of the puddingstone encountered during construction of the road and have stored it on their land. This they have done on their own initiative.

This paper records evidence of Neolithic and probable Roman quarrying and shaping of puddingstone for quern-stones, at a location on private land south of Puckeridge. It also records the recent discovery of a dozen large (*c*.1 m maximum diameter) specimens of puddingstone that appear to have been found *in situ*. They were recovered from a former temporary exposure of the lowermost Palaeogene sediments some 200 m east of Colliers End [NGR 374207 to 374205] (Fig. 2). These specimens were revealed during recent construction of the A10 bypass from Thundridge to Puckeridge, which cuts through the Colliers End Palaeogene outlier (Hopson *et al.*, 1996). Another large (1.6 m maximum diameter) and, unusually, quite complete concretion was found in 2005 by Peter Glogner at Bushey Leys Field, Bromley [412215], close to the 110 m contour, 3 km SE of Puckeridge. The geological setting of the ancient quarry, south of Puckeridge, and of the Colliers End specimens, are described.

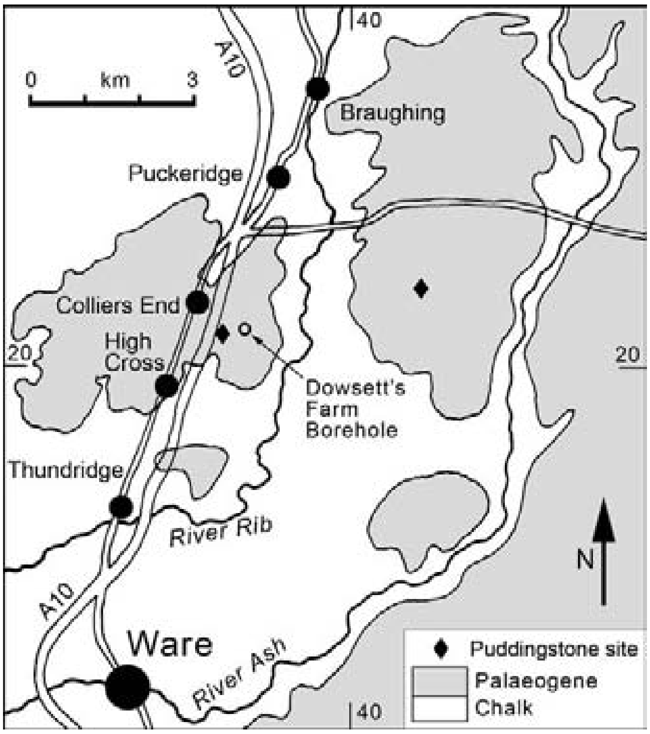

***Figure 2**. Outline map of the area around Puckeridge, Braughing and Colliers End, between Hertford and Bishop's Stortford. The new A10 bypass cuts through the Palaeogene outlier at Colliers End just to the east of the village. The limits of the Palaeogene outlier are after Figure 18 in Hopson et al. (1996). The location of the ancient quarry is not shown (see site access below).*

Archaeology

There is clear evidence for excavation and working of puddingstone at a quarry site south of Puckeridge. Most of the surface area at the location has been disturbed by excavation for solid rock. At the north end of the site, a steep and narrow "valley" is cut into the Upper Chalk; this "valley" has no topographic expression beyond the site itself, and is interpreted as a quarry worked in the abundant large flints found within that rock at this location. Pending full archaeological investigation, this quarry is tentatively assigned a Neolithic age.

A puddingstone implement (Fig. 1) was discovered some 50 m from the putative flint quarry. It has been identified by Julian Watters (Finds Liaison Officer at St Albans Museum) as a Neolithic quern-stone. In his description of this find (BH-416BD3, Portable Antiquities Scheme), he states that it has: 'been deliberately formed and used as a tool in prehistory. It is possible that the object is a hammerstone used in the production of flint tools, but, given the extent of the initial shaping and the subsequent even wear pattern on the underside, it is more likely to be a grain rubber for use with a saddle quern. The object is roughly ovoid, apart from a flat area on the upper surface which has been created in order to make the object easier to handle. On the convex underside is an area which has been flattened by regular use of the implement. It dates from *c*.3500 BC to *c*.100 BC.'

The greater part of the site of discovery of the Neolithic implement is marked by pits and mounds left from working of the lowermost *c*.5 m of Palaeogene sediments. Sharp-edged fragments of puddingstone are scattered amongst these pits and mounds. A specimen, consisting of three-quarters of an original egg-shaped concretion, 0.5 by 0.25 m, was discovered at the western edge of the area (Fig. 3). Its dimensions and shape suggest a failed attempt at beehive quern manufacture. This putative Roman specimen is on loan to Hertford Museum, with a quarter-fragment of a broken but fully shaped beehive quern. This fragment has dimensions of 0.24 by 0.1 m and fits neatly into the missing quarter of the egg-shaped 'failed quern' (Fig. 3). It was found some 50 years ago in the garden of a house in Puckeridge, near Ermine Street (the old A10) and just a few hundred metres south of Braughing [388243], which was an 'important pre-Roman *entrepot* and Roman small town' (Glazebrook, 1997, 40).

At the site of the ancient quarry, a shallow depression extends from the deepest pit towards the edge of the worked area, to join a slope that falls across the Upper Cretaceous Chalk towards a ditch adjacent to Ermine Street. The 'failed quern' specimen was found at the top of this slope. Other fragments of puddingstone, of various sizes up to and just over a metre in greatest diameter, are found across a broad, roughly 20 m, section of the field between the quarry and the ditch. The puddingstone fragments are largely confined to this section of the field, although some redistribution of larger fragments by the plough is apparent. The ditch itself contains several large fragments of puddingstone. The 20 m wide puddingstone-strewn section is interpreted as the route down which both rock and implements were exported from the quarry and factory.

Site geology

The ancient quarry

The unconformity of Palaeogene on Cretaceous has been mapped across fields at this location, south of Puckeridge, and lies close to the 90 m contour. Geological excavation in search of remaining puddingstone *in situ* at the quarry has been postponed, in favour of a future more detailed archaeological examination of the material in both the pits and mounds. What can be asserted with some confidence at this stage is that the puddingstone formed as siliceous concretions within the lowermost section of the Palaeogene sequence, which was penetrated by the Dowsett Farm Borehole [38062079]. This would place it in the Upnor Formation, of the lower Lambeth Group, following Hopson *et al.* (1996). That correlation is supported by additional subsurface data, resulting from the recent construction of the A10 Colliers End bypass, which have kindly been made available by the British Geological Survey.

Figure 3. *Remaining three-quarters of an originally egg-shaped specimen of puddingstone, found by Jane Tubb at the site of the ancient quarry south of Puckeridge. This specimen is interpreted as a failed attempt in Roman times to fashion a beehive quern. A quarter fragment of a Roman beehive quern rests on it. Both specimens are now on loan to Hertford Museum. Scale bars are 100 mm long.*

Colliers End

A dozen large (*c*.1m maximum diameter), isolated, specimens of puddingstone were recovered by the Parkins family during construction of a *c*.200 m long section [374207 to 374205] of the A10 bypass east of Colliers End (Fig. 2). These rocks are retained on private land at High Cross. Their total volume is of the order of 10 cubic metres. It is suggested by Russell Parkins, who regularly inspected the route during construction, that they represent some three-quarters of the volume of puddingstone intersected by workings for the new road.

Were these Colliers End specimens unearthed *in situ*? Mr Parkins collected the largest specimens from around the 90 m contour over a roughly 200 m north-northeast to south-southwest stretch of the route of the new bypass, some 200 m east of the line of the old A10 through the village. The evidence from temporary survey-pits dug in December 1989 indicates that the route of the new A10 intersects base-Palaeogene a little below the 90 m contour about 200 m east of Colliers End, along the 200 m long stretch where the large pieces of puddingstone were found. Only smaller puddingstone fragments were collected from glacial till to the south of that stretch. So it appears that the main puddingstone specimens that Russell Parkins recovered were *in situ*.

The Colliers End specimens do not show clear internal evidence of the fractures described by Robinson (1994) from the famous but well-protected *in situ* puddingstone near Radlett, Hertfordshire (Hopkinson, 1884), but the specimens do show at their broken edges the quite smooth fractured surfaces running through both flint pebbles and siliceous matrix that are characteristic of Hertfordshire puddingstone. These fractures tend to be vertical or sub-vertical to apparent bedding in the Colliers End specimens. In this case the fractures may be the work of ice, or may have arisen during excavation by the heavy machinery used in work on the new road.

One of Russell Parkins' specimens retains uncemented fine white sand on its surface (Fig. 4). This may be compared to Hopkinson's 'beautifully white, fine sand seen reposing upon an unconsolidated portion of the [Radlett] pebble-bed' (Hopkinson, 1884, 455). The presence of the loose sand on the Colliers End specimen reinforces the claim that it was found in place and gives a useful insight into the truly bimodal size distribution of the original sediment. The question of environment of deposition remains open, although it may be hard to improve on Hopkinson's interpretation (1884, 453) that this is 'a shore deposit' of 'a true shingle-bed'.

The puddingstone specimens found in the Colliers End outlier indicate a minimum thickness of 0.3-1.0 m for the original bed of fine sand and pebbles in which these siliceous concretions formed. Hopson *et al.* (1996) give 0.2-0.9 m for the thickness of pebble beds at the base of the Palaeogene (Upnor Formation, lower Lambeth Group) in this area. These thicknesses are confirmed by records from A10 route-survey pits, and current exposures in A10 ditches and adjacent ploughed fields, notably an exposure on the east flank of the new A10 [379200].

Origin of puddingstone

The concretionary masses of puddingstone from the Puckeridge and Colliers End sites contain rounded pebbles and cobbles, characteristically of black-coated flint, set in an abundant matrix of fine sand and silica cement. The pebble beds near the base of the Palaeogene in other parts of the Colliers End outlier (Hopson *et al.*, 1996), recorded in boreholes, temporary pits and present-day exposures in ditches and ploughed fields, are commonly embedded in a muddy and sandy matrix rather than in clean sand. No puddingstone has yet been found in these muddier pebble beds in this area. This supports Hepworth's view (1998) that puddingstone is a minor component of the Lambeth Group, restricted by original depositional environment. Evidence from this new material suggests that an original patchy distribution of sandy Palaeogene pebble beds was a major control on the location of the pervasive silica cementation that formed puddingstone.

Current knowledge of the Colliers End outlier and adjacent areas does not constrain the date of formation of the siliceous concretions found there. The data are compatible with the early formation of puddingstone described elsewhere in the London Basin (Woods *et al.*, 2004) The evidence from current exposures, and from records of temporary pits on the line of the A10 bypass, indicates that the upper surface of the Chalk was weathered and also vegetated in places. Rootlets reported from Palaeogene muds immediately overlying Chalk, in temporary pit no. 53 [37405.20514], 200 m east of Colliers End, indicate contemporary exposure. Desiccation cracks are recorded in Palaeogene muds overlying the 3 m of glauconitic sand with pebble beds that lies immediately above Chalk in the Dowsetts Farm Borehole (Hopson *et al*., 1996).

A first-order control on silica dissolution is temperature (Pettijohn *et al*., 1987). The age of the Lambeth Group sediments that host the puddingstone at Colliers End is 56-55 Ma (Neal, 1996), close to the time of the Paleocene-Eocene thermal maximum (Norris & Rohl, 1999). That notable warming event may have been triggered by regional uplift associated with the early Iceland mantle plume (Maclennan & Jones, 2006). Other putative effects of the plume manifest in the Colliers End outlier may be recognized as the emergence of Britain from the Chalk Sea and its tilting to the southeast (Cope, 1994; Gibbard & Lewin, 2003; Knox, 1996), and episodic changes in Palaeogene regional sea level in response to thermal pulses within the plume itself (White & Lovell, 1997).

So the thoroughly provincial Hertfordshire Puddingstone reflects far broader events. On the local evidence, it is believed that a respectable working hypothesis for its origin includes silica diagenesis that affected the locally sandy patches of Palaeogene pebble beds. On broader evidence, it is suggested that these shore-line deposits were cemented beneath a 55 Ma land surface that enjoyed a climate closer to that of present-day Penang (in Malaysia) rather than that of Puckeridge.

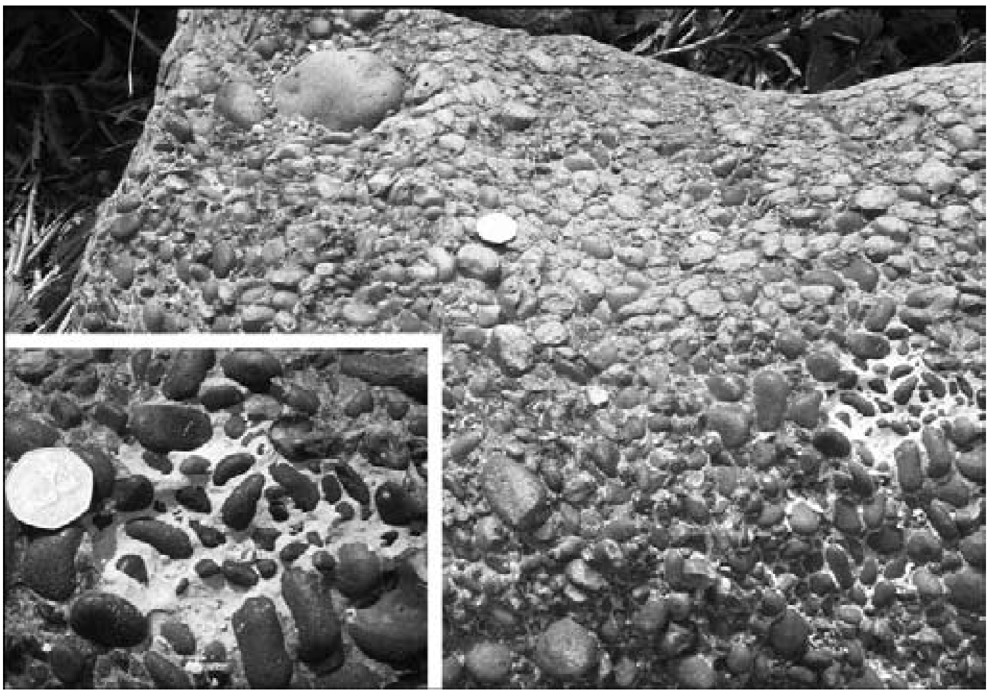

***Figure 4**. Fine white sand in-place, adhering to a small part of the surface of a specimen recovered from puddingstone, evidently in situ, during recent construction work on the A10 bypass at Colliers End. The coin is 25 mm in diameter. The specimen is now on private land at High Cross.*

Inset shows the sand enlarged.

Puddingstone and site access

Key archaeological and geological material is available at Hertford Museum, including a large specimen of puddingstone from the location of the ancient quarry; this now sits in the Museum garden beneath an explanatory plaque prepared by East Herts Geology Club. An even larger specimen of puddingstone from that location was put on permanent display in a prominent position in the grounds of Hertford Castle in March 2006, with another explanatory plaque by the Geology Club. The large and unusually complete specimen recovered some 3 km SE of Puckeridge was moved to Bishop's Stortford in May 2006, to form a feature in a new commercial and residential development by Wilson Bowden at Jackson Square, in the centre of the town.

With these excellent specimens already on public display in Hertfordshire towns, there is no need to trample the farmers' crops to view the material. A search for metal at the key archaeological site in 2005, by John Bullen, was fruitless: nothing of material value exists there. In the interests of geological conservation, and especially given the archaeological discoveries, this report follows Robinson (1994) in not being specific about this puddingstone site: site disturbance or even damage by those in mistaken search of treasure would only diminish the scientific values. On behalf of the farmers and the local and scientific community that they support so willingly, visitors to the area are requested to keep to the clearly identified public rights of way.

Acknowledgements

The two large specimens of Hertfordshire puddingstone now on public display in the County Town, one in the garden of Hertford Museum, the other in the grounds of Hertford Castle, were kindly donated by Philip Smith, whose plough they broke. They were put in place through the combined efforts of John Bullen, East Herts Geology Club, Hertford Museum and Hertford Town Council. We much appreciate the work by Julian Watters on the Neolithic implement and thank him for permission to quote his description of this. We are most grateful for the help given by those farming and working on the area we have studied, namely John Bullen, Peter Glogner, Bessie Parkins, Chris Parkins, Russell Parkins and Philip Smith. We thank the British Geological Survey for kindly giving us access to subsurface data resulting from planning and construction of the A10 bypass of Colliers End. The key archaeological specimens are on loan to Hertford Museum: we thank Curator Helen Gurney and Assistant Curator Sara Taylor for their help with this. We thank Professors Richard Howarth and Eric Robinson for their valuable advice on the manuscript.

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THE RECORD

The level of membership of the Society is being maintained and we extend a warm welcome to members who have joined in 2005. We also mark the passing of those members no longer with us, and to their families we send our condolences. Among those were Dr Ron Firman and Mr Jack Fryer. Their many years of contribution to the Society are remembered.

Field Meetings

The first visit of the season was a full day in May, led by Keith Ambrose, to study changes in the Marlstone Rock Formation across Leicestershire and Rutland.

The visit to Southwell Minster and Bishops Palace led by Ian Thomas in June was very popular. The history of this well known building was told through the story of the stone of its buildings and the memorials within.

Later in the month a review of dry stone walling across Britain was possible during a detailed look at the nineteen sections of the Millennium wall built at the National Stone Centre, which show styles and materials from Caithness to the South Wales Valleys.

In July it was back to the Jurassic with Albert Horton but this time to look at the changing architectural style and use of stone, from Norman times to the present, employed in building the churches found on the borders of Nottinghamshire and Leicestershire.

Good weather blessed the weekend excursion in September to see some of the geology and mineral deposits North Wales and Anglesey, under the leadership of Alan Brandon.

Indoor Meetings

The annual joint meeting with the Yorkshire Geological Society, at the BGS in Keyworth in March 2005, reviewed recent research undertaken there into geology and climate. A short guided tour of the BGS rock and fossil collection was enjoyed so much that it led to a more extensive visit in February of this year.

The winter programme of lectures began in October when Daryl Garton of Nottingham University spoke about Trent Valley geo-archaeology. She focused on the prehistoric log boat (now on display at the Derby Museum & Art Gallery) discovered in the Aston gravel quarry, Derbyshire, where quarrying had been monitored by Dr Chris Salisbury.

In November Dr John Rees, from the Keyworth BGS, gave a chilling account of why the world should be concerned about gas hydrates, their potential part in climate change and how it might be managed.

The annual buffet was preceded in December with the opportunity to go underground with Paul Deakin a well-known cave and mine photographer. He presented a pictorial history of working mines in the British Isles using photographs from his extensive library gathered over a period of nearly 40 years. He shared visits to sites all over Britain, many of which are no longer accessible.

It was underground once more in January thanks to Dr Andy Farrant, from BGS, who demonstrated that caves were not dark dank holes in the ground but could be treasure troves containing geological data that can help unravel past climates and the evolution of the landscape.

The February meeting was held at two venues with a tour of the BGS Collections given by Dr Mike Howe, the Chief Curator, in the afternoon, followed by the President's Lecture in the evening, but regrettably no Annual Dinner this year due to catering difficulties. A large group of members enjoyed the opportunity to view examples from the important and extensive fossil and core sample collections held at Keyworth. The President's Lecture discussed Derbyshire's varied contribution to British mineral production over time, and its impact on the population and landscape.

Council

The plan to help preserve the carvings in the finest of Nottingham's caves has been very successful. The Society has paid for weatherproof doors to be fitted, and they are now in place. Internal conditions are being monitored, but no means have yet been found to restore the damage already done by weathering.

After obtaining more stock from the GA the successful East Midlands Field Guide continues to sell well and the Guide to the Building Stones of Leicester project is nearing publication.

Older editions of The Mercian, now out of print, are occasionally requested for research purposes. Although the secretary holds the archive and can offer photocopies of particular articles, any back copies being disposed of by members could usefully be recycled to those interested.

During the year a start has been made on producing Rock Boxes. These will contain samples of a variety of rocks typical of Britain, and will be available to schools. The cost and quality of commercially available specimens can be limiting so it is hoped that distributing our own will fulfil in some small part one of the objectives of the Society, that is to educate the next generation. Members are asked to bear this project in mind when they visit appropriate localities.

We thank those who have made the Society's programme possible, including all the guest speakers and leaders of field excursions, Beris Cox for organising the indoor programme, Ian Sutton for organising the field programme, Sue Miles for producing the Circular (now largely distributed by email), Rob Townsend for maintaining the website, and many others unnamed for their contributions.

Janet Slatter, Secretary

Palaeoecology of Portlandian Gastropods from the South Midlands

Jonathan D. Radley

Abstract. The Portlandian strata of Buckinghamshire were deposited in sheltered shallow-marine to nonmarine settings during the Late Jurassic regression. Distal environments were characterised by a low diversity gastropod fauna. Proximal marine settings supported micromorphic gastropod faunas, possibly associated with putative algal meadows. Coarser-grained bioclastic substrates were intermittently colonised by the nerineoid *Aptyxiella portlandica*. Low-salinity lacustrine facies are characterised by low diversity faunas dominated by small provalvatids.

This report is founded upon investigations undertaken by the author nearly twenty years ago, whilst researching aspects of the palaeontology and palaeoecology of Portlandian (Late Jurassic) gastropods. The author's interest in Portlandian palaeontology had been initiated through investigation of the poorly exposed succession in the Vale of Aylesbury and Thame Valley of Buckinghamshire, in the southern Midlands of England, during the late 1970s. There, the richly fossiliferous strata (Fig. 1) are stratigraphically condensed and generally poorly cemented relative to the expanded successions in the Dorset type-area of southwest England (Townson, 1975; Wimbledon, 1980). Thus, small exposures were a rich source of invertebrate fossils including many gastropods.

The Portlandian Stage is represented in the Vale of Aylesbury and Thame Valley by siltstones, sandstones (often glauconitic) and sandy, micritic and shell-fragmental limestones (Portland Sand and Portland Stone members of the Portland Formation; Glaucolithus up to Kerberus Zone, up to *c*. 13 m thick), overlain by the fine-grained limestones, mudstones and calcareous mudstones of the Purbeck Formation (Kerberus Zone; up to *c*. 10 m thick; Wimbledon, 1980; Horton, Sumbler, Cox & Ambrose, 1995; Fig. 1). The Portland Sand and Portland Stone are further subdivided into named units (Bristow, 1968; Wimbledon, 1980; Horton *et al*., 1995; Fig. 1; Table 1). Horton *et al*. (1995) took developments of the Upper Shell Marl (Table 1) to mark the base of the Purbeck Formation. It is included within the Creamy Limestone in this account on palaeontological grounds, following Bristow (1968) and Radley (1991).

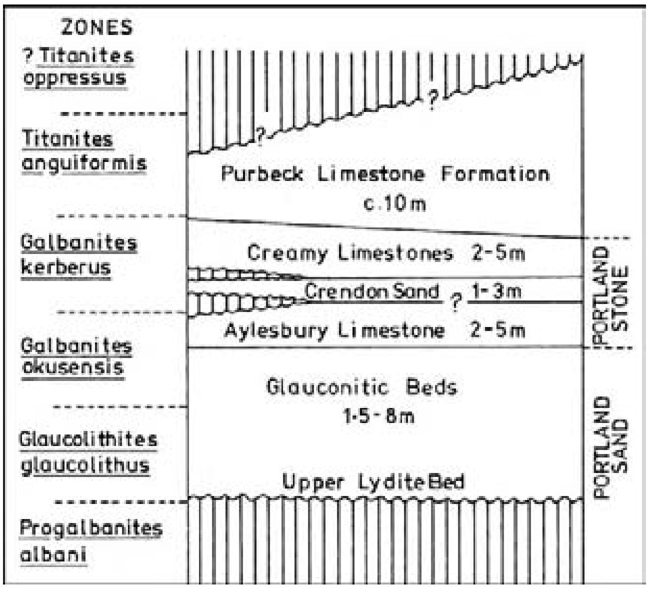

***Figure 1**. Outline of Portlandian stratigraphy in Buckinghamshire; vertical ornament indicates beds locally absent (adapted from Wimbledon, 1980).*

The Portlandian succession represents the last phase of marine deposition in a northeastern embayment of the southern English Wessex Basin adjacent to the London Platform, during the terminal Jurassic regression (Cope, Rawson & Wimbledon, 1992). The Portland Sand and Portland Stone are taken to represent shallow-water nearshore marine environments, influenced by sea-level fluctuations of regional magnitude (Wimbledon, 1987; Cope *et al*., 1992; Horton *et al*., 1995). Above, the Purbeck Formation yields molluscs and ostracods that confirm a marginal-marine to nonmarine setting influenced by fluctuating salinity (Barker, 1966; Radley, 1991; Horton *et al*., 1995).

Gastropod distribution

Gastropod faunas had been previously recorded from the Buckinghamshire Portlandian by numerous authors, notably Fitton (1836), Blake (1880), Hudleston (1881, 1887) and Davies (1899). The author's study of Buckinghamshire material was based upon a combination of newly collected material and specimens preserved in recognised collections, notably that of the Buckinghamshire County Museum, Aylesbury. Among the available fossil localities during the late 1970s and 1980s, there were a small number of disused quarries that included a geological Site of Special Scientific Interest (SSSI) (Warren Farm, Stewkley; SP 852243; Barker, 1966; Bristow, 1968), as well as a freshly dug SSSI excavation on the site of a former quarry (Bugle Pit, Hartwell, SP 79321205; Radley, 1991; Horton *et al*., 1995) and several partly overgrown sections in roadside ditches and road embankments. Temporary exposures were noted in Aylesbury town centre (Radley, 1990, 1993a).

Upper Shell Marl	0.15 - 0.23m
'Last' Portland Limestone	0.30m
Lower Shell Marl	0.15 - 0.23m
'Main' Portland Limestone	>1.8m

Table 1*. Lithostratigraphic terminology for the Creamy Limestone subdivision of the Portland Stone in Buckinghamshire(after Bristow, 1968).*

Portland Sand and Portland Stone

The investigations confirm a low-diversity gastropod fauna throughout much of the Portland Sand and Portland Stone, ranging from the Upper Lydite Bed (basal Portland Sand, Glaucolithus Zone) up into Bristow's (1968) 'Main' Portland Limestone division of the Creamy Limestone (upper Portland Stone, Kerberus Zone; Fig. 1, Table 1). The fauna is dominated by two large taxa: the pleurotomariid *Bathrotomaria rugata* (Benett) (Fig. 2), and the whelk-like *Natica elegans* J. de C. Sowerby (Radley, 1990, 1993b). Additionally, the small, turbiniform *Ooliticia cunningtoni* Cox (Cox, 1925) was recorded from the Upper Lydite Bed in a ditch section north of Whitchurch (SP 80872271). A poorly preserved small cerithioid was noted in the Aylesbury Limestone (temporary sections in Buckingham Street, Aylesbury; SP 819139). The small *Natica*-like *Ampullospira ceres* (de Loriol) occurs rarely in the 'Main' Portland Limestone at Warren Farm, Stewkley.

Blake (1880) and Hudleston (1887) had noted a fauna of small gastropods within the upper part of the 'Main' Portland Limestone. The author's investigations, initially at Warren Farm, confirmed the widespread presence of a micromorphic fauna of gastropods, bivalves and other fossils at this level. Amongst these were large numbers of *A. ceres*, small cerithioids, the inferred rissoid *Rissoa acuticarina* Blake, the aporrhaid *Chenopus* (*Quadrinervus*) *beaugrandi* (de Loriol) and the actaeonellid *Actaeonina* (*Ovactaeonina*) *insularis* Cox (Cox, 1925). *A. ceres* was especially abundant in the now overgrown road cutting at Whitchurch (SP 800211; Bristow & Kirkaldy, 1962).

Figure 2*.* Bathrotomaria rugata *(Benett); internal mould; Portland Stone Member (Portlandian, Upper Jurassic); Buckinghamshire, locality unknown. Buckinghamshire County Museum specimen AYBCM: 1880.190.101. Diameter of specimen is 108 mm.*

Figure 3*. Shelly limestone enclosing moulds of high-spired* Aptyxiella portlandica *(J. de C. Sowerby); 'Last' Portland Limestone (Creamy Limestone, Portland Stone Member, Portlandian, Upper Jurassic); Haddenham Station quarry, Buckinghamshire. The upper internal mould is 45 mm long. Bucks. County Museum specimen AYBCM: 1923.52.1.*

During early 1991, temporary sections in fields adjacent to Dinton Castle, near Stone (SP 765115), exposed various levels of the Portland Sand and Portland Stone (Radley, Shipp & Wimbledon, 1997). There, the highest part of the 'Main' Portland Limestone was developed as poorly indurated chalky micrite. Micropalaeontological residues yielded large numbers of micromorphic gastropods preserved mainly as micritic casts. The fauna is overwhelmingly dominated by minute cerithioideans, generally poorly preserved. Initial investigations also revealed taxa identified earlier from Stewkley and Whitchurch, namely *A. ceres* and *C. (Q.). beaugrandi*. The remaining shells await detailed documentation but include taxa resembling *Actaeonina* (*Ovactaeonina*) *hypermeces* Cossmann, *Hydrobia chopardiana* (de Loriol), *Nerita minima* Credner, *Odostomia jurassica* de Loriol, *Provalvata sabaudiensis* (Maillard), ?*Pseudomelania pupoides* Arkell and *Tornatella leblanci* de Loriol (de Loriol & Pellat, 1866, 1874; Arkell, 1941).

Above the 'Main' Portland Limestone, the uppermost 0.6-0.75 m of the Creamy Limestone comprises a bivalve-rich bioclastic limestone bed interbedded with oyster-rich shelly mudstones ('Last' Portland Limestone and Lower and Upper Shell Marl of Bristow, 1968; Table 1). Sieved residues from the Lower Shell Marl at Warren Farm (bed WH3 of

Barker, 1966) yielded a number of badly preserved micromorphic gastropods including shells resembling *Provalvata* cf. *helicoides* de Loriol, *H.* cf. *chopardiana* and *Orthostoma granum* de Loriol. The 'Last' Portland Limestone was exposed at a number of sites, notably Dinton Castle, the Bugle Pit, Whitchurch, and Warren Farm. It was confirmed as the sole source of the high-spired nerineoid *Aptyxiella portlandica* (J. de C. Sowerby) in Buckinghamshire (Fig. 3), together with *A. ceres*, a few minute *Hydrobia*-like shells and probable cerithioids including *Uchauxia quadrigranosa* Cox (Cox, 1925), poorly preserved as moulds or calcite replacements.

Purbeck Formation

The basal beds of the Purbeck Formation were sampled at the Bugle Pit, Whitchurch, Warren Farm (see above) and temporary exposures on Whaddon Hill, near Stone (SP 787133). Thinly-bedded ostracodal limestones yielded a few small gastropods including probable hydrobiids and cerithioids, the provalvatid *P. helicoides* and a possible neritoid (details provided by Radley, 1990). Clements (1973) recorded a number of taxa including *Hydrobia* sp. and *P. helicoides* from various levels of the Purbeck Formation at the Bugle Pit (Figs. 4, 5). Higher in the

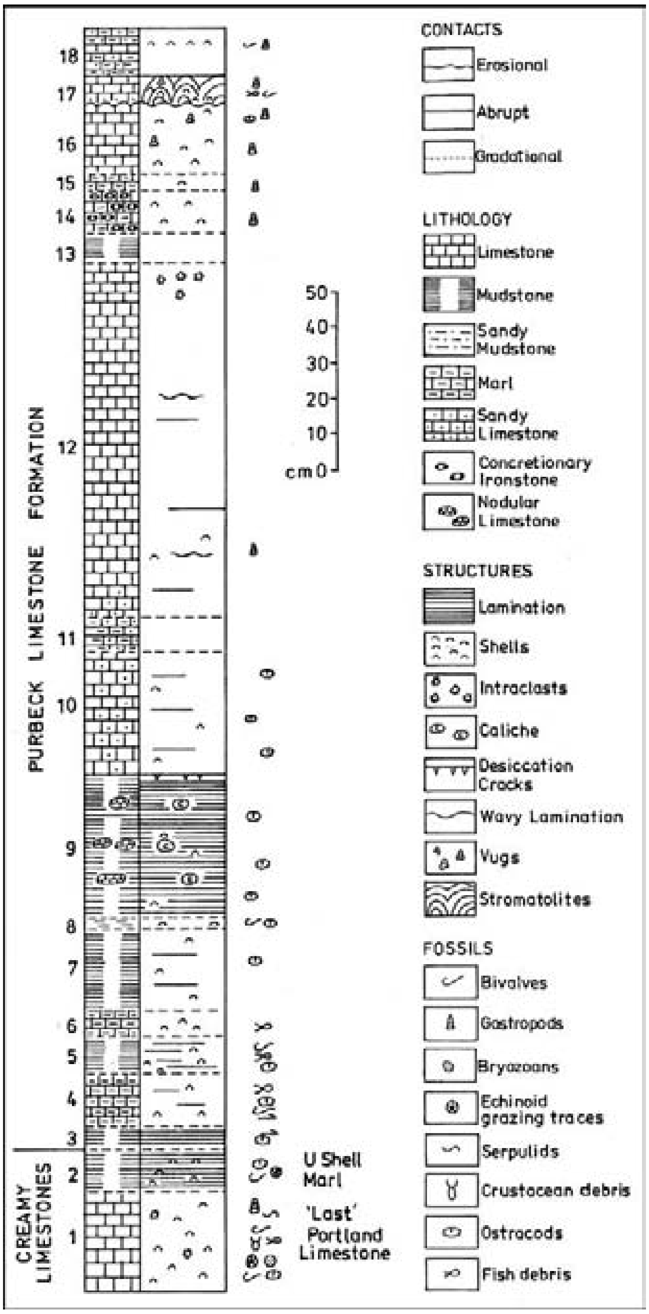

Figure 4. *Succession of Portlandian strata at the Bugle Pit, Hartwell, Bucks. (SP79321205) (from Radley, 1991).*

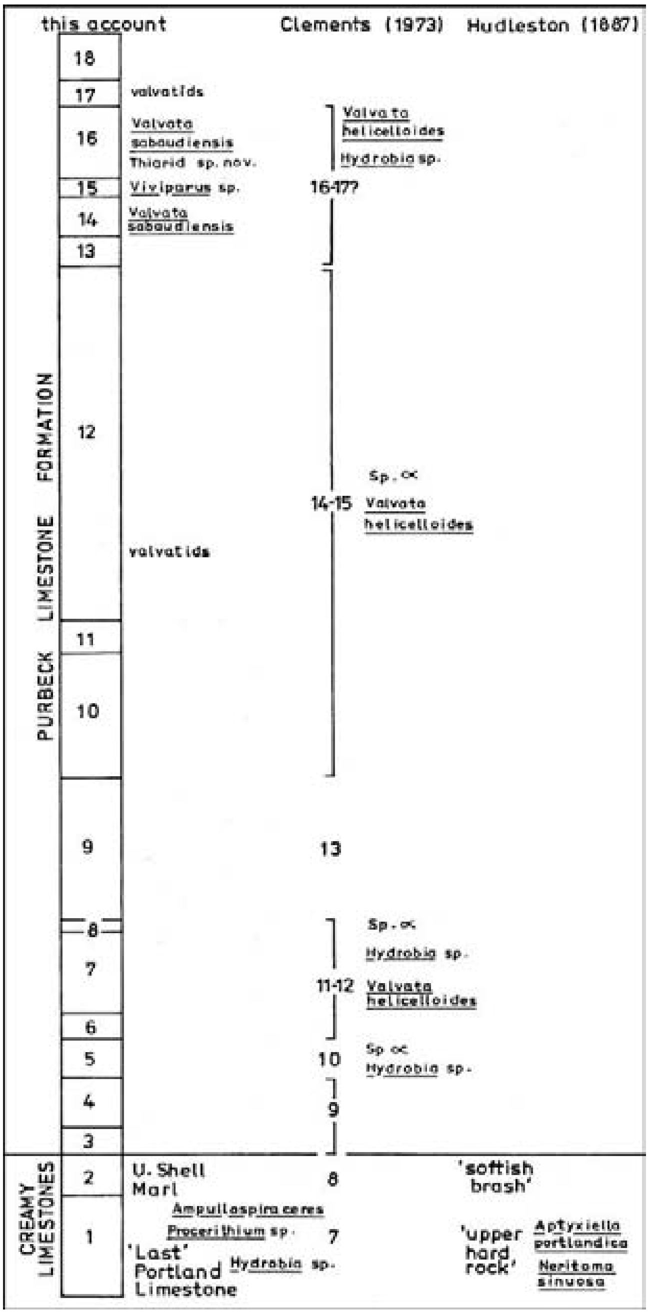

Figure 5. *Distribution of gastropods in Portlandian strata at the Bugle Pit, Hartwell, Bucks. (from Radley, 1991).*

Purbeck Formation, relatively massive micrites locally enclose dense concentrations of shell debris including *P. sabaudiensis*, preserved mainly as casts and moulds (Radley, 1991). Fossil sites include the Bugle Pit, Whaddon Hill and Warren Farm. Other, rarer taxa at the Bugle Pit include a small viviparid and a possible thiarid (Fig. 5). Additionally, *Hydrobia* sp. was recorded at Warren Farm (Radley, 1990).

Palaeoecology

Most of the gastropod taxa encountered have been previously recorded from the Portland Sand, Portland Stone and Purbeck Formation of Dorset, by Blake (1880), Cox (1925), Clements (1973) and others. Several are new records for Buckinghamshire (Radley, 1990, 1991), where the Portland Sand and Portland Stone are also rich in large bivalves, ammonites, serpulids, bryozoans, echinoderms, foraminifera and ostracods (Blake, 1880; Arkell, 1947; Barker, 1966; Radley *et al*., 1997). Normal or near-normal marine conditions undoubtedly prevailed, notwithstanding the scarcity or absence of other marine groups such as corals, nautiloids and brachiopods.

Extant pleurotomariids are unspecialised epibenthic grazers on sponges, gorgonians and other invertebrates, generally below the level of primary photic plant production (Hickman, 1984; Harasewych, Pomponi & Askew, 1988; Anseeuw & Goto, 1996; Harasewych, 2002). In Dorset, southwest England, the pleurotomariid *B. rugata* ranges from the deep-water sandstones of the West Weare Sandstones (Portland Sand Formation; Glaucolithus up to Okusensis Zone) through to the shallow-water carbonates of the Portland Stone (Radley, 1993b, Fig. 2). Radley (1993b) took the wide bathymetric distribution as evidence for an algal grazing mode, though Harasewych, Pomponi & Askew (1988) had earlier suggested that pleurotomariids had become spongivorous by the Late Jurassic. Perhaps significantly, sponge remains are widely distributed in the Portland Stone (Townson, 1975), adding weight to this hypothesis. Naticoid predatory drill-holes (Kowalewski, 1993) have not been identified in potential Portlandian prey (bivalves; other gastropods). It has been suggested that possible Portlandian naticoids such as *N. elegans* and *A. ceres* were unspecialised opportunistic scavengers and/or predators of soft-bodied organisms (Radley, 1991).

By analogy with the molluscan faunas of extant marine seagrass ecosystems (Brasier, 1975), and the shallow-water setting envisaged for the Creamy Limestone (Radley, 1991), the micromorphic fauna at the top of the 'Main' Portland Limestone (Table 1) was taken to indicate a sheltered algal 'meadow' environment (comprising areas of mud-grade sediment colonised and stabilised by rooted algae), inhabited by a phytal microfauna (Radley, 1990; Radley *et al*., 1997). Algal environments of this nature may have been widespread in Mesozoic shallow-marine settings, before the radiation of true seagrasses (Fürsich & Wendt, 1977). Recent analogues may occur along the Trucial Coast of the southeastern Persian Gulf, where gastropod-rich lime muds are accumulating in protected shallow coastal embayments colonised by seagrasses (Purser & Evans, 1973). Like Recent counterparts in tropical and subtropical vegetation-rich marginal marine environments, the abundant cerithiids may have fed upon algae as well as organic-rich sediment (Warmke & Almodovar, 1963; Houbrick, 1974; Taylor & Reid, 1984).

Nerineoid gastropods such as *A. portlandica* (Fig. 3) are interpreted as herbivorous deposit feeders. High-spired *A. portlandica* was probably at least semi-infaunal (M.J. Barker, 1990). In Buckinghamshire and elsewhere, the association of *A. portlandica* with coarse-grained shelly carbonates rich in micritised bioclasts and/or ooids (Radley, 1990, 1991; Townson, 1975; Fürsich, Palmer & Goodyear, 1994) suggests that this taxon was a deposit feeder amongst algoid-infested grains, within temporarily stabilised bioclast-rich sediment (Radley, 1991).

Among the low-diversity, essentially micromorphic fauna of the Purbeck Limestone, the provalvatid *P. helicoides* characterises high salinity facies within southern English basal Purbeck beds. Conversely, *P. sabaudiensis* appears to typify low-salinity settings in these strata (Clements, 1973; Radley, 2002). Recent valvatoids commonly occur in shallow, sheltered fresh water rich in vegetation (Yen, 1951). Such a setting is envisaged for the Purbeck fauna (Radley, 1991).

The Portlandian strata of southern England illustrate Walther's 'law' of facies (Hallam, 1975), whereby in regressive situations, successions of strata lacking major stratigraphic breaks can equate to the former offshore-onshore arrangement of facies belts. Thus, within the context of the semi-enclosed south midlands embayment (Bristow, 1968; Cope *et al*., 1992), the essentially fine-grained strata that dominate the Portland Sand and Portland Stone are taken to represent low-energy shallow marine environments influenced by minor sea-level fluctuation, passing up into the marginal-marine to non-marine Purbeck Formation (Wimbledon, 1987; Horton *et al*., 1995). Tidal effects were probably negligible, given the restricted epicontinental setting and absence of tidal sedimentary structures. A simple pattern of gastropod distribution emerges within this palaeoenvironmental framework, dominated by *B. rugata* and *N. elegans* within the mixed clastic-carbonate strata that comprise the marine succession. Algal meadows are thought to have existed close to the shoreline, inhabited by the micromorphic fauna noted herein. The 'shell marls' and 'Last' Portland Limestone (Table 1) are attributed to very shallow muddy nearshore settings, influenced by periodic current and/or wave agitation that generated molluscan bioclasts. Micritisation of this shell debris, and colonisation of the coarsest substrates by *A. portlandica* was widespread (Radley, 1991).

The Purbeck Formation represents a mosaic of coastal lagoonal, lacustrine and carbonate mudflat environments, fringing the retreating sea (Radley, 1991; Horton *et al*., 1995). Low diversity gastropod faunas, dominated by provalvatids, characterised the more permanent low-salinity water bodies (Radley, 1991). Inferred nonmarine gastropods of 'Purbeck' aspect may have been reworked into shallow-marine 'Portland' settings through alluvial runoff.

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REPORT

Carboniferous stratigraphy

Perhaps "Farewell to the Dinantian" would have been a better title, but this report relates to changes that are going to creep into the lives of all British geologists.

Following five years of deliberation by the Subcommission on Carboniferous Stratigraphy, and ratification by the International Commission on Stratigraphy and the International Union of Geological Sciences, a new official subdivision of the Carboniferous System has been adopted. This is summarised in the table below. Further details on the palaeontological definitions of the standard stage boundaries, and on some of the type localities, is at - www.stratigraphy.org/gssp.htm. Some of the new nomenclature brings notable changes for those involved with geology in the East Midlands and Pennines.

The name of the Carboniferous System is retained, but it is now divided into two subsystems, Mississippian and Pennsylvanian, with names that are taken from American stratigraphy. These do not exactly equate with the relegated divisions of Lower Carboniferous (Dinantian) and Upper Carboniferous (Silesian) used in western European.

Standard Divisions SS	Se	Stage	Regional Divisions (Western Europe) Stage	Substage		obsolete
PENNSYLVANIAN	U	Gzhelian	Autunian *(part)*		Kuzel	SILESIAN
			Stephanian		Stephanian C	
		Kasimovian			Stephanian B	
				A	Barruelian	
					Cantabrian	
	M	Moscovian	Westphalian	D	Asturian	
	L	Bashkirian		C	Bolsovian	
				B	Duckmantian	
				A	Langsettian	
			Namurian		Yeadonian	
					Marsdenian	
					Kinderscoutian	
					Alportian	
					Chokierian	
MISSISSIPPIAN	U	Serpukhovian			Arnsbergian	
					Pendleian	
	M	Visean	Visean		Brigantian	DINANTIAN
					Asbian	
					Holkerian	
					Arundian	
					Chadian	
	L	Tournaisian	Tournaisian	Courceyan	Ivorian	
					Hastarian	

SS = Sub-System; Se = Series

A largely new sequence of stage names borrows much from Russian localities, though the Visean and Tournaisian do survive from the Belgian Ardennes. Other European terms are now relegated to mere regional status, and it is accepted that these will remain in local use for some time. However, the name Dinantian, so well known for its limestones in both the Derbyshire Peak and the Yorkshire Dales, has been dispatched to obsolescence.

Though not all boundaries and correlations have yet been completely fixed, these stage names should now be used in any descriptions, and will soon become more widely recognised. In practice, the British and European terms will continue in use, largely because they are so well understood. The British and European stratigraphies do have some real advantages over the international terms, notably related to the Mississippian-Pennsylvanian boundary which lies badly within the development of the Namurian delta in northern Europe; it is totally lost within our Millstone Grit Series. Proper geological descriptions should now include correlation with the international stratigraphical sequence.

The above comments all refer to the chronostratigraphical units, which are defined by time boundaries and can therefore be correlated worldwide. A second set of names constitute the lithostratigraphic sequence, which applies to recognisable and mappable rock units referred to as Formations and Groups. These can only have local significance, as the lateral extents of individual rocks were limited by contemporary environments. A full review of Carboniferous lithostratigraphy is currently in the publication pipeline at the British Geological Survey [Waters, C N, Browne M A E, Dean M T and Powell J H: Lithostratigraphical framework for Carboniferous successions of Great Britain (onshore): *BGS Research Report* RR/05/06]; it is eagerly awaited, and will be reviewed in the next *Mercian Geologist*.

This short report has been compiled by the Editor of Mercian Geologist, with generous assistance from Stewart Molyneux (who also provided the table) and David Lowe, both at BGS at Keyworth.

Mississippian limestone at Dinant, Belgium

REPORT

Re-evaluation of the holotype *Cyclomedusa cliffi* from the Precambrian in Cliffe Hill Quarry

Precambrian rocks in Cliffe Hill Quarry, near Markfield in the Charnwood Forest of Leicestershire, have over the years yielded numerous fossils, including the discs and fronds of *Cyclomedusa cliffi*. During several visits to the quarry by the author and Leicester Museum geologists Andy Mathieson and Mike Jones in the 1970s (when access was unrestricted), a number of both large and small discs were revealed on steeply dipping bedding planes of the north face of the quarry. Further specimens were found on a large block lying at the foot of the quarry face, and this was subsequently broken up by the quarry so that three out of the five large discs on it were retrieved (Boynton, 1978; Boynton & Ford 1995). One of these discs became the holotype *Cyclomedusa cliffi* (Fig. 1).

Five other specimens in Leicester Museum have now been re-examined, along with a number of black-and-white photographs and transparencies from the author's and the Museum's collections. The following details can therefore be discussed.

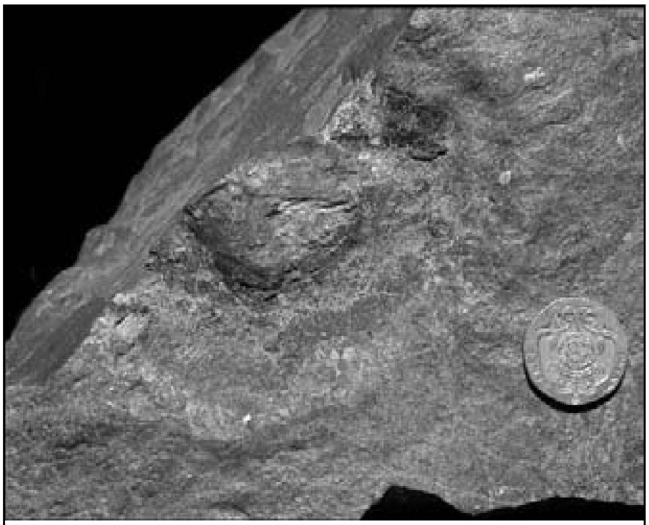

Figure 1. The holotype *Cyclomedusa cliffi* Boynton & Ford 1994. This was described as an ovoid medusoid impression, characterised by a raised, oval, central boss and an irregular outer margin, in an incomplete ovoid disc 150 x 120 mm. Within the outer margin a concentric flat area 2 mm wide surrounds a slightly depressed area 20 mm wide. The centre of the disc has a raised convex boss 30 x 22 mm across.
Leicester Museum specimen 0730.1993

Figure 2. A slightly ovoid disc with an outer irregular raised ring, with a small asymmetrically placed boss and a knotted stem emerging from it.
Leicester Museum specimen 342.1970/71.

Palaeontology

The fossils from Cliffe Hill Quarry are described alongside their photographs. Most scales are given by a 20 pence coin, which is 20 mm in diameter.

The fossil fauna from the Bradgate Formation at Cliffe Hill Quarry appears to be far more varied than

Figure 3. An almost circular disc with a wider, flat, outer ring and a large, irregular boss, with a knotted stem emerging to the right and then bifurcating. Scale is given by the lens cap 50 mm across.
Leicester Museum transparency 47210/11.

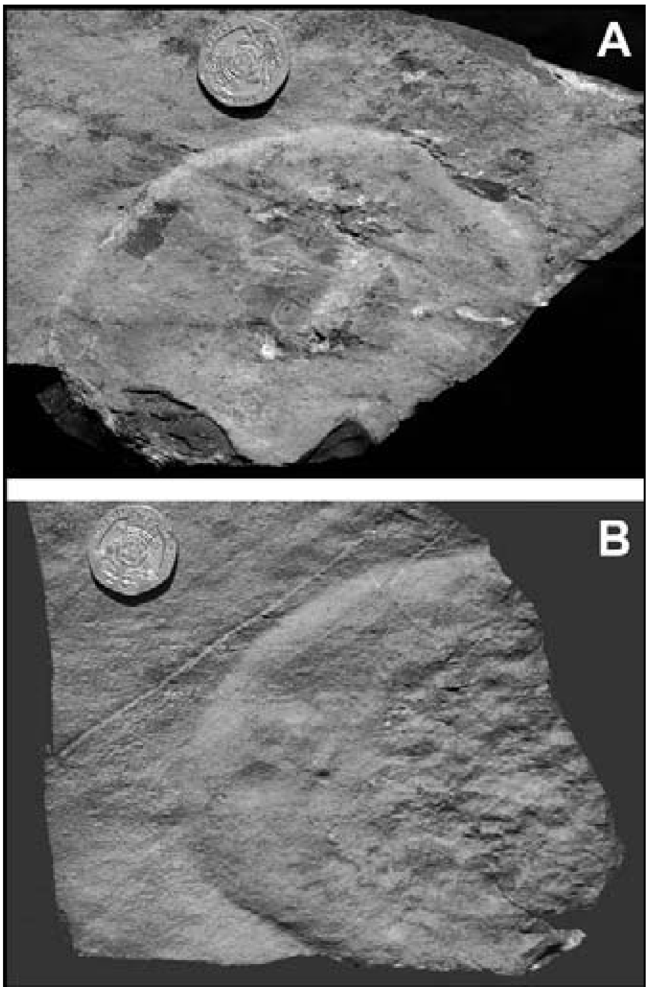

Figure 4. Two ovoid discs from the under-surface of one of the bedding planes.
A: a slightly convex ovoid disc with very little internal structure visible;
Leicester Museum specimen 487.1972/2.
B: an ovoid disc with a faint, wide, outer ring and irregular internal structure; there may be a faint trace of a stem emerging from the left side of the disc;
Leicester Museum specimen 487.1972/1.

was originally described (Boynton & Ford, 1995). It is probable that, with the discovery of two specimens each with stems emerging from a boss, the discs are not medusoids (as was originally thought), but are holdfasts of colonies of fronds, most of which are no longer preserved. They can be compared with *Charniodiscus concentricus,* which is widespread in the Ediacaran fauna. The disc with a faint bush-like mass of fronds emerging from it (Fig. 6) could be a new species of *Charniodiscus* sp., but as this specimen is no longer available for examination, no formal name is given here. There are certain similarities to a modern sea fan with anastomosing branches attached to a holdfast (Fig. 7). It is probable that some of the small discs are also holdfasts, but why they often occur in pairs is unknown. This suite of discs has not been found elsewhere in Charnian rocks.

Figure 5. Two adjacent, small discs, with that on the left in filled with dark green chlorite. These are on a bedding plane different from that containing the discs in Figure 4.
Specimen in the author's collection.

Sedimentation

The fossiliferous beds of the Bradgate Formation in Cliffe Hill Quarry consist of green to grey, parallel-laminated, volcaniclastic siltstones and mudstones (Carney & Pharaoh, 2000; Carney, 2005). These also show graded bedding, and probably represent a distal turbidite succession that is favourable to the preservation of fossils.

The strata of this fossil locality exhibit low-grade metamorphism, and are found about 150 m east of a small faulted intrusion of markfieldite of the South Charnian Diorites. The small discs show some impregnation by chlorite, which may have filled a hollow holdfast or may have replaced an internal structure. Mineralisation could have occurred at the same time as the intrusion, or during a later Acadian tectonic event, when cleavage, faulting and large scale anticlinal folding of the Charnian Supergroup took place.

Acknowledgements

The author is very grateful to John Carney, Richard Aldridge, Michael Howe and Roy Clements for their very helpful discussions, while Leicester Museum (Mark Evans) made the specimens and transparencies available for examination. John Murray took six of the photographs.

The fossiliferous bedding planes have long since been removed by quarrying, and access to Cliffe Hill Quarry is now very restricted, although may be possible with written permission from the Quarry Manager.

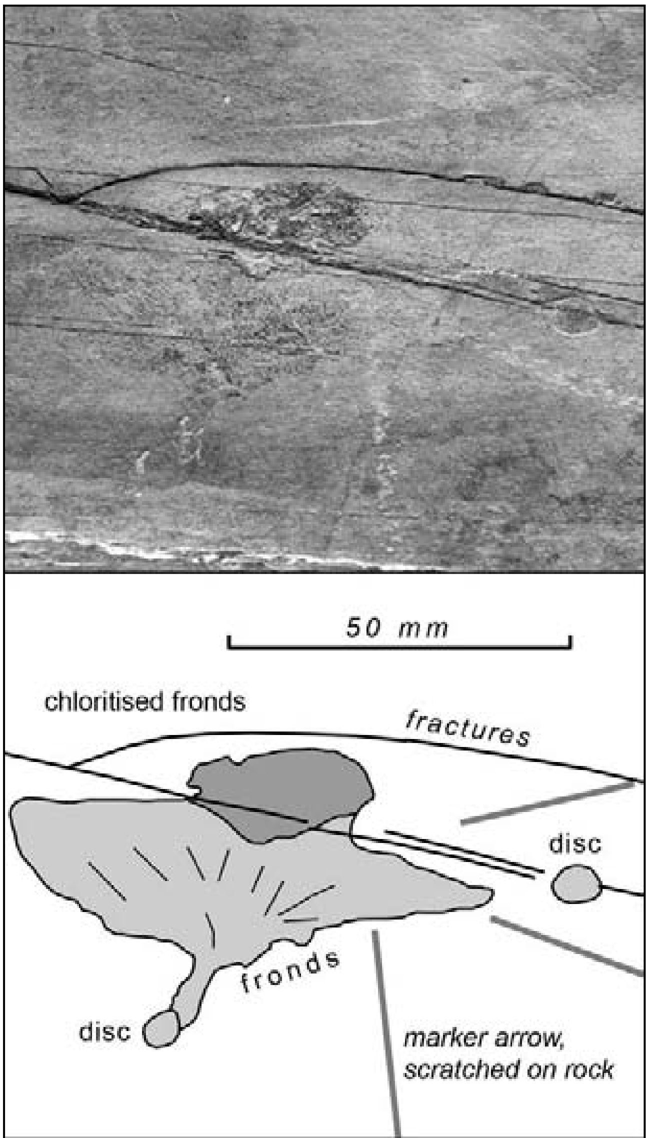

Figure 6. A colony of fronds on a thick knotted stem emerging from a disc; the upper part of the fronds is clouded by dark chlorite. The colony is about 100 mm high and 70 mm wide; it bears a resemblance to both *Charniodiscus concentricus* and to a modern sea fan (Figure 7). There is a second small disc on the same bedding plane.
Photograph by the author in 1976, and interpretation. The bedding plane has since been lost in quarrying.

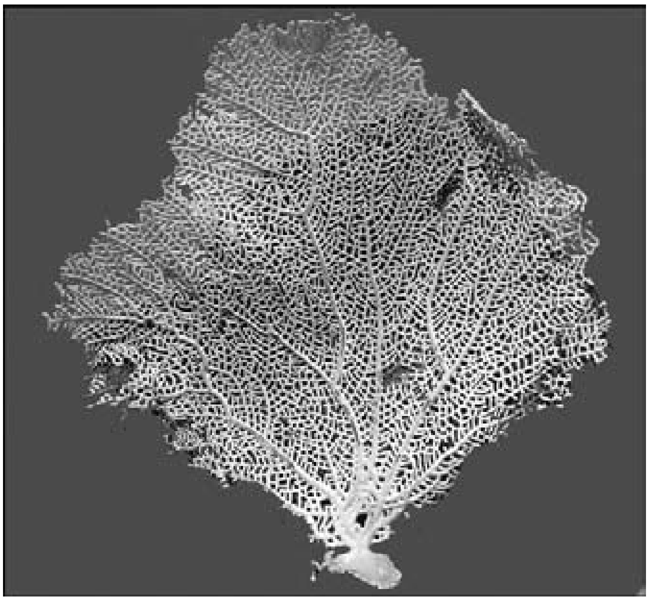

***Figure** 7. A modern sea fan, about 240mm across, for comparison with* Charniodiscus concentricus.

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REPORT

Manganese mining in the Peak District

The Carboniferous Limestone of the Peak District in Derbyshire is well known as the host rock for numerous mineral veins containing lead, zinc and copper ores, as well as the gangue minerals fluorspar, barytes and calcite. All have been exploited at various times and many hundreds of old mines can be traced along the mineral veins. But there are several other less common minerals which have had economic importance. Most literature on the region either totally ignores them or at best gives them a one-sentence mention. Any applied geologist studying such an area as the Peak District should be aware of these minor mineral deposits and give them due attention. Apart from fluorspar, barytes and calcite, all still produced today, there was once active mining for the zinc ore sphalerite, smithsonite (zinc carbonate, locally known as calamine), iron ore, chert and manganese wad.

The wad is an impure deposit of a mixture of manganese and iron oxides (Ford, 2001). The former is chiefly present as the hydrated manganese oxides pyrolusite and psilomelane whilst the latter are earthy hematite or limonite, but no modern analyses of Derbyshire material could be found in a literature search. Elsewhere wad has been determined as birnessite, a hydrated manganate of sodium, calcium and potassium; this may well be present in Derbyshire wad, but no analyses are known to have been made.

Wad Deposits

Workable wad deposits were at least 50% manganese oxides in layers generally less than half a metre thick found within sand and clay fills of caverns close to the contact of dolomitized and unaltered limestone. These have long been worked out and none of the recorded deposits is accessible for study today. However, open-pit fluorspar mining does occasionally reveal wad deposits, as in Winster Moor Spar Pit (SK234597) where several layers were seen interbedded within coloured clays in April 2005 (Fig. 1).

The formerly mined deposits were in sub-surface phreatic solution caves, mostly with no known natural openings to the surface, though there must have been some fissures for the sand and clay fills to have been washed in later. The fills were probably early Pleistocene glacial outwash but without samples it is difficult to be sure. A thin layer of wad-like material is present in a sand and clay fill in the Golconda Mine, near Brassington (Fig. 2), but it is not thought that it was ever worked there. Small patches of wad, up to about 30 cm across, have occasionally been found around the margins of the silica-sand Pocket Deposits (Mio-Pliocene Brassington Formation) that lie near Brassington. Subsequent collapse of these Brassington Formation sands and clays has resulted in the former horizontal sheet of sediments sagging into hollows, but no wad deposits are visible at the time of writing. Locally known as pockets, the collapses are thought to have occurred in the early Pleistocene, so both cave and pocket wad deposits can be regarded as having been formed during Pleistocene times.

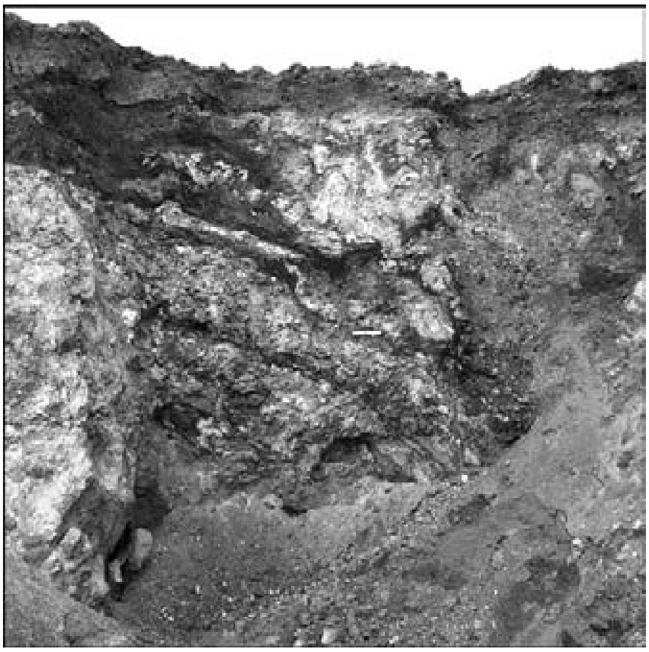

Figure 1*. Wad deposits in Winster Moor fluorspar open pit.*

Manganese coatings are sometimes present on pebbles in stream caves; these are thought to be of bacterial origin, deposited from sinking streams flowing off the Millstone Grit country.

Deposits with considerably less than 50% manganese oxides were brown in colour and known as umber. As with wad, umber was used in paint manufacture but little is known of this aspect of the pigment industry.

The distribution of wad deposits is largely related to the boundaries of the dolomitised areas of the White Peak, with the principal workings being in the Elton and Winster area, west of Matlock (Fig. 3). Between those villages, Heyspots Mine had the largest recorded yield; it lay on part of the important lead ore deposit in the Portaway Pipe vein, but unfortunately its workings have long been inaccessible and no mine plans are known to survive. Other wad deposits were around Brassington, Parwich and Youlgreave. Indeed a field name near Kenslow Knoll (one of the Pocket Deposits southwest of Youlgreave) is Manganese Close.

The source of the manganese and its mode of concentration are problems still requiring research. Whole rock analyses of the Carboniferous Limestone show traces (generally around 100-200 ppm) of MnO in pore-filling cements in some limestones and in a few microfractures in calcite veins, but this trace proportion seems unlikely to be have been enough to account for the wad deposits. Detailed studies of the geochemistry of limestones in Longcliffe Quarry

(Pugh, 1994) revealed around 60 ppm Mn as impure rhodochrosite forming a thin early phase of pore-filling cement. Microfractures in calcite veins occasionally had a few traces of rhodochrosite (Bennett, 2004). However, the amount of manganese present in these cements and fractures is far too small to account for the tonnages of wad that were mined, unless some means of concentration can be found: none is known at present. No records have been found of macroscopic manganese minerals in the lead-zinc-fluorspar-barytes veins.

Analyses of dolomitised limestones (Harrison & Adlam, 1985) generally show much higher manganese figures (mean 1014 ppm) than in the limestones (638 ppm). Weathering of dolomite could release manganese into the soil whence percolating rainwater carried it into sub-surface cavities. Once in the cave environment increased alkalinity of limestone waters presented an environment suitable for manganese oxide precipitation in preference to iron hydroxides, particularly at the permeability changes where clay beds are interlayered with sands. Oxidation from the soluble bivalent ion to the insoluble quadrivalent ion causes precipitation of managanese oxide minerals (Hill & Forti, 1997, 2004) and this mechanism may well have operated in Derbyshire. Elsewhere, bacteria have been shown to precipitate manganese oxides (Engel, 2005) so it is possible that bacteria were an active oxidation agent in the Peak District, but without appropriate microbiological analyses it is difficult to confirm their presence.

***Figure 2**. A minor wad layer in a sand fill in a cavern in the Golconda Mine, near Brassington.*

Mining and processing

Mining wad was simple: a pick and shovel were all that was needed to dig into the sand-and clay fills, taking care not to mix them with the wad.

Once raised to the surface, wad required some processing to remove lumps and to clean away unwanted sand and other rock fragments. There were several local mills, e.g. at Matlock Bath, Wensley and near Bonsall, but none has survived. The little that is known of the processing was summarized by Paulson (1997). It appears that the wad was ground to an even grain and subjected to levigation – an early form of flotation - to separate it from waste sediment. It is not clear how excess iron oxides were removed.

Uses of wad

The use of Derbyshire wad was first recorded by the pioneer chemist Robert Boyle in 1670 but no other details are known. By the mid 18th century artists in Derby such as Richard Roe sought it as a pigment. While its black colour had an obvious attraction, there were other less expensive black materials available, but wad was valued for its property of accelerating drying of paint by oxidation of the oil carrier in the mixture.

A letter contributed to the Derby Mercury on December 4th 1783 (kindly supplied by Roger Flindall) adds a little more:-

As I know you wish to propagate all Kinds of useful Knowledge to your entertaining Paper, I send you the following , viz. "There is a light black earth found about Matlock and Porridge which they call WAD, and which has lately been much used as a Pigment, or Colour to cover Ships with. This Black Earth is an ORE of Manganese, and, when mixed with Lime, will make a Mortar, which will set firmly under Water, as is lately discovered by Professor Bergman, of Upsal**. About 20 years ago, Mr Roe, a Painter of Derby,observed this Black Earth, when mixed with Linseed Oil, spontaneously to take Fire: I am lately informed, that to produce this Effect, the Oil must be very rancid.*

Yours etc X.Y.

** Porridge is now known as Parwich.*
*** Upsal is now known as Uppsala in Sweden*

The letter goes on to mention that manganese was used in glazing blue tiles in Staffordshire, but no details were given.

From the 1780s wad was much in demand for use in treating ships' bottoms, indeed in the Napoleonic wars there was a strong government demand for wad to be used on Royal Navy ships' bottoms. Again, while its

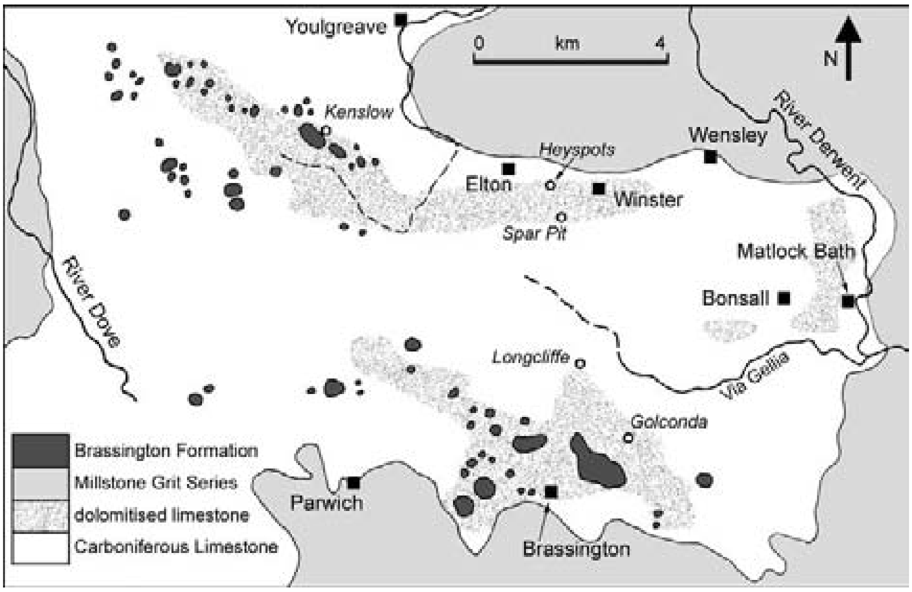

***Figure 3**. Wad mining localities in relation to dolomitised limestones and silica-sand pockets in the Peak District.*

colour was an attraction, it was much more important as a desiccating agent hastening paint drying. Paint in those days was based on either linseed or tar-oil: with a component of creosote as a wood-preservative; it took days if not weeks to dry without the addition of wad, so the drying agent was vital.

Another use for wad was mixing it with hydrochloric acid to yield chlorine gas used in bleaching textiles. Later the chlorine was combined with powdered lime as bleaching powder. In 1790 a factory was set up at Widnes to produce bleaching powder and it became one of the founding factors of that area's chemical industry today.

Small quantities of manganese oxides added to molten glass reduce the colour imparted by too much iron in the glass sand, a phenomenon known in ancient Egypt. It is not known if any Derbyshire wad was used for this purpose.

Manganese metal was not recognized as a separate chemical element until 1774. In 1839, alloying manganese with steel was found to yield a very hard metal which later became important in munitions production and demand grew rapidly. However, no record of Derbyshire wad being sold for metallurgical purposes has been found and the limited quantities of wad available make it unlikely that it was ever used in such alloys. Manganiferous beds in the Cambrian successions of the Harlech Dome were the main British sources of manganese for steel alloy manufacture. Minor quantities were raised from mines in equivalent Cambrian strata near Nuneaton.

Production

Regrettably few production figures for late 18th and early 19th centuries are available, but from 1876 to around 1904 a total of just under 5000 tons was recorded (Burt et al., 1981), and it is reasonable to surmise that at least as much was raised before 1876, making a total yield of around 10,000 tons, perhaps as much as 15,000 tons. Such a figure is much smaller than those for lead ore and fluorspar production, and it is possible that the mining companies concerned regarded it only as a profitable sideline. Heyspots Mine, near Winster, had the highest recorded production yielding 573 tons in four years 1877-1881. With lead ore being the principal product raised from that mine and the adjacent Portaway Pipe, wad on its own would not have made much of a living.

Acknowledgments

Thanks to Jim Rieuwerts and Roger Flindall for much useful information, to Roy Paulson for a copy of his thesis, and to Lynn Willies for photographs of the Winster Moor deposit.

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Trevor D. Ford, University of Leicester

REPORT

Bobkingite – the untold story

It is not often that a new mineral is discovered, anywhere in the world. This is an account of how it happened on our doorstep, and how the persistence of its discoverer, Neil Hubbard, finally paid off.

Our story begins in August 1993, in Charnwood Forest. Neil Hubbard was walking round the newly created footpath at the base of a man-made hill that was part of the screening to the New Cliffe Hill Quarry. Judging by all the debris, this hill evidently contained many tonnes of interesting copper mineralisation, and in a nearby drainage ditch was a lump of cuprite and malachite, about the size of a house brick but broken in two. Within the cuprite were tiny sprays of dark blue connellite, a complex chloride and sulphate of copper. This was sufficient to warrant collection and within a few days Neil had carried out a microscope study, by carefully breaking down one of the samples. Not much was found at this stage, but in the spring of 1994 the second piece was examined.

Again, very little was found and it was not until the last small fragment was investigated that the real discovery was made. The fragment was broken down into four pieces, each smaller than a thumbnail, and on investigating the first of these by microscope, a pale blue platy mineral, in crystals less than 1 mm across, became immediately apparent. The same mineral appeared in each of the other three pieces and on checking various reference books, the closest comparison seemed to be with claringbullite, a very rare, pale blue, platy copper chloride that occurs with connellite in cuprite. As claringbullite had not previously been found in the UK, such a potential identification was obviously of major importance, so Neil decided to seek confirmation by sending a piece for X-ray analysis at the Department of Mineralogy of the Natural History Museum in London.

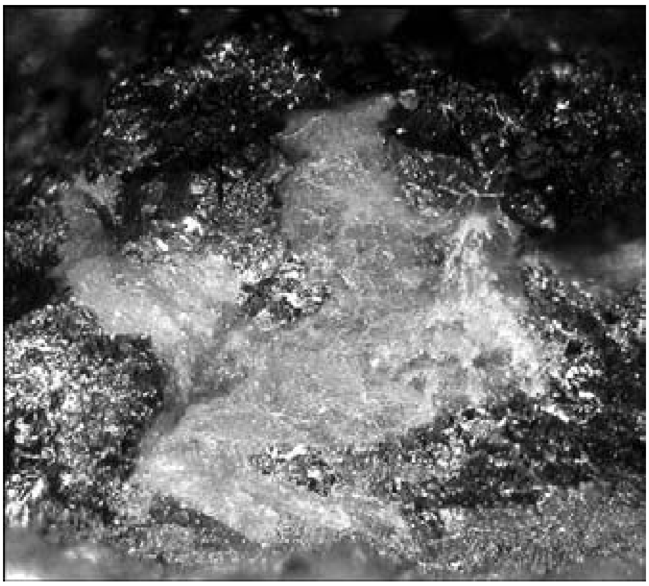
Here commences the next part of the saga. A couple of months later, Neil received a letter from the museum saying only: “pale blue platy crystals, New Cliffe Hill Quarry, Leics. X-ray 9833F = unknown (good pattern)” and asking if there was any more sample to probe, in order to obtain a qualitative analysis. A second sample was sent to the museum, which duly reported back within a couple of weeks confirming that the mineral was indeed a copper chloride. As there was not enough of it to do any further work, however, they asked to keep the two samples in case more of it became available later. Neil was now left with only two tiny specimens of a probably rare, but as yet unidentified, mineral.

The big break came in the February of 1999, when Neil attended the largest mineral, fossil and gem show in the world at Tucson, Arizona. There he met Frank Hawthorne of the University of Manitoba, but a native of Somerset and probably the world leader in determining the crystal structures of minerals. Frank happened to be working on the structures of copper chloride minerals and was keen to see the samples from Cliffe Hill. Unfortunately, the Natural History Museum did not reply to Neil’s request for their return, so the two remaining samples - possibly the last in the world - were sent off to Canada.

The gamble paid off in July of 1999, when Frank reported that this was a new mineral, and provided the details of its chemical formula and crystal system. Neil decided to name the mineral ‘bobkingite’ after Dr R J King, formerly of the geology department of Leicester University, founder of the Russell Society and the person who has perhaps done more than anyone else to promote the mineralogy of Leicestershire.

All that remained to do was to write a short account of the geology and minerals of New Cliffe Hill Quarry, which was added to the formal description of the mineral. A paper describing the discovery subsequently appeared in the Mineralogical Magazine of April 2002, Vol. 66, pp. 301-311, written by F C Hawthorne, M A Cooper, J D Grice, A C Roberts and N Hubbard; its title was: “Description and crystal structure of bobkingite, $Cu^{2+}_5Cl_2(OH)_8(H_2O)_2$, a new mineral from New Cliffe Hill Quarry, Stanton-under-Bardon, Leicestershire, UK”.

John Carney



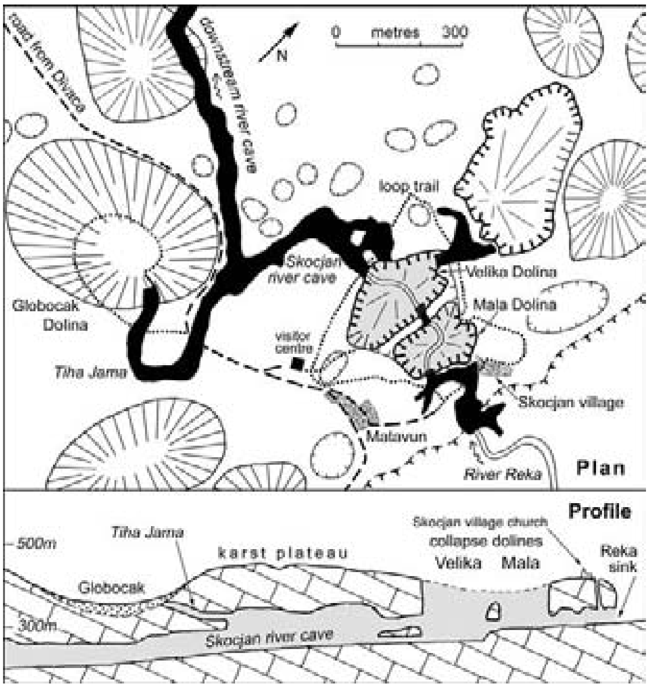
Bobkingite is pale green and blue, but looks unremarkable in black-and-white; see the colour image on the back cover; this photograph is just 1.5 mm across. (Photo: David Green, Manchester Museum)

Skocjanske Jame, Slovenia

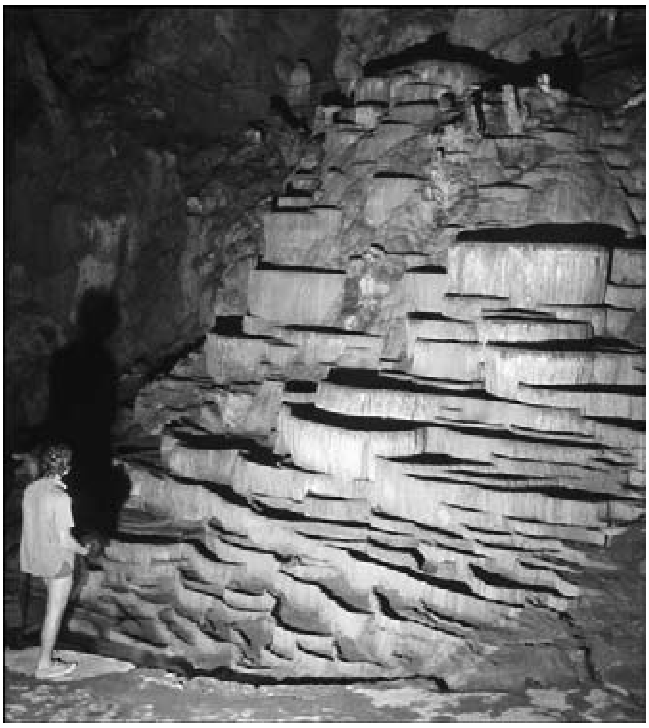
The swathe of limestone that reaches down the Dinaride Mountains of what used to be Yugoslavia gave its name to karst - the landscape of limestone - from the local word *kras*, meaning stony ground. Now the Dinarides are in two parts. The white islands and rocky coasts of Dalmatia lie within Croatia, while Slovenia has the best of the inland karst - including the best of the caves that are the arteries of the underground drainage characteristic of karst.

Postojna has the best-known tourist cave. Its huge visitor complex is a major local industry, swallowing thousands of visitors who take a train ride into the caves and then walk around huge stalagmite chambers in groups designated by half a dozen languages. Postojna is magnificent, and well worth a visit, but the *cognoscenti* head for Skocjan - one of the world's great caves, and maybe the finest show cave anywhere.

It's not so easy to find the Skocjan Caves (Skocjanske Jame), because all the advertising and most of the signs have been taken over by Postojna - who have the local economic clout. Head for Divaca, half-way along the motorway from Postojna to Trieste. A car is nearly essential, as there are no trains and few buses, and the coach trips all whiz past to Postojna. From Divaca it's just a few kilometres southeast to the tiny village of Matavun. Skocjan is a great tourist site without crowds of visitors.



Map and profile of the Skocjan Cave



Terraced calcite rimmed gour pools beside the tourist path.

The karst landscape is all cut into Cretaceous limestones that form the southeast sector of the Kras plateau. Draining in from flysch and shale outcrops further southeast, the River Reka sinks into the cave's grand entrance at the edge of the limestone. The water flows through the Skocjan river cave, and is then lost into flooded passages; it is next seen at the resurgence just above the coast near Monfalcone, 32 km away, and 20 km northwest of Trieste.

From the small visitor centre, the cave tour starts with a walk back along the road and then down a country lane, to a steep descent into a giant doline; this is Globocak, 500m across and 90m deep. Near its floor, a short tunnel passes through the breakdown and fallen rock that lines the doline slopes, and leads straight into the end of a very old cave passage - Tiha Jama. Comfortably large, and liberally decorated with stalactites and stalagmites, this could constitute a delightful show cave on its own. But it is just a high-level distributary, abandoned when the river cut a newer and lower level. And it ends on a balcony - a viewpoint high above Skocjan's enormous river passage.

Far above the cave river, the tourist path has been engineered along a high ledge and across a bridge that spans the river far below. The underground canyon continues into darkness downstream; its exploration during the 1880s was a remarkable feat. Today's path turns upstream on various ledges until it descends to the banks of the cascading cave river. This part of the river passage is over 50m high and wide. Few others in the world match its size. There are just enough lights to see around, and there is a lot of space. Visitors cannot fail to be struck by the huge powers of erosion that have carved out the massive tunnel.

The tourist trail then rises into a high-level passage, passes a splendid set of terraced gour pools dammed by walls of calcite, and emerges into the huge Velika doline. Cliffs and rock crags give this a more rugged profile than the smooth Globocak - because Velika is a collapse doline. It formed by roof collapse into the river passage and then expanded by progressive cliff retreat; more than 150m deep and wide, it is large enough to be known as a tiankeng (a term from China's karst). The long steps back up to plateau level are now been replaced by the comfort of a cable car, which ends just behind the visitor centre.

Don't leave straight after the cave tour, but take a walk round the loop trail from the visitor centre. This circles the Velika doline and the adjacent Mala doline, and offers a pleasant stroll back through Skocjan village. If time is short, just go clockwise to the viewpoint above the western cliff of Velika. This offers a spectacular view across both giant dolines, and clear down to the cascading river. It's a very dramatic demonstration of the large-scale collapse processes that occur in a karst landscape.

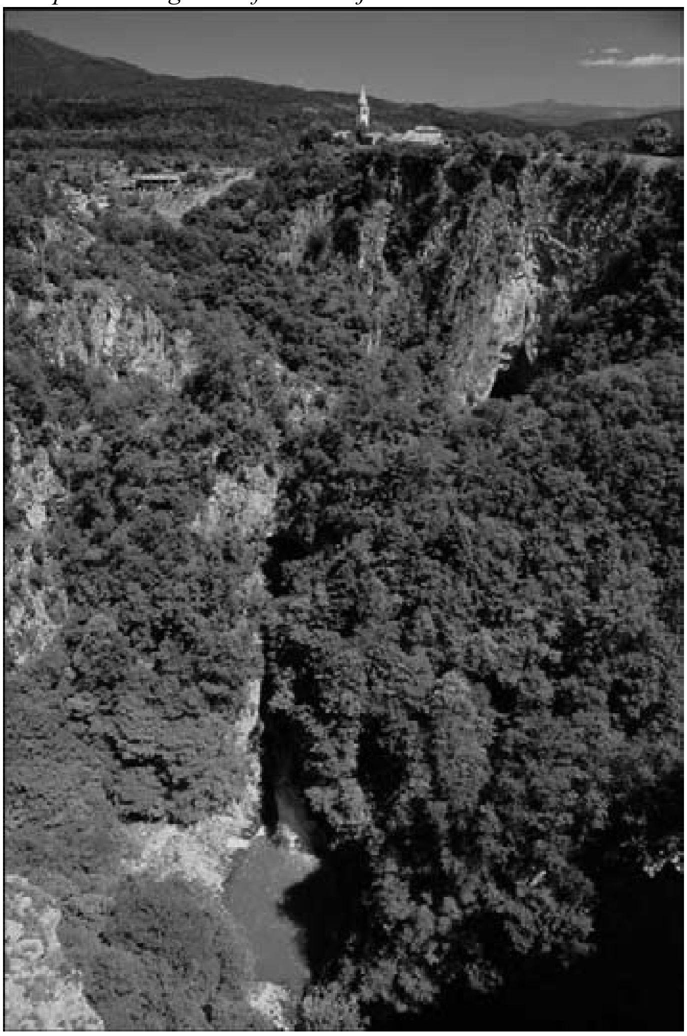
Anyone with any interest in geology and the natural world, who is driving down to the Croatian holiday coast, should make the short diversion to take in Skocjan. It is unforgettable geology-in-action.

Tony Waltham

The river passage just inside from Velika Dolina.

The tourist trail bridge over the underground canyon.

The view eastwards across the Velika and Mala collapse dolines, with Skocjan village church on the cliff above the upstream segment of the Skocjan cave.



HOLIDAY GEOLOGY

Galapagos Archipelago

Though a main reason for a holiday in the Galapagos Islands is the unique opportunity to see the wildlife at close hand, there is much to interest geologists, for the islands are among the world's most active volcanic areas. Of the many recent eruptions, the latest was in the Sierra Negra caldera on Isabella Island in October 2005. Moreover, the location in the trade winds and in an area of major oceanic current mixing has lead to a climate with moist highlands but arid lowlands. Erosion is slow in the latter, and the lavas, tephras and volcanic structures are all well preserved (Fig. 1).

The Galapagos lie on the equator, about 1000 km west of Ecuador, as an archipelago of thirteen large islands and six smaller islands together with many small islets, all formed by basaltic volcanism. Each island appears to be a single volcano except Isabella, which consists of an arcuate chain formed by merging of six volcanoes. The archipelago stands on the Nazca plate, just south of the Galapagos spreading centre that separates the Cocos and Nazca plates, and the islands rise from a broad shallow platform near the crest of the East Pacific Rise.

The archipelago is thought to have originated by passage of the Nazca plate, ESE over a hotspot known as the Galapagos mantle plume. Thus, the oldest island, Espanola, which is volcanically extinct, lies to SSE and beyond that is a chain of seamounts, forming the Carnegie Ridge, extending towards South America. A second seamount chain, the Cocos Ridge, extends NE from the Galapagos spreading centre on the Cocos plate and was produced about 5M years ago, when the spreading centre was situated over the mantle plume. Since then the spreading centre has migrated northwards leaving the plume beneath the Nazca plate. The youngest islands and most volcanically active are Isabella and Fernandina in the NW of the archipelago, which now lie directly above the hotspot. The islands do not form a single or dual line of volcanoes, but (as noted by Darwin, 1860) are oriented in two alignments ENE and NNW. These appear to have no relationship either to absolute plate motion (easterly), or to plate divergence (southerly). Their orientation has been ascribed to subjacent lithospheric fractures (McBirney & Williams, 1969).

Volcanism

Galapagos volcanoes are basaltic shield volcanoes, and two different morphologies are seen. In the east, smaller volcanoes with gentler slopes are akin to those of Hawaii occur and likened to upturned saucers. In the west the shields are unusual in having gentle lower slopes that steepen above to slopes of ~30º, before flattening at the summit, to create the profile of an upturned soup bowl (Fig. 2).

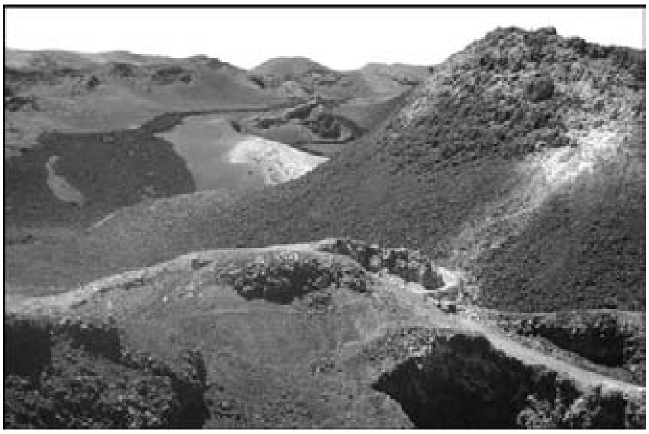


***Figure 1**. A dark flow of fresh lava amid a landscape dominated by parasitic volcanic cones of tephra and spatter on Isabella Island.*

The cause of this non-uniform profile may be the presence of intrusive sills, ring dykes or cone sheets that support the steeper flanks at high levels. Alternatively, the profile may be created by an abundance of vents along concentric fissures that are circumferential to the flat summits, while fewer radial fissures are the only vent sites on the lower flanks and aprons. An arresting feature of the Fernandina volcano is the swarm of arcuate fissures around the caldera, and no other volcano in the world shows this feature so vividly (McBirney & Williams, 1969).

The contrast in volcano profiles may relate to differences in lithospheric strength and thickness beneath the western and eastern islands, as a fracture zone at 91ºW separates oceanic lithosphere of different ages. West of the fracture zone, the lithosphere is older, colder and thicker, better able to support the load of a large volcano than younger lithosphere to the east (White, 1997).

The western volcanoes are characterised by large deep summit calderas due to collapse of the subjacent magma chamber. That on Sierra Negra is about 10 km in maximum diameter. The collapse of a caldera appears to be episodic, and a partial collapse on Fernandina in 1968, when the floor dropped by over 300m, is recorded by McBirney and Williams (1969).

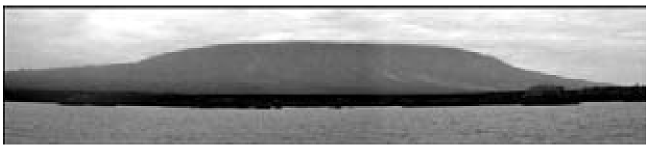


***Figure 2**. The shield volcano on Fernandina Island, with the inverted-soup-bowl profile characteristic of the western volcanoes. Local cloud cover is due to temperature inversion that creates the garua mist at high levels.*

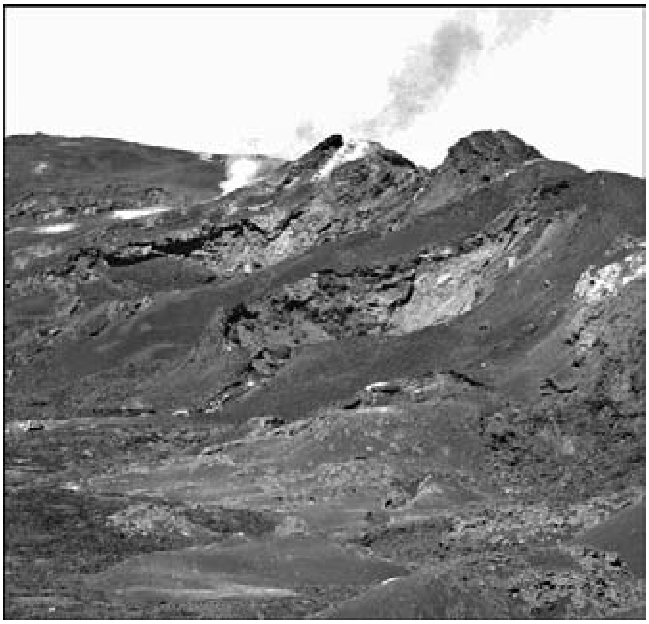


***Figure 3**. Active fumaroles on the caldera rim of Sierra Negra. (Photo: Ron James)*

Sierra Negra, Isabella Island

This volcano erupted for several days in October 2005, producing lava flows into the caldera and also down the northeast slopes. On our visit, about one month later, the lava flows had ceased but fumaroles on the caldera rim were still active (Fig. 3) and vegetation on the caldera floor had been burnt off. Fresh lava flows covered the northeast sector of the caldera floor, and some appeared to have originated at vents along circumference fissures near the caldera rim (Fig. 4). Myriads of fine filaments of fragile golden Pele's hair were scattered over the surrounding landscape downwind of these recently active vents.

***Figure 4**. The Sierra Negra caldera with recent lava flows down its wall and across its floor. (Photo: Ron James)*

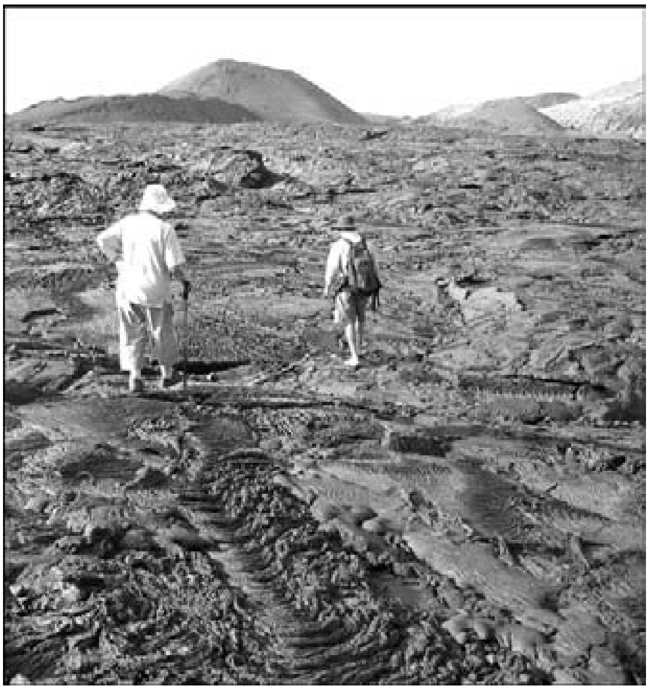


***Figure 5**. Lava flows and tephra cones at Sullivan Bay.*

Sullivan Bay, Santiago Island

The southeast end of Santiago Island is a barren waste of black lavas, dotted with spatter and driblet cones. Two large buff-coloured palagonite tuff cones dominate the landscape at the bay (Fig. 5) and have arisen from phreato-magmatic eruptions of basaltic lava through water-saturated rocks (McBirney & Williams, 1969). The lava flows are generally smooth, either flat or gently undulating, and including spectacular examples of pahoehoe (Fig. 6).

Flank eruptions were recorded here in 1897, and were pre-dated by active lavas recorded by FitzRoy, predate these. Yet a striking feature is that the delicate surface features of the lavas are still preserved and appear to have undergone little erosion.

Darwin (1860) was struck by the numerous tuff cones on the Islands, and San Cristobal reminded him of the Midlands: *one night I slept on shore on part of the island where black truncated cones were extraordinarily numerous: from one small eminence I counted sixty of them, all surmounted by craters more or less perfect. The greater number consisted merely of a ring of red scoriae or slags cemented together and their height above the plain of lava was not more than from fifty to one hundred feet: none had been very lately active. The entire surface of this part of the island seems to have been permeated, like a sieve, by the subterranean vapours: here and there the lava whilst soft has been blown into great bubbles; and in other parts, the tops of caverns similarly formed have fallen in leaving circular pits with steep sides. From the regular form of the many craters, they gave to the country an artificial appearance, which vividly reminded of those parts of Staffordshire where the great iron foundries are most numerou*s.

***Figure 6**. Intestinal pahoehoe basalt at Sullivan Bay.*

Climate

The islands are isolated and surrounded by hundreds of kilometres of open ocean, and the climate is largely determined by the ocean currents and the trade winds. The islands' climate is therefore surprisingly comfortable, as Darwin commented: *Considering that these islands are placed directly under the equator, the climate is far from being excessively hot; this seems chiefly caused by the singularly low temperature of the surrounding water, brought here by the great southern Polar current.*

In fact the Galapagos are situated at a meeting point of several major ocean currents: the Humboldt Current sweeping north from the Antarctic, the warm Panama Current from the north and the cold equatorial counter-current. The intensities of the currents vary cyclically as the trade winds that blow them weaken and strengthen, giving rise to two distinct seasons. For most of the year the islands are cooled by the Humbold Current, which is energised by the Southeast Trades. On reaching the Galapagos platform the cold waters of the deep current surface to cool the overlying air immediately above, and thus produce a temperature inversion in the atmospheric column. The column contains much evaporated moisture, and when the inverted layer is intercepted by the high volcanic mountains it is condensed as a high level mist known as the *garua*. The cool season lasts from May to December, producing moist damp highlands but arid dry lowlands and low lying islands. Erosion of volcanic tephra at these low levels is reduced and surface features of great age persist in apparently fresh forms.

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Gerard and Brenda Slavin

REPORT

Visean coal seam in Crich Quarry

Limestone quarrying in late 2004 at the northern end of the Crich anticline (beyond the Tramway Museum), on the eastern margin of the Derbyshire Dome, revealed a coal seam within the Visean succession of the Carboniferous Limestone (Fig. 1). This report places the coal on record before its loss by quarrying. It also raises some questions of palaeo-environmental significance that are briefly discussed below.

Description

The coal is variable in thickness, up to 300 mm at maximum, and is exposed over a distance of around 100 m (Fig. 2). It is crumbly with streaks of mudstone, and rests on a clay wayboard that is also of variable thickness, averaging about a metre. This in turn lies on an undulating, "potholed" surface of the underlying limestone. The coal is capped by higher limestones, some 10 m thick, with a sharp but undulating base.

Previous research

While thin coals, up to 50 mm thick, have been recorded on wayboards elsewhere in Derbyshire over the last century and a half (Worley & Dorning, 1977), this exposure of Visean coal at Crich is exceptional. It is a new record, as it was not mentioned either in the Geological Survey Memoir (Frost & Smart, 1979) or in Bridges' study of cyclic sedimentation in the Carboniferous Limestone of Crich (Bridges, 1982). A brief note by Sargent (1912) referred only to a former exposure of coal at an unspecified locality "near Matlock".

Stratigraphy

The stratigraphical position of the Crich coal seam appears to be close to the boundary of the Monsal Dale Limestones (formerly Matlock Limestones) and Eyam Limestones (formerly Cawdor Limestones), both of upper Visean (Brigantian) age. The underlying wayboard appears to be that recorded as Clay Horizon D in Bridges' (1982) study of cyclic sedimentation in the limestones, though he did not mention any coal being present; nor did he offer any stratigraphic correlations between the areas around Matlock and Wirksworth.

Discussion

The cyclic sedimentation within the limestone sequence (Bridges, 1982) signifies transgression-regression cycles, and it is in these that coal represents maximum regression with emergence to form land areas. Equivalent cyclic shallowing has also been recognized in the nearby Wirksworth area (Oakman & Walkden, 1982), though few traces of coal were noted. The carbonate cycles there mostly end with some evidence of emergence above sea level, marked by palaeosol textures in the limestone representing caliche and rhizoliths as evidence of soil-forming processes in the topmost carbonate sediments. These carbonate palaeosols are capped by clay wayboards representing air-fall dust tuffs, which Walkden (1972) demonstrated to be degraded volcanic ash layers, also known as K-bentonites. The dust tuffs may well have been palaeosols but do not show evidence of soil textures. The tuffs rest on "potholed" palaeokarstic surfaces (Walkden, 1974; Vanstone, 1998), which are widespread within the Carboniferous Limestone of Britain (e.g. Davies, 1991). Outside the Peak District the potholed surfaces are commonly covered by mudstone seat-earths as they are in areas without obvious volcanic associations. Davies (1991) noted that clays in Anglesey also contained K-bentonites, possibly contributed by wind-blown dust from distant eruptions, and were apparently bound by rootlets.

The sharp but undulating base to the limestone that caps the coal suggests a period of erosion, before a sharp rise in sea-level led to submergence in the transgressive phase. The succeeding limestones are coarse-grained indicating the deeper part of a shallowing-upwards cycle. As no coal was recorded either in the Geological Survey Memoir (Frost & Smart, 1979) or by Bridges (1982) it could be that the

***Figure 1**. The coal at Crich (with 200mm bands on staff).*

Figure 2. The quarry outcrop of the coal seam within the Carboniferous Limestone at Crich; the coal lies over the pale shale that forms the lower part of the face in the foreground.

coal seam was not exposed at Crich during their research or is only present over a limited area due to Carboniferous erosion.

The Crich "coal" is in reality a crumbly and highly pyritic carbonaceous mudstone. The crumbly nature suggests a predominance of fusian, derived from comminuted vegetable matter. Pyrite is common in such coals, and often occurs in the limestones adjacent to waybords and lavas elsewhere in the Peak District.

None of the thin Dinantian coals associated with wayboards elsewhere in the Peak District has been described in detail as to its content of clarain (fossil wood), durain (comminuted vegetable matter such as twigs, leaves, spores etc) or fusain (partly oxidised leaf detritus), but some accounts note the "sooty" nature of the coals, suggesting fusain. From this, it may be inferred that the coals were largely comminuted vegetable matter that drifted in from surrounding areas such as emergent islands covered with low scrubby vegetation instead of trees. Transported vegetable material would explain the lack of root structures. However, Dorning (in Worley & Dorning, 1977) recorded spores of lycopod trees in a thin coal at Tearsall, west of Matlock, indicating the presence of at least a few trees on what must have been islands somewhere on the carbonate platform. The new exposure at Crich has little sign of clarian, denoting either few trees or drifted trunks.

The duration of coal formation is uncertain though Walkden (1974) argued that the accumulation of dust-tuffs could have taken anywhere from 30,000 to 100,000 years. A comparable period would be necessary for the growth of vegetation and accumulation of enough peat to form 300 mm of coal.

The much better known coals in the later Coal Measures normally rest on seat-earths (fireclays or ganisters) with ample evidence of tree roots, either as carbonised rootlets normal to bedding or as the much larger structures commonly known as Stigmarian roots. None of the wayboards in the White Peak has been reported to carry either rootlets or *Stigmaria*. The new exposure of coal at Crich also appears to be without roots or rootlets in the underlying clay wayboard. Their absence also indicates that the coals were transported vegetable matter.

In both Anglesey (Davies, 1991) and northwest England (Vanstone, 1998), it was argued that the potholes, up to a metre deep in the undulating limestone surfaces beneath wayboards (and seat-earths elsewhere), could be due to acid rainwater draining down from the bases of tree trunks through the clays to attack the limestones beneath. However, no fossil root structures that could have led such waters downwards have been recorded in Derbyshire wayboards. While the wayboards may well have provided acidic soil conditions with potentially corrosive effects on the underlying limestones, the problem of potholed surfaces beneath wayboards remains incompletely explained.

Conclusion

The phenomena of cyclic sedimentation and clay wayboards with occasional coals clearly indicate intermittent emergence above sea-level through much of late Visean time in the Crich and Matlock areas. This appears to have created temporary islands that supported terrestrial vegetation. The coals, wayboards and the pot-holed surfaces are worthy of further research both in the Peak District and elsewhere in the British Carboniferous Limestone.

Acknowledgments

Thanks are due to the manager of Bardon Aggregates at Crich quarry for permission to visit the site, and also to Ken Dorning for his data on spores at Tearsall, and to Duncan McLean for his report on the Crich coal in the appendix.

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Trevor D. Ford, University of Leicester, and Lynn Willies, Matlock

Appendix

The coal is possibly best described as a highly carbonaceous mudstone. Several grams were prepared for palynology using standard fuming nitric acid and Schulze's Solution maceration, followed by heavy liquid separation to remove the remaining silicate minerals. The organic residue is dominated by heavily degraded, broken and sub-rounded humic material with lesser amounts of angular vitrinite. The humic material is deformed by intergrowths of pyrite. Spores are very scarce and poorly preserved with only questionably identified specimens of *Calamospora* sp., *Cyclogranisporites* sp., *Lycospora pusilla* and *L. orbicula* recorded. These provide little biostratigraphical information other than to indicate a post-Tournaisian, Carboniferous age for the material. They also provide little evidence to allow reconstruction of the coal mire vegetation other than to suggest that it included sphenophylls, ferns and aborescent lycopsids, as would be expected of a British Carboniferous coal.

As unusual feature of the coal residue is the common presence of tubular organic remains that are broadly similar in form to *Reduviasporites* Wilson 1962 emend. Foster *et al*. 2002. This is either of algal origin (Foster *et al.* 2002) or fungal origin (Elsik, 1999) depending on which interpretation is believed. The palaeo-ecological significance of the common occurrence of *Reduviasporites* in the coal at Crich cannot be understood until the biological relationships of this form are resolved.

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LECTURE

Anhydrite to zinc - a pictorial survey of working mines in the British Isles

Summary of the lecture given to the Society on Saturday 10th December 2005 by Paul Deakin of the Royal Photographic Society.

For many years, Paul Deakin has been photographing the mines of Britain, both working and disused. His presentation to the Society was more of a visual experience than a lecture. Consequently, in place of a summary text, a small selection of Paul's photographs from mines in the East Midlands appears on both front and back covers of this issue of *Mercian Geologist*. Though these mines were working when Paul photographed them, they are now all closed, except for the tiny Treak Cliff operation.

The hydrothermal veins within the limestone of the Derbyshire Peak District are only economic if worked on a large scale, though now only in Sallet Hole. Trackless transport is used, as in the Mill Dam Mine on the western end of the Hucklow Edge Vein. Large stopes are created and generally remain stable in the strong limestone; unusually, the big vertical stope in the Long Rake Mine, near Youlgreave, was worked for its pure calcite. Lead ore is now just a by-product from mines that target fluorspar. The Ladywash Mine, near Eyam, was an older and smaller mine that was worked for lead, and it still has veins rich in galena that survive in remnant pillars of ore.

Treak Cliff Mine, at Castleton, is only worked by hand on a very small scale for selective extraction of Blue John fluorspar for the jewellery trade. It is also in the limestone, but the ore is found only within pockets in the structurally complex reef beds.

North Nottinghamshire still has a handful of deep coal mines, all using the longwall method of total extraction. Though Bolsover Mine is now closed, its face was typical, with the coal shearer moving along the long wall cut into the seam, while the roof was temporarily supported by a line of moveable hydraulic props. Roadways within the pillars that were left between extracted longwall panels are subjected to huge pressures; the roof of the roadway in the Clipstone Mine, also now closed, was supported by colliery arches, but the need for its continual maintenance was a big factor in the mine economics.

LECTURE

Caves: dark dank holes in the ground, or geological treasure troves?

Summary of the lecture given to the Society on Saturday 14th January 2006 by Dr Andy Farrant of the British Geological Survey.

Mention caves, and most people think of dark, wet holes in the ground, or maybe a show cave. But caves are more than that; they have benefits for geoscientists.

Not only do caves enable the geologist to see the rocks from the inside and provide first hand knowledge of underground drainage patterns, but they are also superb repositories of geological information. Unlike surface exposures, caves are protected environments. They are less susceptible to erosion, weathering and bioturbation than surface environments. Over time, underground streams cut new routes at lower levels, leaving former conduits high and dry. Old stream routes are preserved as relict passages, unlike rivers which erode their former flow stages. The morphology of these relict passages contains clues to their function.

Flow direction within the relict passages can be determined by sediment ripples and cross bedding and by scallops on the passage walls. Scallops are shallow, asymmetric, dissolutional, scoop-shaped hollows that are etched into the bedrock with their steeper sides facing downstream. Their size is inversely proportional to flow velocity, and an empirical equation can be used to determine flow velocity, and hence discharge, if the passage cross section is known.

In addition, former base-levels can be identified from passage morphology. Vadose passages, formed above the water-table, are easily distinguished from sub-water-table phreatic passages. A vadose passage is often canyon-shaped, with small irregular scallops indicative of rapid flow, whereas phreatic passages have an elliptical or circular, smooth, sculpted morphology, generally with large rounded scallops. Former water-table elevations can be constrained by noting where a vadose passages changes into a phreatic passage. In addition, the water-table is often marked by concordant loop crests in an undulating phreatic passage, notably where a phreatic cave cuts across dipping strata. Relict passages can thus be used to build up a picture of how a cave system evolved over time, which can then be related to changes in surface environments or base-level changes.

Dating techniques

Cave deposits, both sediments and speleothems, can be dated using a variety of techniques, the most common of which is dating of speleothem calcite using uranium series disequilibria. This uses the radioactive decay of uranium (notably ^{234}U) into thorium (^{230}Th). Uranium is soluble in water, whereas thorium is not. Thus when stalagmites form from water percolating through the rock, the drip-water contains uranium, but no thorium. Once the stalagmite has formed, the uranium isotope ^{234}U gradually decays into the thorium isotope ^{230}Th, at a known and constant rate. As time passes, the amount of thorium in the stalagmite therefore increases. By measuring the ratio of ^{234}U and ^{230}Th, using a mass spectrometer, the age of the stalagmite can be calculated. This method works for stalagmites up to about 500,000 years old. In stalagmites older than this, thorium also begins to decay and tends towards secular equilibrium, and the U/Th ratio becomes unreliable.

An alternative method of determining the relative age of a cave is palaeomagnetic dating. This technique utilises known changes in the Earth's magnetic field. Through time, the Earth's magnetic north pole has 'wandered' around by several degrees, periodically 'flipping' from north to south and back again. These fluctuations in the magnetic field have been independently dated using other methods. The last time the magnetic pole reversed was 780,000 years ago, and before that, approximately 910,000 years ago. These changes in the Earth's magnetic field may be recorded in cave sediments. Clay particles deposited in still water preferentially align themselves to the prevailing magnetic field at the time of deposition. So by taking carefully oriented cores of fine-grained, clay-rich sediment, it is possible with a magnetometer to determine the direction (and polarity) of the magnetic pole when the sediment was deposited. The most recent sediments are aligned towards the current North Pole. However, older sediments preserved in high-level, abandoned caves may preserve evidence of former pole positions. By taking a suite of 'fossil' sediment samples at progressively higher elevations, it may be possible to work back through time to when the sediments were deposited during the last period of reversed polarity. Various cave systems, including Masson Cave, at Matlock, have been dated in this way.

Folded Black Rock Limestone in Swildon's Hole, Mendip.

Uranium-lead dating is a similar technique to U-Th methods and relies on the decay of ^{238}U to ^{206}Pb. However, this dating method is still in its infancy, and the initial state of ^{238}U disequilibrium in Quaternary and Tertiary samples needs to be assessed; also, it can only be used for samples with high U/Pb ratios.

Cosmogenic isotopes have also been used date cave deposits. The ratio of the isotopes of ^{10}Be and ^{26}Al, both produced by cosmic rays, is constant at the Earth's surface. However, below ground, where samples are shielded from cosmic rays, ^{26}Al decays faster than ^{10}Be so their changing ratio can be used to calculate age since burial. This technique has been successfully applied to cave sediments in Mammoth Cave, Kentucky, and elsewhere.

Landscape evolution

Caves are an integral part of the landscape and are affected by changes in the surface environment. Base-level decline, driven by uplift or valley incision, causes changes in cave systems. A period of valley incision, perhaps by glacial erosion, causes a cave system to adjust to the new base-level by developing a new lower level set of passages. Over time, valley incision results in a vertically stacked series of cave passages. Dating of the deposits preserved within these caves can give an estimate of rates of base-level lowering. A series of cave levels in Cheddar Gorge has been dated, and gives a rate of about 20 mm per 1000 years. Similar calculations have been made for cave systems elsewhere in Britain and overseas. The oldest caves in the Peak District pre-date the last magnetic reversal 780,000 years ago.

Palaeoclimate

As well as being tools with which caves can be dated, speleothem deposits (mainly stalagmites) are versatile, datable, proxy palaeoclimate indicators in their own right. A slice though a stalagmite reveals many growth layers, hiatuses and erosional events. Dating these layers, using high-precision U-Th techniques, can constrain when and how fast they grew, and when growth was curtailed. Speleothem growth is controlled by external factors such as rainfall and temperature, and generally only form if the climate is relatively warm and wet. Thus by dating enough stalagmite deposits over a suitable time span, periods of speleothem deposition and non-deposition can be identified and correlated with glacial, interglacial and interstadial cycles, or with periods of aridity. As with tree rings, examining speleothem growth bands (using luminescence techniques combined with dating) has demonstrated that some speleothems contain annual banding. The thickness of these bands can be related to external changes in climate and environment, sunspot cycles and even volcanic eruptions.

Most speleothem deposits form from drip-waters in subaerial caves. However, in many parts of the world, there are submarine caves that are filled with fabulous arrays of speleothems. Excellent examples occur around the Bahamas and in Florida where they are known as Blue Holes, and in the Yucatan peninsula in Mexico where their entrances are the well-known cenotes. These submarine caves often form at the mixing zone between salt and fresh water, and can be very extensive. Speleothems deposits can only form in these caves when sea-level falls during glacial periods that leave the caves high and dry. Sea-level rise at the end of a glacial period drowns any speleothems, and stops their growth. Thus by constraining when these submerged speleothems grew and at what depth, palaeo-sea-level curves can be constructed.

Phreatic tube in Peak Cavern, formed beneath a water-table level with an old contemporary higher floor of Hope Valley

As well as information gained from the presence or absence of speleothem growth, analysis of material contained within speleothems, such as isotopes ($\delta^{13}C$ and $\delta^{18}O$), trace elements, pollen and spores, can also provide clues about the palaeo-environment. Pollen trapped within speleothem calcite can record information about the vegetation history of the cave surroundings at the time of deposition. Analysis of $\delta^{13}C$ in calcite can do the same. Different types of plant use isotopes of carbon in different ways. C4 type plants, mainly warm season grasses adapted to high temperature have higher (less negative) $\delta^{13}C$ than C3 plants, mostly trees and shrubs, and cool season grasses. This differential isotopic uptake in plants affects the amount of $\delta^{13}C$ in the drip-waters feeding the speleothem. Similarly, changes in the $\delta^{18}O$ of rainfall caused by changes in global ice volume are reflected in $\delta^{18}O$ values preserved in speleothem calcite which can be accurately measured and dated.

Ongoing advances in dating techniques and palaeo-evironmental analysis will continue to provide geoscientists new tools with which to study past climates and environments. Caves provide excellent, undisturbed and relatively unstudied field laboratories for a whole host of disciplines across the Earth Sciences. As such, even the darkest, dankest cave may still contain material of interest to the geoscientist.

EXCURSION

Marlstone Rock, Northampton Sand, Leicestershire and Rutland

Leader: Keith Ambrose

Sunday 15th May 2005

This day excursion was organised to look at the changes in facies displayed in Lower Jurassic Lias Group rocks of the Marlstone Rock Formation at three localities across eastern Leicestershire and Rutland and to compare it with the Northampton Sand Formation. The two formations show similar types of ooidal ironstone as well as other quite different lithologies. The trip commenced at Browns Hill Quarry, Holwell, near Melton Mowbray.

Brown's Hill Quarry, Holwell

Brown's Hill Quarry [SK741233] worked the Marlstone Rock Formation for iron ore between 1917 and 1930, with some later working in the 1950s. It is one of a number of quarries that exploited this resource between 1875 and 1962, the Holwell area having the last operating ironstone quarry in Leicestershire. The iron content of the Marlstone has been enriched by weathering, and in the Holwell area, varied between 25-40%, making it a good workable ore. As well as quarrying, the ore at Brown's Hill was also mined from three main adits, one of which can be seen in the main part of the quarry that is a RIGS site. The undermined area is still very unstable and there are signs on the road warning of possible subsidence; collapses of the workings still occur periodically in the adjacent fields.

The quarry exposes a full sequence of the Marlstone, 3.7 m thick, together with the basal part of the Whitby Mudstone Formation and the top of the Dyrham Formation. Chalky till (Oadby Till) occurs at the top of the quarry. The visible Jurassic sequence is summarised in the table below.

This sandstone of the Dyrham Formation has been given the local name *Sandrock* by past workers. It has been included in the Marlstone by others, but the recent remapping of the area by BGS has shown it to be a lenticular bed that is best equated with the Dyrham Formation. The basal bed of the Marlstone is usually a phosphatic and intraformational pebble bed, but this facies is only locally developed and is absent at Brown's Hill. Where present, the pebble bed marks a major non-sequence and forms the most appropriate level for the base of the Marlstone.

Pickwell

Two Marlstone quarries occur in the village of Pickwell [SK78411157]. They demonstrate a facies change in the formation, in that they show a sequence of interbedded ooidal ironstones as at Holwell, and ferruginous, ooidal and shelly 'limestones'. The ooidal ironstones are paler and appear to be much less ferruginous than those at Holwell, whereas the interbedded limestones appear to be more ferruginous. The quarry visited shows five ironstone-carbonate cycles, each between 0.1 and 0.9 m thick. The lowest cycle is incomplete and is of ooidal ironstone with a very shelly upper part. The ooidal ironstone is thickest component of the cycles. One bed also shows well developed cross bedding. The iron content at Pickwell is lower than at Holwell, so the Marlstone was not worked extensively as an ore. The nearest available analyses are for the nearby Somerby area, about 1 km to the south, where the iron content is around 19%.

Whitby Mudstone Formation	MUDSTONE, grey, finely laminated and fissile ('paper shales'), less fissile where fresh; scattered bivalves and ammonites, including harpoceratids and dactylioceratids; some bedding planes crowded with fossils	1.9m
	MUDSTONE, ochreous, very silty, soft; scattered harder, ?calcareous, cemented concretionary patches	0.2m
	MUDSTONE, grey to brown and ochreous; blocky, structureless; scattered bivalves; many pale grey fissures	0.3m
	MUDSTONE, ochreous and grey, generally blocky and structureless, fine lamination locally; a few bivalves; 10 mm hard, pale buff, ?calcareous layer at base	0.4m
Marlstone Rock Formation	IRONSTONE, orange-brown, fine-grained, ooidal; scattered shell detritus, locally common and sometimes abundant with local lags, commonly with abundant fine crinoid debris; cross bedding locally visible, with current directions to east and south-east. Impersistent mudstone parting near the top; uppermost 50 mm very hard and calcareous, packed with belemnites in approx.NE-SW alignment and with belemnite pavement at top; cross lamination developed in places to top commonly defined by coarse shell debris. Layer of siderite mudstone nodules at 0.7 m	2.8m
	IRONSTONE, orange-brown, fine-grained, ooidal; basal shelly lag with large shells and shell fragments and fine shell detritus – belemnites very common, plus bivalves, brachiopods; possible quartz grains. No appreciable grain size variations throughout the bed; no visible internal structures	0.9m
Dyrham Formation	SANDSTONE, orange-brown, fine-grained, calcareous, ferruginous, scattered shell debris; coarsening-up cycle at top showing more common shell debris in top 50 mm with belemnites and bivalves on upper surface; possible slight preferred orientation of belemnites E-W. Two more fining-up cycles to base of visible section; upper one scours into lower one by up to 100 mm, becomes paler and very fine-grained below 0.37 m	0.6m

Marlstone Rock Formation exposed in the Brown's Hill Quarry. (Photo: Keith Ambrose, British Geological Survey, © NERC, 2006)

Tilton Railway Cutting

This former railway cutting [SK761055] is a SSSI and exposes one of the best and most complete sequences of the Marlstone Rock Formation in Leicestershire and Rutland. A full sequence of the formation can be seen, together with adjacent beds of the overlying Whitby Mudstone and underlying Dyrham formations. The Marlstone has been worked extensively as an iron ore just to the north of the railway cutting at Tilton, and on a much smaller scale as a building stone; it can be seen in many houses and walls in the area. The ore typically yielded 25-34% iron.

Exposure 1: Foot of steps down into the cutting

This first exposure [SK76160555] represents the most complete sequence of the Marlstone, although the overlying Whitby Mudstone is not visible. The uppermost beds comprise around 2.8 m of fine-grained, ooidal ironstone, typical of the formation elsewhere in Leicestershire and Rutland. It contains abundant fossils and fossil debris, including brachiopods, bivalves, belemnites, gastropods and the ammonites *Tiltoniceras acutum* and *Dactylioceras cf. directum.* Most of the Marlstone lies within the tenuicostatum Zone of the Toarcian stage; originally, its top was thought to mark the Pliensbachian - Toarcian boundary, but this datum is now placed 2.5 m below the top of the formation. Cross bedding and cross lamination is visible in places, often with much crinoid debris. Where fresh, the Marlstone is greenish grey, due to the main constituent iron mineral being berthierine (a variety of chamosite). This weathers to the rust coloured limonite that is visible in the face.

The base of the upper ooidal ironstone is not well defined in the face. It rests on a c.2.85 m unit comprising beds of very sandy, ooidal, shell detrital ironstone with significantly fewer ooids than the overlying bed. It has been described as a sandstone by some workers but recent petrographic work by BGS showed that all samples examined were sandy grainstones/ironstones, although it may locally be a sandstone. It was sufficiently rich in iron to have been worked for ore nearby. Within the lower unit there are three beds that are rich in the brachiopods *Tetrarynchia tetrahedra* and *Lobothyris punctata.* The lower two beds are particularly prominent but the upper one less so. They are very hard and well cemented and are very fresh compared to the surrounding rocks. Lithologically and petrographically they appear similar to the immediately adjacent rocks. This lower bed of the Marlstone is entirely within the spinatum Zone. The high quartz sand content of the Marlstone is unique to the Tilton area and suggests a very localised influx of terriginous sediment probably from the nearby London-Brabant landmass.

The lowest part of the Marlstone below the 2.85 m thick sandy ironstone and immediately overlying the Dyrham Formation, comprises two distinct beds. The upper c.0.15 m is a pebble bed of rounded intra-formational clasts set in a sandy, ooidal shell-detrital ironstone matrix. This rests on a 0.05-0.12 m bed of fine-grained, ferruginous limestone with a few intraformational pebbles. The upper surface of this limestone is commonly coated in iron oxide and is intensely bored. The borings are infilled with the overlying pebbly, shell-detrital ironstone.

The lower part of the face exposes the uppermost beds of the underlying Dyrham Formation. The top bed is a 1.15 m thick grey, micaceous, well laminated muddy siltstone that is typical of the Dyrham Formation. This rests on a prominent bed of grey, fine-grained, sandy, ferruginous, shelly and shell-detrital limestone. More siltstones occur below this. Locally the Dyrham Formation is very fossiliferous, with mainly bivalves present. The section has yielded the ammonites *Amaltheus margaritatus* and *A. subnodosus* which indicate the subnodosus Subzone of the margaritatus Zone.

Exposure 2

Followed southwards along the cutting from the first exposure, the Marlstone forms a continuous outcrop on both sides of the cutting and shows some localised cross bedding in places, although it is not particularly well developed here. Also clearly visible are various seepages on the face that are marked by concentrations of iron oxide. Parts of the cutting are unstable and small landslides can be seen.

Exposure 3

Continuing southwards along the cutting, the Marlstone dips below the level of the cutting floor, and the overlying Whitby Mudstone is well exposed in a series of steps although there is no complete sequence visible. The exposures show fissile mudstones or paper shales and blocky mudstones. In parts, the mudstone contains common non-calcareous ooids and pisoids, together with thin beds of ferruginous limestone. The sequence is locally very fossiliferous with dactilioceratid and harpoceratid ammonites common, together with bivalves and belemnites.

Away from the Tilton area, other facies changes in the Marlstone are evident. Eastwards, it loses the high sand content of the lower part. Southwards, in the Stockerston-Horninghold area, the beds seen at Tilton and Pickwell are replaced by a ferruginous mudstone with thin beds of ferruginous limestone. This facies is present in only one small area and passes eastwards into mainly ooidal ironstones.

The three formations are part of the Lower Jurassic Lias Group, and were all deposited under marine conditions in a warm tropical sea that was teeming with life. The earliest strata of the Lias Group, the Blue Lias Formation and its lateral equivalent, the Scunthorpe Mudstone Foramtion, are mainly interbedded limestones and mudstones deposited in a relatively shallow sea. The mudstones of the succeeding Charmouth Mudstone Formation were deposited predominantly in deeper water punctuated by periods of shallowing. The Dyrham Formation represents a major shallowing interval with land in close proximity providing the sand and silt that typify the formation. Further shallowing induced shoaling conditions suitable for the formation of ironstones, again with a significant local influx of sand for some of the time, such as is seen at Tilton. The sea floor was agitated by southeasterly flowing currents, indicated by cross bedding that is commonly preserved. These currents were often strong, transporting coarse crinoid and other fossil debris. More gentle current activity was responsible for the formation of ooids that characterize the formation. With later deepening waters, there was a return to mudstone deposition in the overlying Whitby Mudstone Formation.

Holt Quarry, Neville Holt

The final locality [SK48142926] shows a 3 m thick exposure of the Northampton Sand Formation, which is the basal unit of the Inferior Oolite Group that overlies the Lias Group. It is in a complex of old iron ore quarries that were worked from 1862. Typically, this formation shows an interbedded sequence of ooidal ironstones that are identical to the Marlstone, as well as ferruginous sandstones. Here at Holt Quarry, only the ooidal ironstone is exposed; it is ochreous and fine-grained with some shells and shell debris. The rock is well cemented in the uppermost c.1 m and again from about 2.0-2.4 m in the face, but elsewhere it is soft and poorly cemented. It is generally poorly bedded but one outcrop shows good flaggy weathering in the upper 1 m. Iron rich laminae up to 10 mm thick can be seen in places, generally at 200-300 mm intervals; there are some more irregular veinlets and box-structure weathering in the basal 0.5 m. The Northampton Sand consists mainly of the mineral siderite, but with some berthierine. There are no published analyses for the Neville Holt area, but generally the ore contains 30-40% iron although in some areas it is as low as 18%.

The party was in agreement that there was very little difference between the ooidal ironstones of the Marlstone Rock Formation and the Northampton Sand Formation. The latter tended to be softer and more deeply weathered at the exposure visited.

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EXCURSION

Churches of SE Nottinghamshire

Leader: Albert Horton

Wednesday 6th July, 2005

Churches provide an opportunity to study the lithology of rocks, many of which are no longer exposed locally. Although the parishes of Willoughby-on-the-Wolds and Upper Broughton are adjacent, the dominant building stones in the churches are different, being Barnstone Member and Sandrock respectively.

The church buildings of today are the product of up to 1000 years of construction, extension, remodelling and repair. Most of the churches were built during the period from the Norman Conquest to Henry VIII's Reformation. From then, limited repairs were made until the Victorian era, when many of the churches were 'restored', sometimes destroying their character.

Most churches are built using local material, hence the close correlation between building stones, source and rock outcrop. The parish system probably dates from the Saxon era. Some churches were built of stone before the Norman Conquest, but the centralisation of power and taxes by the Normans started a building boom.

Architectural style evolved progressively from the Celtic and Roman churches through to the 17th century. New ideas and techniques developed locally, then to be propagated by the stonemasons who travelled from site to site. New styles developed at different times in diverse places and regional variations were imposed upon them. The Victorians arbitrarily defined styles of architecture, but accepted that they could not be dated precisely.

Saxon	pre-1066
Norman	1066 - 1200
Transitional	1150 - 1200
Gothic - Early English	1170 - 1300
- Decorated	1272 - 1350
- Perpendicular	1350 - 1530
Tudor	1485 - 1689

Approximate chronology of architectural styles

St Mary and All Saints, Willoughby-on-the-Wolds

The **exterior** of the church is built almost entirely of pale grey stone derived from the Barnstone Member (Blue Lias), the basal division of the Charmouth Mudstone of the Lias Group. It is a fine-grained limestone in which three lithologies can be recognised:

- the dominant pale grey subporcellaneous limestone
- a slightly darker grey structureless micritic limestone
- a similar rock with thin cemented bands showing lamination, very low-amplitude ripple-like structures and very shallow erosional surfaces.

Fossils are rare and bioturbation has not been noted.

The outcrop of the Barnstone Member extends from Lyme Regis in Dorset to Whitby in Yorkshire. Locally it crops out in the stream bed at Widmerpool. Since Roman times it has been extensively worked at Barrow upon Soar and more recently near East Leake. It can be seen in the flooded excavations of the defunct cement factory at Barnstone in the Vale of Belvoir.

The rock is a rubblestone and is used *as dug* with a minimum of dressing. It is laid in courses, the heights of which are in part dependent on the thickness of the original bed. The clay-rich beds weather badly, showing vertical, crumbly, surface exfoliation, bedding plane flaking and differential decalcification. Cemented laminae stand out above the more clayey matrix. The sub-porcellaneous lithology is largely unweathered and still shows a subconcoidal fracture.

The **Chancel** is built with massive blocks of the sub-porcellaneous limestone. This lithology is used extensively in north Leicestershire. Note that at some time the height was increased. In 1829 the church was repaired and four new windows were installed. These are all of Perpendicular style and probably include the two south-facing windows of the Chancel, the west-facing window of the South Aisle and the east-facing window of the North Aisle. The main east window, also of Perpendicular style (1350-1530) was inserted during the 1891 restoration.

Changes in the masonry show that it was smaller than its predecessor, the surrounding gap being infilled with smaller blocks of the Barnstone Member. The window frames are Lincolnshire Limestone oolite, which is also used in the parapet, facing and coping. The buttresses are built with medium-grained Triassic sandstone and some of Sandrock. All are freestones.

To the right is the junction of the Chancel with the **North Aisle**. This angle reveals the oldest masonry in the church. It comprises thin blocks of Barnstone Member, limestone rubble and larger blocks of Sandrock. This masonry encloses an Early English Y-shaped tracery window; the original sandstone mullions have been replaced by oolite. The remaining North Aisle is built of Barnstone Member and Sandrock, and there is an identical west window.

The **North Chapel**, the Willoughby Chantry, was built in the 13th century using a fine-grained Triassic sandstone. The exceptions is the niche at the base of the central light of the three-panel Perpendicular east window. This fawn, ripple-marked sandstone contains ferruginous grains and is laid on end (i.e. the bedding planes are vertical). It is Carboniferous, possibly from the Wingfield Flags in the Lower Coal Measures.

A small **Vestry** was added in 1998 using Barnstone Member transported from Somerset, and Lincolnshire Limestone oolite freestone was used for the door and window frames. The former comprises structureless micritic limestone, with a few blocks showing fine lamination identical to the local rocks. Some of the blocks have been split with a vice along joints that were filled with crystalline calcite.

The new vestry built with Blue Lias at Willougby church.

The **Tower** has a Triassic sandstone basal course, succeeded by Barnstone Member rubblestone with repairs using Sandrock, Bulwell Stone and oolite. The two buttresses are of similar design, but one is built of Sandrock and the other, possibly a replacement, is of Triassic sandstone, which is also used for the quoins.

The **South Aisle** again has a sandstone basal course, overlain by Barnstone Member, and has south- and north-facing Early English Y-tracery windows of Triassic sandstone with oolite repair. The west-facing window is in Perpendicular style that used Triassic sandstone, but with coarse Millstone Grit sandstone repairs. The porch arch is framed with Millstone Grit.

Internally, the columns of the arches are circular. Two are composite with the lower part built of Sandrock, which is succeeded by pale grey Triassic sandstone; the rest are entirely sandstone. Pevsner (in *The Buildings of England: Nottinghamshire*, 1979: Penguin, p379) noted that 'one capital has primitive upright leaves: others are octagonal' and concluded 'the date is about 1200 or a little later'. He suggests that the North Chapel, the Chancel and the Tower are all 13th century. The internal wall of the Tower shows two former roof mouldings, which predate the building of the Clerestory and the present roof line (?C14th).

The **North Chapel** was built as a chantry where a priest could pray daily for the lords of the manor. It now contains the Willoughby monuments. The two oldest are ladies wearing wimples, which suggest a date of about 1300. Both effigies have been carved in oolitic limestone. The one in the corner (1 on the wall guide) is buff-coloured with shells and shell debris; the other (2) is a white oolite. Both are worn, possibly due to weathering. The adjacent tomb (3) is thought to be that of Sir Richard Willoughby, who died in 1325, and his wife; it is a brownish grey oolite with shells. The remaining tombs are of alabaster. One is the tomb of Richard (died 1362), and, on the basis of the costume of the effigy, he was a judge. Another tomb is that of Sir Hugh (died 1448) (5) and his second wife (died 1493): his first wife is remembered by a floor slab (7). A third tomb chest (8) may be H Willoughby, a priest of 1320-29, who died about 1344. In the adjacent aisle there is a brass memorial set in Bulwell Stone to Colonel Michael Stone, who was killed in the Civil War Battle of Willoughby Field, July 5, 1648.

A notice in the porch records the current keyholders.

St Luke's, Upper Broughton

Although this is a much smaller church than that in Willoughby-on-the-Wolds, it displays a great variety of building stones that reflect the changing use of stone during various stages of construction and repair.

The oldest part of the church is a Norman-style window, which has been blocked off and is visible now only from the inside, in the second stage of the **Tower**. The external south wall of the **Nave** is built of Sandrock, and incorporates an older arcade to a former **South Aisle**. Only one complete arch and part of a second remain. The semicircular double-chamfered arch rests on a capital with dog-tooth ornamentation above a circular column. Pevsner (p360) considers this to be Transitional (late Norman) style '*c*.1200 or a little later'. The south door is built into the arch. The remnant of the **South Arcade** and the **North Arcade** are both built of Lincolnshire Limestone oolite. The columns of the latter are octagonal, the arches are chamfered but slightly pointed, and the capitals show traces of dog-tooth ornamentation, which Pevsner considers to be 'later still, but also C13th'. A carved fragment of Lincolnshire Limestone oolite, originally a Norman tympanum (door head) is built into the porch.

Externally, the older parts of the church are Sandrock. This is the highest bed of the Dyrham Silt Formation, which underlies the Marlstone Formation. Both are Lias Group of Early Jurassic. Unweathered, the Sandrock is a pale greenish grey chamositic silty sandstone with a calcareous cement; the colour depends on the iron content, and the proportion of shells and shell debris varies. Stratigraphically, it is overlain by the Marlstone, with the boundary marked by a thin conglomerate of reworked phosphatised platy nodules. The rest of the Marlstone is a chamositic-sideritic limestone with shell debris and ooliths.

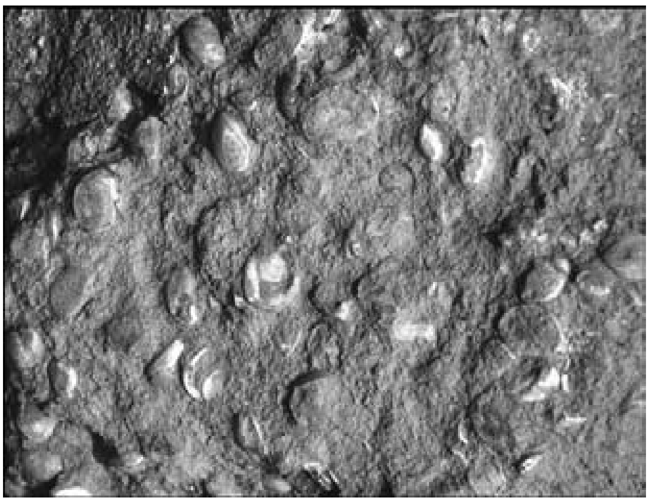
St Luke's church at Upper Broughton

Both rocks are very susceptible to oxidation by percolating ground water, so that, in the near-surface zone, iron minerals have been altered to limonite, giving the stone its characteristic ochreous colour. Leaching of the calcium carbonate of the Marlstone limestone increases the residual iron content to the level at which the rock becomes ore grade. This, and the redistribution of the limonite as veins, generally renders the rock unsuitable for use as a building stone.

However, some hard, dense, reddish brown, ironstone blocks have been used for repair work on the upper part of the western end of the South Aisle. The Sandrock was sufficiently uniform to be used as a freestone, with large blocks in ashlar style. Unfortunately the stone weathers badly and in some cases up to 100 mm of the surface block has been lost, leaving a rounded surface. Differential weathering has caused the crystalline calcite brachiopods, belemnites and some bivalves to stand out above the weathered surface. Some beds show weak grain-sized banding of shell debris, while others are intensely bioturbated, with paler burrows up to 4 mm in diameter. The brachiopods 'float' in the matrix, and clusters of them could be growth assemblages.

When brachiopods die the dentition tends to keep the valves closed. Where silt only partly fills the body cavity, and crystalline calcite fills the upper part, the shell can be used to determine the 'way up' of the rock, to indicate the depositional base of the bed in which it occurs. In tectonically complex areas, such structures are used to identify overturned beds. In churches they only tell us whether the building block has been laid as dug, on edge or upside down.

Because of the susceptibility to weathering, many blocks of the original Sandrock have been replaced, particularly by pale cream-coloured Lincolnshire Limestone oolite, for example in the second stage west wall of the **Tower**. Elsewhere, Bulwell Stone, Barnstone Member (Blue Lias) and very rarely an unidentified shelly limestone of the Charmouth Formation (Lower Lias) and ironstone have been used.



Brachiopods in Sandrock at Upper Broughton church

The new clasping buttress of the west end of the Tower, Choir Vestry, and that between the Tower and the North Aisle are build with Banbury Marble from the Wroxton area to the north-east of Banbury. Similar to the Sandrock in lithology and with superb burrows, it is less weathered at outcrop and some blocks show only slightly oxidised, green-tinted core stone. This is an excellent freestone, and like the Sandrock has been used in the past for window frames, mullions and quoins. Sadly, some blocks already show weathering fractures, mostly vertical exfoliation cracks parallel to vertical faces, probably the result of freeze-thaw.

The outside wall of the **Nave** is almost entirely built of Sandrock. The oolite windows are in the Decorated Style, but there is evidence that they replace much younger Classical Style windows. The date of the removal of the **South Aisle** is not known. This predates construction of the **Porch** in 1733, when an unusual Lincolnshire Limestone lithology was used. This rubblestone is a cream micritic limestone with 'floating' ooliths, a little shell debris and a few shells; it is characteristic of the lower part of the Lincolnshire Limestone. A crudely carved oolite lintel is built into the inside wall of the Porch. A Norman-style window on the inside wall of the first stage of the Tower is further evidence of the antiquity of the building.

The **Chancel** was rebuilt in 1844-5 using Sandrock with inset dressed blocks of the Barnstone Formation (Blue Lias). These are the more argillaceous variety, characteristic of Victorian churches in Nottingham.

The **North Aisle** was rebuilt in 1980 using dressed Bulwell Stone, a slightly orange-tinted, honey-brown dolomite, above three original courses of Sandrock. The Permian Bulwell Stone originated as a limestone, and was changed to dolomite by magnesium replacement during diagenesis. Because dolomite has a smaller crystal volume than the calcite it replaced, the new crystals developed rhombic crystal faces around voids, creating the saccharoidal texture.

The Sandrock and Marlstone Formation form the escarpment to the south of the church, and there are ancient workings in the Sandrock at Stonepit Spinney [702233]. Early last century there were extensive opencast excavations of the Marlstone Formation iron ore in the Wartnaby, Ab Kettleby and Holwell areas. The Barnstone Formation crops out from Barrow on Soar to Newark; its nearest source would have been the stone pits [630285] north of Widmerpool. Bulwell Stone quarries are at Bulwell and Linby, NW of Nottingham. The source of the Lincolnshire Limestone is uncertain; the nearest outcrop is at Wartnaby on the Wolds, NE of Melton Mowbray, but major quarries worked it at Weldon, Kelton, Clipsham and Ancaster.

The key to the church is available during licensing hours from the Golden Fleece public house.

EXCURSION

Southwell Minster

Leader: Ian Thomas, National Stone Centre

Wednesday June 8, 2005

A large number of Society members turned out on an idyllic summer evening, to view the various building and decorative stones used in the Minster and former Bishop's Palace. The visit was also intended to explore some of the history behind the main material used, currently the subject of research by the leader. The phasing of construction of the building as we see it now, is an important part of the story.

Apart form its twin steepled towers and the famous "leaves of Southwell" (carved in stone), the most striking feature of the Minster must be the beauty of its stone. Today's Minster was built in two main phases, replacing an earlier saxon church. The nave is in the bulky Norman style. It was begun in 1108 and took 50 years to build. Shortly after completion, the altar and choir were taken down, and rebuilt on a larger scale, beginning in 1234 in the graceful Early English style. Initially this involved the building of a new eastern end beyond the pre-existing structure. Work progressed westwards; the old building was partly demolished and some stone was reused in the new structure. The original and new sections (completed in 1241) were slightly misaligned, as can be seen in the south wall of the choir. Smaller changes followed: 1288 saw the start to the building of the celebrated Chapter House. The choir screen, intricately carved in the Decorated style was erected in c.1320-40, and the great perpendicular west window was inserted in the Norman façade in the 15th century.

The Trent lies only 3 km south east of Southwell, and east of the river, many of the churches are of Middle Jurassic limestone. The limestone scarp from which they were supplied can be seen on the skyline from near Southwell and navigable Roman waterways such as Foss Dyke had been reopened for traffic by c.1121. Medieval, and many post-medieval, historical references suggest that the bulk of the stone was quarried in the Mansfield area, and these are repeated time and time again in more modern accounts. So why did the builders arduously haul Magnesian Limestone (Cadeby Formation) across such alien territory, through Sherwood Forest, rather than rely upon the Jurassic oolites? We shall probably never know the true reason, but it is likely to be related to rights to land and minerals and possibly the dominance of Lincoln over those eastern sites. Or maybe the challenge of trudging heavy stone across the clay vale of the Trent was too great. It is also likely that Southwell held land or interests in the Mansfield area from an early date. This deserves further investigation.

The so called "Mansfield" source itself deserves further scrutiny. The first written account covering stone is the grant of a licence to the chapter of Southwell by Edward III on 16th October 1337, to permit the carting of stone for the Minster, through Sherwood Forest, free of toll, from their quarry at "Mansfield". In this period, Mansfield was often used to describe a much larger area than the town or district of today. Also, by the time of the grant, the main structure of the Church had been built, and already extended to provide the new choir and altar almost a century earlier. By the 1340s, only the choir screen, by comparison a small feature, was being constructed, but even this timing is not fully substantiated.

Local tradition in Mansfield Woodhouse has it that the stone came from there, and not from Mansfield itself. The most likely scenario is that the western portion, i.e. the older Norman building, was of stone from Mansfield Woodhouse (which is unlikely to have been differentiated in documentation from Mansfield at the time). The C13th eastern extension and later works appear to be largely of real Mansfield stone.

The Norman walling is generally of a stone yellow ochre in colour, that usually lacks veining, is notably consistent, but has blackened in response to pollution. In subtle contrast, the eastern portion is stone of a lighter hue, more buff/light grey, apparently having a much higher sand content with some slightly blue/green clay veining. Weathering in this stone has preferentially removed areas, highlighting bedding planes (with cross bedding) or following clay veining. Cadeby dolomitic limestone locally has more sand in the Mansfield material than in that from Mansfield Woodhouse.

The west front of Southwell Minster; with the twin steeples (or 'pepperpots') that were added in the 19th century.

The leaves of Southwell, carved in dolomitic limestone.

The most obvious and worst example of the effects of clay veining is seen inside the Chapter House where (even without external weather), some of the famous carved leaves have exfoliated along the planes of clay veins. Society members also noticed a small section of Mansfield stone, on the southwest side of the eastern transept, with barite mineralisation.

This general picture is complicated by the re-use of old stone and by a significant amount of later repairs by replacement. Much of the repair stone, in both main sections of the church, is from Mansfield, but also includes some blocks of the shelly Ancaster Stone of Middle Jurassic age from near Sleaford.

The precise source of the stone has yet to be verified, but appears to be an area between Mansfield Woodhouse and Warsop for the older building, possibly that marked on some maps as “Hills and Holes” (a common indicator of ancient quarries) not far from a “Minster Wood” (now under a coal waste tip) at the latter village. The Stuffyn family held land in the area and had close connections with the Archbishop of York; they also promoted the rebuilding of Mansfield Woodhouse church in stone in 1304. The Mansfield material could well have been won from the quarries (later called Gregory’s, and operating up until the last few years) between Nottingham Road and Sheepwash. In terms of bulk, most of the stone was probably from the Mansfield Woodhouse and Warsop areas, while the post-1200 material was from Mansfield.

There is an interesting stone-related sidelight. The weather-resistant qualities of the stone employed at Southwell attracted the attention of the Commissioners seeking stone to rebuild the Houses of Parliament (reporting in 1839). They accordingly recommended the use of stone from “Bolsover Moor or thereabouts”. It was later realised that the main source was in fact Mansfield Woodhouse, and that stone was at first used in the reconstruction. However supplies were too limited for such large works and most was eventually sourced from South Yorkshire. The so-called Parliament Quarry at Mansfield Woodhouse was later owned by the leader’s great grandfather in the 1920s and then in the 1930s by the Rouse family, coincidentally related to another member of the group.

Inside the Minster, most of the structure and fabric conforms to the exterior, with the Norman work in stone from Mansfield Woodhouse stone the later work in Mansfield stone. However there is one intriguing exception. The western façade of the stone rood screen (or pulpitum) dividing the choir from the nave is of a distinctly pink, locally red, sandstone with occasional grey/green veining. This is likely to be the so-called “Red Mansfield” (from the area west and northwest of that town), but there is a passing reference of about the same vintage to some stone being delivered via the Trent, which might raise the prospect of other sources.

Members also viewed a range of decorative stones inside the building. The C19th stone semi-chequered floor around the altar is of black and white “marble”. The lighter is almost certainly Hopton Wood, while the black could be from various sources - but is probably Carboniferous Limestone from Belgium, Kikenny in Ireland, or Ashford in Derbyshire. Other marbles used are green Connemara, red (probably Italian) and white Carrara. The kneeling steps are of another darker stone, possibly “birds eye” marble from either Ashford or Wirksworth, both in Derbyshire. Whereas the imported marbles are all true metamorphic marbles, those derived from Britain are highly polishable sedimentary limestones.

Ironically the only Minster stone mentioned in Nikolaus Pevsner’s Architectural Guide is ‘Purbeck Marble’, the attribution he gives to the eight narrow columns framing the entrance to the chapter house. In fact, these are not Purbeck, but are richly crinoidal Carboniferous Limestone. The most likely source on

Thirteenth Century exterior work in Mansfield Woodhouse stone, with barite mineralisation visible top centre.

palaeontological evidence, according to Murray Mitchell (via the late Ron Firman, who was then attending his last EMGS field visit) is Derbyshire (not Co Durham as suggested by Alec Clifton-Taylor). Assuming this was a Victorian replacement, the potential quarries would be Ricklow (Monyash), Once a Week (Sheldon) or Dene (Cromford). Other "marbles" form a floor slab in the north transept (probably Purbeck), and the three slender columns of the portal to the corridor from the chancel to the chapter house; Ron Firman identified the latter as Adwalton Marble from near Peterborough (with concurrence from Jenny Alexander).

In the north transept, the plinth of the 1925 memorial to Bishop Hoskyns is of an attractive, green, metamorphosed, ultrabasic rock (a variant on serpentine). This rests on a base of white-flecked, black, bird's eye marble, again almost certainly from the Hopton Wood Stone Firm's works at Coal Hills, Wirksworth.

There are two notable and large alabaster tomb chests. That in the north transept to Archbishop Edwyn Sandys is regarded as a superb example of Elizabethan work. The Trent Valley was a European centre of alabaster production, with Nottingham and Burton being the focus of carvers ("kervers"). Although it is virtually impossible to distinguish between sources, the 1588 date suggests Chellaston in Derbyshire. The second alabaster tomb chest is that below the memorial to Bishop Ridding (d. 1904), on the south side near the altar rail; the date here implies Fauld, in Staffordshire, rather than Chellaston or Red Hill.

At the time of the visit sculpture by Nicolas Moreton in Hoptonwood and Portland roach stone was on display in the Chapter House.

Records apparently suggest that most of the flooring was replaced by local stone – in which case this would imply the fine sandstone lenses (skerries) interleaved in the Mercia Mudstone, although the colour is buff rather than the more typical grey of the skerries. However, the floor of the choir side aisles (or 'quire' as sometimes referred to), is of the fine cream Hoptonwood Stone, a mid-C19th introduction from near Wirksworth (also often known as a marble).

The adjacent Bishops' Palace, now in ruins, was built between mid-C14th and 1436. Many materials were employed, and the rough stonework was probably hidden under limewash. The main stone was the only local, reasonably robust material available – the fine-grained lenses of skerry sandstone in the Mercia Mudstone. The nearest available would have been just to the west at Norwood in the scarp overlooking Halam, but there were other possible sources capping the hills to the south. Alex Clifton Taylor (in Pevsner) suggests that the main building material here was Blue Lias limestone, but that rather indifferent stone, although similar in general appearance, was not seen in significant amounts, and would have had to travel from the far side of the Trent.

REVIEWS

Glacial and Pre-Glacial deposits at Welton-le-Wold, Lincolnshire, by Allan Straw, 2005, privately published: Exeter. iv + 39pp. £3.95 (£4.90 p&p) from David Robinson, The Museum, 4 Broadbank, Louth LN11 4AB

Welton-le-Wold is a small village set within the chalk country of the Lincolnshire Wolds some 6 km west of Louth. In the vicinity of the village are extensive Pleistocene deposits in part occupying a paleo-valley, and these have sustained an aggregate working dating back into the nineteenth century, but it was World War Two which stimulated significant excavation. From 1954 through to 1973, when the quarrying was abandoned due to excessive overburden, Allan Straw as a geomorphologist at the University of Sheffield, was a regular visitor, and it is through his sustained energy that we now have a very detailed knowledge of the stratigraphy. This new monograph, with a range of figures (including colour photographs), presents his findings in an integrated manner and interprets them from a present day perspective.

The site came into national prominence when, in 1969-1973, a sparse vertebrate fauna and three derived hand axes plus a worked flake were discovered. With the exception of the classic Kirmington site in north Lincolnshire, Welton is undoubtedly the most important Quaternary location in the county. Unlike much of the county there is a well-established lithostratigraphy with the main package of sediments being divisible into a tripartite Welton Gravels, Welton Till and Calcethorpe Till succession. The flint dominated Welton gravels are surprisingly chalk free and contain a sand component derived from inliers of the sub-chalk succession lying in the valley heads. The two tills are quite different in character, with the lower one having similarities with the Basement Till of the east Yorkshire coast, whereas the upper is very rich in chalk. Remarkably, the outer north-south trending limit of a subsequent glaciation occurs at Welton, and this deposited the Marsh Till over the eastern sector. On the basis of extensive geomorphological field work Straw has divided this later glaciation into 2 phases, 'early' and 'late' each with meltwater channels of contrasting freshness. It is the early phase which Straw sees as being responsible for the Marsh Till at Welton and an associated meltwater channel and gives it an age of c40 ka, which by national definition has to be Middle Devensian. This chronology is anomalous since it is not in accord with the known stratigraphic evidence elsewhere.

Naturally a key issue which arises is where within the regional picture does the sequence at Welton lie? The answer is inevitably dependent upon the individual's perception of the known stratigraphic framework. Since in situ biogenic evidence is conspicuous by its absence, judgements have to be placed on mainly lithological and geomorphological extrapolations. The reality is that interpretations of the sequences identified in eastern England are currently in a state of flux especially when it comes to defining the number of glacial stages and attendant ice advances. Straw takes the view that there is no evidence of the Anglian glaciation at Welton and prefers to interpret the main glacigenic succession as post Anglian but pre Last Glacial in age. In the earlier literature this glacial event was assigned to the Wolstonian but since the type site of the latter has convincingly been shown as being of Anglian age the term has to be abandoned. Of late the practice has been to assign divisions of the marine stable isotope record to terrestrial stratigraphy and utilising this approach Straw suggests that the main Welton succession as a product of glacial and periglacial processes in MOI Stage 8.

We clearly do not have unanimity over the Welton chronology. But that is the spice of working on the sequence of Quaternary glaciations in our country. However, we now have a clear description of the entire sedimentary record at Welton by the only observer capable of producing it. For this we must be very grateful to Professor Straw and for his initiative in publishing it for posterity. He has also set a fine example by depositing archive material in the museum at Lincoln.

Peter Worsley

A Geological Walk around Cliffe Hill Quarry (28 pp, 38 figs, ISBN 085272485-3); **A Geological Walk around Bradgate Park and Swithland Wood** (32 pp, 60 figs, ISBN 085272486-1); both by Annette McGrath, 2005, British Geological Survey, for the Leicestershire and Rutland Geodiversity Action Plan, £2.50 each.

These two booklets emerge from a team at BGS, many of whose members have contributed to EMGS publications, and have led field trips to various Leicestershire localities for Society members. We can, therefore, be confident that the geological information is both accurate and up to date.

There is good information on finding the location of the start of the walks, car parking, comfort and refreshment stops, and locations are marked on OS maps reproduced in the booklets. Appropriate conservation information is given.

The Bradgate Park booklet is the first we have come across that suggests that you might like to take a kite with you! However one soon gets used to the bouncy, let's-have-a-great-day-out style of both booklets, to find that the content is very sound geology, pitched at a level which is accessible and informative to Society members.

Both titles share almost common geological introductions to describe the geological events and processes of the Precambrian, Cambrian and Triassic eras that formed the rocks visited on the itineraries.

The Bradgate Park walk is largely similar to Excursion #1 in the Society's *The Geology of the East Midlands*, though explanations are more expansive and pitched at a lower expectation of the reader's knowledge. All localities are easily found from the text description. Anyone who has followed a geological trail will know that finding a particular small scale feature can be quite difficult, even for the reasonably experienced. Here, photographs and sketches of features in the outcrops aid location and identification.

We would suggest, however, that anyone using this booklet ignores the low-level, low-energy, non-geological part of the route back to the Hunts Hill car park, and instead climbs via the memorial, as this passes some of the most striking and interesting rocks in the Park.

The Cliffe Hill Quarry walks were visited in the height of summer, when some of the exposures on Billa Barra Hill were difficult to see through the verdant undergrowth. Similarly, due to the intensive tree planting as part of the National Forest project, the recommended views back to Barden Hill are obscured. However, these minor inconveniences were fully compensated by the abundance of birds and butterflies. The really outstanding feature is the panoramic view of the Triassic wadi channel sitting unconformably on the Pre-Cambrian Diorite in the New Cliffe Quarry: a classic indeed. The section on Hill Hole Quarry, refers to "various new footpaths into the quarry from the car park" at Hill Lane. After a couple of false starts, we found that there are only two entrances into the quarry (which is now a nature reserve), one from near the church in nearby Markfield, and one from a little way down Hill Lane from the carpark itself.

The booklets are available at the Bradgate Park Visitors Centre, and are cheaper that the car park fee!

Alan Filmer and Tony Morris

Structure and Evolution of the Southwest Pennine basin and Adjacent Area: a Subsurface Memoir, by N.J.P. Smith, G.A. Kirby and T.C. Pharaoh, 2005; British Geological Survey: Keyworth. 129 pp, ISBN 085272518-3, £40.

The Southwest Pennine basin is here interpreted rather widely as covering the area from the Vale of Clwyd to Sheffield in the north, and from the Longmynd to Charnwood Forest in the south. Thus it includes the Cheshire basin and the northern part of the Welsh Borderlands, the Peak District, most of the Trent Valley and the Midland Coalfields. It covers the Millstone Grit country but excludes the Derbyshire-

Nottinghamshire Coalfield. The theme is a summary of the findings of 800 seismic reflection profiles (or do they mean 800 *km* of profiles?) and numerous boreholes in the largely unsuccessful search for oil and gas resources. Fifteen of the profiles are shown.

The arrangement is stratigraphical, providing an account of the subsurface distribution of each system in turn, with discussions of sedimentary facies and structural features accompanied by palaeogeographic maps. The scattered Precambrian outcrops are regarded as resulting from large scale lateral shifting of terrains to explain their disparate nature and difficulty of correlation. Deposition of the Lower Palaeozoic strata is shown to have been controlled by a sequence of different tectonic events collectively called the Caledonian orogeny, through which the plate collision caused by the closure of the Iapetus suture can be regarded as a sequence of tectonic events from mid-Ordovician to mid-Devonian, each affecting stratal distribution, structures and palaeogeography in turn.

A tabulation of these events would have been helpful. The Midlands micro-craton is still invoked to explain tectonic lineations, but the authors now regard the basement beneath the White Peak as early Ordovician in both the Woo Dale and Eyam boreholes, in spite of previous arguments that the basement was at least partly Charnian. Apparently no evidence has been found that the Charnian massif extends north of the Trent Valley, though it may still be present beneath the Ordovician.

The bulk of the Memoir is concerned with the Carboniferous, subdivided herein into syn-rift (Dinantian) and post-rift (Silesian). The use of the term *rift* is misleading as I expected to find some argument for a major rift, but herein it refers to extensional stress tectonics creating a scatter of fault-bounded basins during Dinantian times. Some of the bounding faults ceased to move before the end of the Dinantian, so that they are masked by later Dinantian limestones and have little or no surface expression, e.g. the Bakewell and Alport Faults (the latter name apparently replaces the Edale Fault of some previous reports). The deltaic complex of Millstone Grit and the fluviatile Coal Measures forms a post-faulting, post-extensional blanket cover. The authors admit that the lack of seismic profiles across the White Peak leaves the interpretation of the Bakewell fault and associated tilt-blocks uncertain, but they prefer a north-down model with the Woo Dale borehole on an upthrown southern block. The Bonsall Fault is more enigmatic – the profiles through the adjacent Millstone Grit country suggest a major downthrow north, partly cancelled out by a later downthrow to the south: only the latter has been recognized by surface mapping of the Dinantian limestones west of Matlock.

There is a useful summary of Dinantian igneous activity but there is no comment in the text regarding the thick volcanic sequences found in the Hope Cement Works, Ashover and Duffield boreholes, even though these are shown on the map (Fig. 28). Also, on Fig. 28, for Cotton Hill, read Calton Hill.

The Silesian (Namurian and Westphalian) chapter is a competent stratigraphical summary, but is marred by several errors and omissions. Whaley Bridge is not in the Derwent Valley (page 57). Lognor appears several times (for Longnor); also the authors' colleague's name is mis-spelt several times (Chislholm for Chisholm). Fig. 31 shows the exposed coalfields, but surely the concealed extensions and prospects could have been indicated. The Variscan structural map (Fig. 36) has the Ashover anticline marked in two different positions, and presumably Coaldale should read Coalville. On page 80 surely the Western anticline in the Potteries coalfield is *west* of Stoke-on-Trent? Similarly the Ashby anticline is *west* of the Coalville syncline (page 83).

While the principal concealing cover strata of the region are Permo-Triassic, the Memoir briefly argues for a former extent of up to 2100m of Mesozoic cover over at least the South Pennines. Together with the thick Permo-Triassic of the Cheshire and other basins the total cover may have been 6000m by the end of the Mesozoic. The significance of this depth of burial to (and beyond?) the window for hydrocarbon generation is, however, only briefly mentioned without any real discussion of evidence and effects.

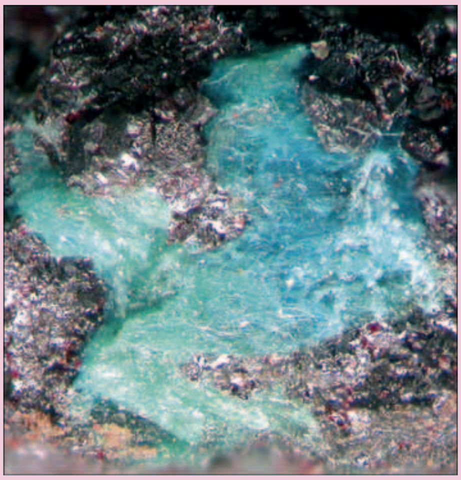
In a Memoir describing the region's structure and evolution, I expected to read a discussion of the Peak District's mineral vein pattern and the changing stress fields that may have affected it, but mineral deposits get only the briefest mention with no discussion of the implications for structural evolution. Indeed, what is meant on page 93 by Triassic, Dinantian and Longmyndian "reservoirs" in relation to the mineral deposits around the Cheshire basin? And in the last sentence (page 93) where are the fluorspar mines at Chance and Eckington? I have never heard of any such mines.

The Memoir concludes with a comprehensive bibliography, list of maps, memoirs and boreholes. Finally there is a series of ten coloured structure contour and isopach maps at five successive horizons– these would have been easier to understand with keys to the colour schemes and a few place names.

The Memoir as a whole is a valuable contribution to the knowledge of Midlands stratigraphy, structure and palaeogeography, but it is a pity that it is spoilt by so many errors and omissions. It does not come up to the standard we have come to expect in BGS publications: perhaps a revised second edition should be considered?

Trevor Ford

Guidance notes for contributors to *Mercian Geologist* are printed in the first issue of each volume.



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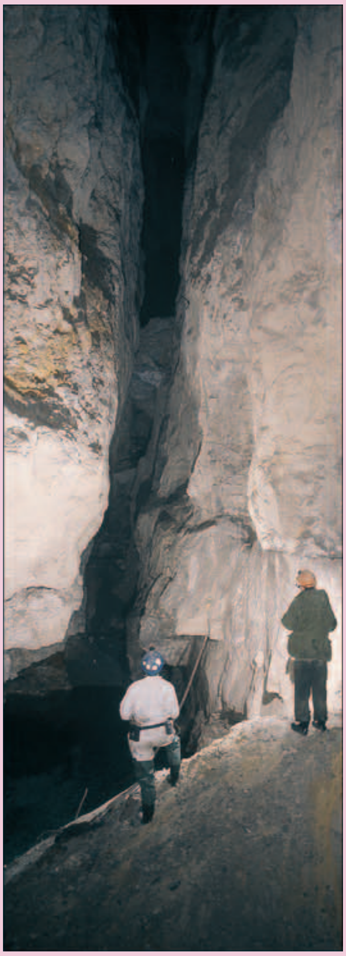

Ladywash

Clipstone

Bolsover