MERCIAN
Geologist

The Journal of the East Midlands Geological Society

Volume 15 Part 3 July 2002

MERCIAN Geologist

VOLUME 15 PART 3 JULY 2002

Address for Correspondence
The Secretary, E.M.G.S.
Rose Cottage, Chapel Lane,
Epperstone, Nottingham NG14 6AE
0115 966 3854 alan.filmer@which.net

The Mercian Geologist is published by the East Midlands Geological Society and printed by Norman Printing Ltd (Nottingham and London) on paper made from wood pulp from renewable forests, where replacement exceeds consumption.

Registered Charity No. 503617

ISSN 0025 990X

Cover photograph: The eastern face of Bardon Hill Quarry, Charnwood Forest, exposing two Triassic palaeovalleys that were cut into a hillside of Precambrian rocks and filled by red beds of the Mercia Mudstone Group [photo: John Carney, with kind permission of Aggregate Industries UK].

Contents

MERCIAN NEWS

Melton Mowbray Earthquake

At 4.25 pm on Sunday, 28th October, 2001, the East Midlands was affected by a sizeable earthquake. It has been termed the 'Melton Mowbray Earthquake', although its epicentre was actually located farther north, just west of Eastwell (SK770283). The UK Seismic Monitoring and Information Service, based at the British Geological Survey offices in Edinburgh, determined its local magnitude to be 4.1 ML, a figure revised from the value of 3.8 that had been calculated immediately after the event. According to the European Macroseismic Scale (EMS), its intensity of just over 5 denotes a strong earthquake… '*felt indoors by many people, outdoors by a few, with a strong vibration causing windows, doors and dishes to rattle, hanging objects to swing, doors to open and close and top heavy objects to fall over*'. Such effects were widely experienced in an area between Mansfield, Northampton and Kings Lynn and some minor structural damage was also reported, involving fallen chimneys and cracked walls.

Contrary to media reports, this was not the 'worst earthquake in 250 years' in these parts. That honour goes to the Derby Earthquake of 11th February, 1957, with an intensity of 6-7 EMS (magnitude 5.3 ML) and an aftershock of 5 EMS (magnitude 4.2 ML). A chart of main shocks experienced throughout the UK landmass would nevertheless place the Melton Earthquake currently at number 20. It was therefore an important event, although to keep it and the Derby Earthquake in perspective, it should be noted that the ten largest earthquakes in the world since 1900 had magnitudes of 8.5-9.5.

What caused the earthquake is a difficult question to answer. Seismologists at BGS Edinburgh calculate that one solution may be that the shock was generated at a depth of 11.6 km beneath the epicentre by a dextral, oblique slip type of movement (ie extensional combined with dextral strike-slip motion). This motion occurred along a northwards-dipping fault, the orientation of which was east-west. Such a depth would place the earthquake focus within early Palaeozoic basement rocks lying below a major rift structure known as the Widmerpool Gulf. The latter is a deep, sediment-filled graben of Carboniferous age that is concealed by Triassic and Jurassic beds in this part of the Midlands. We know that the Widmerpool graben was controlled by very large faults, of broadly east-west orientation, extending deep into the basement. We also know that the modern tectonic regime of Britain is controlled by factors that include pressures exerted by the south-easterly 'drift' of the Eurasian Plate, away from the Mid-Atlantic Ridge. Putting these lines of evidence together, it seems possible that the orientation of the Widmerpool graben faults, or of similar easterly structures in the basement, would enable them to absorb modern intraplate strains by allowing portions of the crust to slide laterally past each other. It could be this process, operating at depth and involving no surface rupture, that periodically generates earthquakes of the type we experienced last year.

Bingham Trails Heritage Association

As part of the Society's charitable objectives of encouraging education, research and conservation in geology in the East Midlands we have provided funding of £250 and intellectual support to the Bingham THA. Support by EMGS and other local and regional bodies enabled the BTHA to obtain lottery money administered by the Local Heritage Initiative Fund. Phase one has seen the publication of five free leaflets (including one on geology), a display in the Old Court House and Bingham Library of a 1:10,000 geological map and other exhibits, and creation of a website (www.binghamheritage.org.uk). The geological leaflet, written by Andy Howard, is very impressive; it should bring a greater geological awareness to the residents of Bingham, and also provide useful publicity for the Society in an area where there is little surface geology to be seen.

Nottingham's medieval caves

It is unusual for a journal to include review of a paper in any other journal, but it is appropriate in this case because of the Society's interest and involvement with Nottingham's sandstone caves. The paper of note is *Nottingham's underground maltings and other medieval caves: architecture and dating* by Alan MacCormick, on pages 73-99 of volume 105 of the Transactions of the Thoroton Society of Nottinghamshire, dated 2001. This is a significant paper on all the older caves (pre-dating 1950) known under Nottingham. These include the 28 cave maltings that are Nottingham's speciality, unmatched elsewhere. It also covers the 27 other dated medieval caves, with illustrations and discussion on the carved pillars and ornamental detail that distinguish them from the larger numbers of later and more functional caves. Appendices include listings of all the cave sites, and also a valuable series of contemporary records of the older caves. Alan's very welcome paper may not be an easy read (though there are more than 40 drawings and photos), but it is a fascinating and authoritative account that adds greatly to the documentation of old Nottingham.

The Society logo

Unusually for a society or organisation, the EMGS has thrived since its formation in 1964 without a logo. But the Society's imminent guidebook on the geology of the East Midlands has required a logo to go on the cover alongside that of our co-publishers, the Geologists' Association. Accordingly, members were asked for ideas, which were then considered by Council. Hammers were rejected on conservation grounds, mammoths are used elsewhere and the choice appeared to be which fossil was most identified with the East Midlands. Charnia was the front runner, but a draft appeared to be too botanical, the palaeontologists lost to the sedimentologists and the Hemlock Stone was chosen. Various modern forms of lettering were tried but eventually a traditional form of letters encircling the stone were chosen in a similar arrangement as used by the Geologists' Association.

Looking back in the Mercian Geologist, the secretary was surprised to find only a single reference to the Hemlock Stone - in Volume 1 part 1, of 1964, in a report by Dr Frank Taylor (still an active member of the Society) of an excursion he led to localities in the area west of Nottingham. The Stone gets just six lines in the report. Happily, Frank Taylor's views expressed in 1964 are still supported by geologists currently working in the area (see page 154 of this issue).

Editorial

This issue of Mercian Geologist is rather slimmer than the first two issues of the volume merely because those two were very large; we are now down to smaller issues to bring roughly the right number of pages within the volume of four issues. Compensation appears by way of the supplement on the geology of the Matlock mines, which is a joint publication with the Peak District Mines Historical Society. The EMGS secretary has also launched a new initiative with his item on page 177 of this issue on some geological sites in France; Society members are invited to contribute to this series on "Holiday Geology", especially with accessible sites and sights in Europe.

THE RECORD

The Society has welcomed 18 new members, and membership stands at nearly 400 at the end of 2001. Special tributes were paid to three members who had recently died. Ben Bentley was unable to complete his term on Council due to illness; his enthusiasm and energy, particularly in staffing the Society display at numerous events and enthusing geology to all who passed by, will be greatly missed. Edna Colthorpe and Josie Travis were founder members from 1964; both worked hard in the early days of the Society to ensure its smooth operation and to lay the foundations of its success today, and both were regular attenders at Society lectures until this year.

Field meetings

The programme was disrupted by access problems due to the outbreak of foot and mouth disease, but four excursions were possible.

In July 2001, Peter Gutteridge led a trip to the area around the National Stone Centre in Derbyshire, and Keith Ambrose led an evening visit to the Millstone Grit of South Derbyshire.

In September, Andy Howard led a weekend excursion to Staithes and Cayton Bay, and Neil Aitkenhead led a trip by coach to Fountains Abbey and Brimham Rocks.

Indoor meetings

In March 2001, after the AGM, Dr A.R. Helmsley lectured on hay fever in the Palaeozoic.

In April, Prof. J.D. Hudson talked on the geological history and the history of the geology of the Hebridian island of Eigg.

In October, Dr Sarah Davies talked on forests, floods and fires in the Carboniferous with insights from the sediments of Nova Scotia, Canada.

In November, Dr D.T. Aldiss presented his lecture on the geology of the Falkland Islands.

In December, Dr R.L. Leake talked about new perspectives on gold in Britain and Ireland.

In January 2002, the lecture was by Dr Alf Whitaker on the deep geology of Britain.

In February, Prof. Peter Doyle entertained us with his lecture on belemnites, the mystery thunder bolt, revealing new findings that featured in the national media the following week.

Events

The Society was represented at the Geologists' Association Reunion in Liverpool and at the Creswell Crags Archaeology and Geology Road Show. Unfortunately some regular events were cancelled due to the foot and mouth outbreak.

Alan Filmer, Secretary

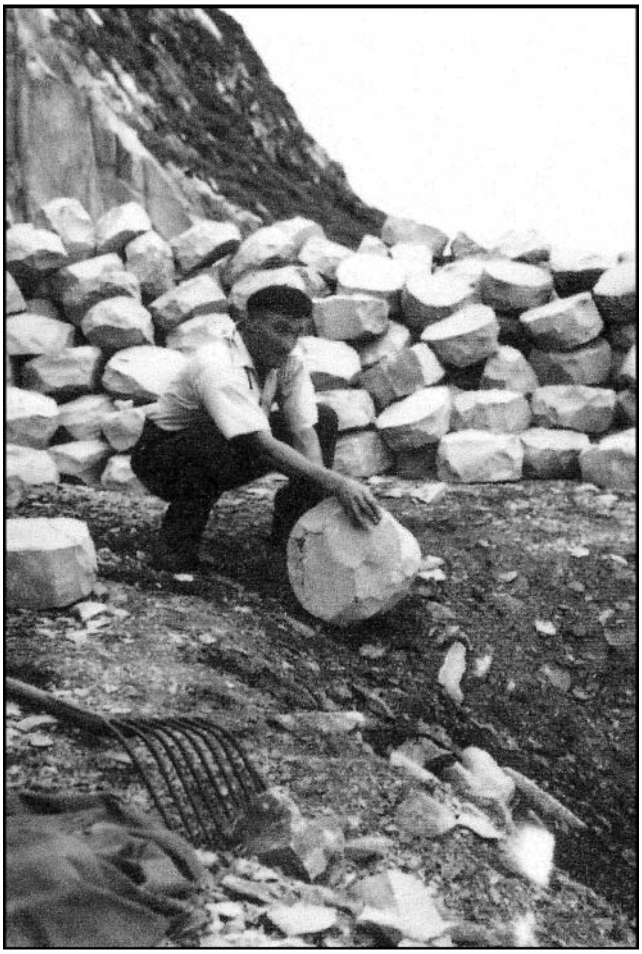
GEOBROWSER

Geology goes for gold

The victory of the UK women's curling team at this year's Winter Olympics not only gripped the nation, but also gave a measure of quiet satisfaction to those whose only recollection of geology undergraduate teaching was being told that curling stones come from Ailsa Craig. To find out if this is still the case, we made enquiries north of the Border and have been assured that the finest quality stones are of microgranite obtained solely from that island in the Firth of Clyde.

This alkaline rock is extremely hard and resistant to erosion, which is why it forms upstanding features such as Ailsa Craig, as well as Rockall Island in the Atlantic. At Ailsa Craig it contains a distinctive riebeckitic arfvedsonite variety of amphibole, and it represents a small pluton intruded during the early Tertiary magmatism (at 62-52 Ma) of western Scotland. Although it is true that the bodies of some curling stones are now made of granite quarried from Wales, their most important part, that in contact with the ice, must be made of Ailsa Craig microgranite, and in the trade this is called an 'Ailsinsert'.

With the sport now extending worldwide (Brazil and Israel were the latest to catch the craze), specifications are being tightened and a run on the existing stone resource is expected. The main curling stone quarries are on the northeast side of the island where the rarer, red (as opposed to blue) variety is particularly prized. They ceased working in 1973, but thousands of tons of the rock remain as a stockpile. As shown in the picture, roughly hewn stones are prepared on the island for shipment to workshops on the mainland.



Blocked-out curling stone 'biscuit' being rolled to the foreshore for transport by boat (photograph from BGS Report Vol. 16, No.9, 1987).

Big in Patagonia

New research is suggesting that the 'Walking with Dinosaurs' series may have been made a little too hastily. Apparently there were much larger creatures that could have been illustrated, and as reviewed in the *New Scientist* (September 2000, p.23) these have been known about for at least 15 years. Their existence has not been widely publicized because to date all the finds come from the former southerly continent of Gondwana, whereas the dinosaur hunters' favourite stamping grounds have been in sequences originally from the more northerly, Laurasian continent, in localities such as the Isle of Wight. Many Gondwanan dinosaurs fall into a new category, the 'titanosaurs', and include such species as *Gigantosaurus*, a carnivore from the Cretaceous of Patagonia, which at 14 m long and 8 tonnes was bigger than the largest *T. Rex* yet found, although apparently only half as intelligent. Even this creature may have given a wide berth to *Argentinosaurus*, 45 m long and weighing 100 t, the largest animal ever to walk the Earth. These more primitive dinosaurs apparently survived for 50 million years into the Cretaceous of South America, as well as in other parts of Gondwana such as India and Africa. What is intriguing is that close Laurasian relatives are now being found in Europe, including the Isle of Wight. So it may be that the dinosaurs of North America and Eurasia, although better known, were actually the unusual ones, generated in isolation, and it is the southern hemisphere species that represented the evolutionary mainstream during the Cretaceous.

Resurrected fossils and an old bug

While new fossils are constantly being found, it seems that other finds are more in the nature of rediscoveries that have prompted palaeontologists to re-examine many of the 'established' extinction events. A good example is the early Cretaceous (Cenomanian-Turonian) extinction among the echinoderms. Instead of the 71% of species previously supposed to have perished, examination of much younger strata, well above this time boundary, now suggests that only some 17% did not make it (*Science 2001*, p.1037). Basing the magnitude of the extinction on groups of shallow-water taxa may have been the reason for the previous error, because after the seas retreated these creatures were not widely preserved. They only returned to the fossil record some 20 million years later, after global sea levels were re-established and shallow-water environments became better represented in the rock sequence. Other extinctions are now being looked at, to see if there has been a similar bias towards the sampling of species from certain environments only. Perhaps the most spectacular example of a 'lazarus' organism is the 250 million year old microbe discovered in New Mexico. As reported in a *Times* article (19 October 2001), but not yet confirmed, this early Triassic bacterium was found as spores sealed in a salt crystal, which was retrieved from 600 m below the ground by drilling. It was revived from suspended animation by using a growth promoter of amino acids, and belongs to one family of microbes that presently thrive in the salt-rich environments of the Dead Sea.

Delphi is not just archaeology

The testimony of certain ancient authors has linked the Delphic oracle of Greece to specific geological phenomena that have included toxic gaseous emissions, a spring, and a fissure in the bedrock. Many archaeologists and geologists have previously ridiculed these theories, geologists believing that such gases could only have been derived from volcanic activity, for which there is no evidence around Delphi (nor the Gulf of Corinth in general). Support for the ancient ideas is now at hand, however, due to recent work (*Geology*, 2001; p.707) showing that the Temple of Apollo, in which the oracle or 'Pythia' resided, is situated directly over an extensional fault. That structure controlled the locations of several springs, two of which rose within the Temple itself. Waters analysed from the one remaining spring have included traces of ethylene, most probably incorporated by passage through the highly bituminous strata beneath Delphi.

As the article explains, and we hesitate to make this generally known, the inhalation of ethylene can induce a sensation of 'floating or disembodied euphoria, with a reduced sense of inhibition and …. a frantic thrashing of the limbs'. It was the high priest Plutarch, quoted in a further recent article (*Geology*, 2000; p.651), who provided the explanation for the oracle's eventual demise. He noted that things were never the same since the destruction wrought at Delphi by the famous earthquake of 373 BC in the Corinthian Gulf. The oracles did struggle on, but by AD 381 the 'euphoric' powers of these ladies had declined to such an extent that the attraction was closed, so ending a tradition that had been in existence since at least 1400 BC.

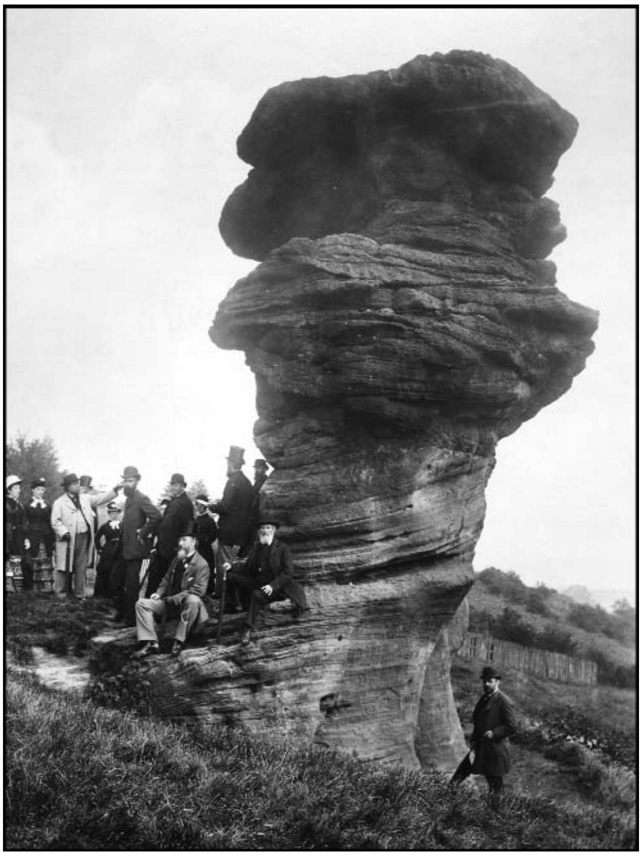
FROM THE ARCHIVES

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

The Hemlock Stone

One of the East Midlands' most well-known geological landmarks, the Hemlock Stone is of course very familiar to *Mercian Geologist* readers, having adorned the cover of each individual part of Volumes 13 and 14. The Hemlock Stone now sits proudly in the centre of the Society's new logo, so it seems fitting to choose the Stone as the subject of this issue's '*From the Archives*'.

Previous archive features have used images from the British Geological Survey's own collection of survey photographs. BGS is also the custodian of the British Association for the Advancement of Science archive of geological photos, which numbers over 9000 images dating from 1861 to 1945. This photo of the Hemlock Stone, taken in 1890, is from that collection. Like almost all photos or drawings of the Stone, it shows the pillar from the south, its narrowest and most spectacular perspective. The pillar is in fact several metres broad along its north-south axis, but it is an imposing feature from any viewpoint.



The Hemlock Stone (BAAS photo #1488, British Geological Survey Library). We have no information on the people in the photograph, nor on the event they were attending. Can any readers help? If so, we will publish a note in the next issue.

The Hemlock Stone lies on the eastern side of Stapleford Hill (at NGR SK499386), to the west of Nottingham. The hill is underlain by Permo-Triassic sandstones of the Sherwood Sandstone Group. The Lenton Sandstone Formation (formerly Lower Mottled Sandstone) forms much of the slopes, with the basal beds of the Nottingham Castle Sandstone Formation (formerly Bunter Pebble Beds) forming a thin capping on the Hill. Almost all descriptions mention that the Hemlock Stone is composed of 'Bunter Pebble Beds', but the reality is rather different. The sandstone platform on which the pillar stands, plus the lowermost 2 m part of the pillar itself (up to the heads of the tallest figures in the photograph) is in fact in the Lenton Sandstone Formation, a deep red-brown, very fine-grained cross-stratified sandstone. The rest of the pillar (abou 7 m) is in the overlying Nottingham Castle Sandstone. This is a yellowish grey, medium to coarse-grained, cross-stratified sandstone with common large mudstone clasts. Extraformational quartzite pebbles, typical of this sandstone, become common towards the top of the pillar. The Nottingham Castle Sandstone part of the pillar is strongly cemented by the mineral baryte (barium sulphate), but the underlying Lenton Sandstone Formation is not, and retains the characteristic, very friable texture seen elsewhere in this formation in the Nottingham area.

Theories abound about the origin of the Hemlock Stone, ranging from the supernatural to the scientific. Many have been documented in a well-researched booklet on the Hemlock Stone by R W Morrell, a former Secretary of the EMGS. Familiar old chestnuts such as druids, ley lines and demonic activity have all appeared in various interpretations. The views of medieval scholars are the most entertaining. They maintained that the Devil hurled the Stone into place from Castleton in Derbyshire, in irritation at the chiming of local church bells. Most readers will no doubt discount this theory on intuition alone, but sticklers for a scientific refutation should note that there is no Triassic sandstone at Castleton.

The Nottingham Castle Sandstone was originally deposited as a pebbly, fluvial sand by a major, possibly seasonal, river in a semi-arid continental drainage basin, perhaps like the Murray-Darling Basin of present day Australia. Baryte is an authigenic cement that was precipitated in localised zones within the formation during burial diagenesis, partly by corroding and replacing detrital feldspar sand grains. Pore-filling carbonate cements, principally ferroan calcite and dolomite, were formed at about the same time and probably pervaded the entire formation. Most of these carbonate cements were subsequently removed by reducing, meteoric groundwaters when the Nottingham Castle Sandstone was exhumed from its overlying cover rocks by erosion during the Tertiary and Quaternary periods. This has left the familiar, weakly cemented, friable pebbly sandstone seen at most exposures today. The baryte cement, due to its lower solubility, resisted this solution process, leaving patches of more strongly cemented sandstone within an otherwise friable rock.

Though geologists agree that the strong baryte cement accounts for the preservation of the pillar, debate continues about the agency responsible for removing the surrounding, weaker sandstone. Was natural erosion responsible, or was the pillar left behind after ancient quarrying activities? According to Morrell, the earliest scientific attempts to explain the origin of the Stone were by William Stukeley in the late 18th century, who was the first to put forward the quarry remnant theory. James Shipman, the foremost amateur geologist in the East Midlands in the late 19th century, favoured natural erosion, especially glacial action, as the cause, an explanation later followed by the Geological Survey in 1908. The current, 'official' BGS view, expounded in the Derby Sheet memoir and also favoured by Frank Taylor in an early *Mercian Geologist* article, is that the Hemlock Stone is a quarrying artefact.

Those favouring the natural erosion theory mainly allude to the lack of any documented quarrying activity in the vicinity. However, even a casual stroll around Stapleford Hill reveals copious evidence of former quarrying on all sides of the Hill and around the Hemlock Stone itself. This includes several old quarry faces and spoil heaps in various states of degradation, indicating a long history of quarrying. Extraction seems to have favoured the Lenton Sandstone Formation, possibly for use as a moulding sand, but the Nottingham Castle Sandstone was probably also won in lesser quantities. It is easy to visualise how, once quarrying had exhumed the baryte-rich sandstone from its softer rock surroundings, it would have been impossible to work the Stone pillar further for fear of toppling it, with possibly catastrophic results. Interestingly, the baryte-cemented upper part of the pillar still bears a coating of industrial grime that probably pre-dates modern air pollution controls, indicating negligible erosion. The lower part, in the friable Lenton Sandstone, has no grime coating and is actively eroding at present. This will eventually undercut the pillar and cause the entire upper part to fall *en masse* - but visitors are safe at present!

Andy Howard, British Geological Survey

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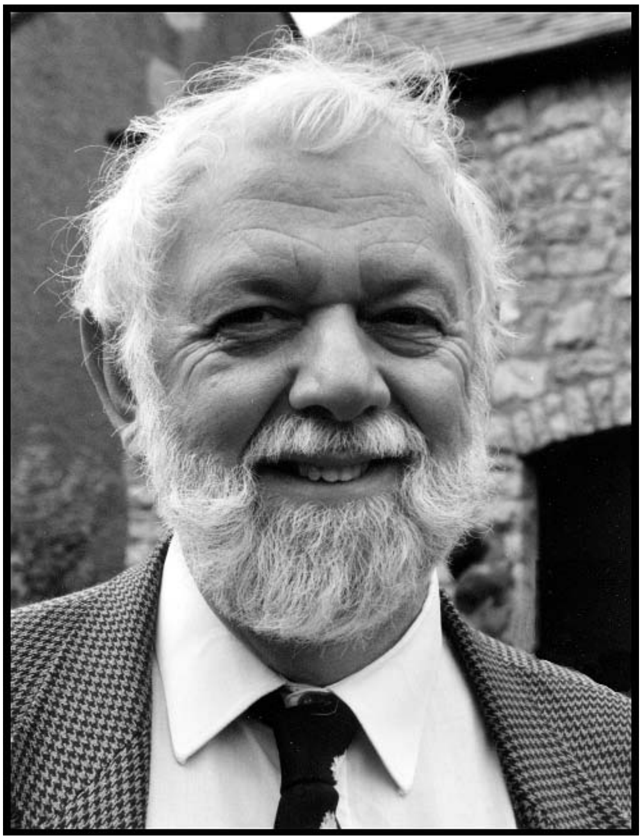
VALE



Bill Sarjeant 1935-2002

Well known to many members of the Society, William Antony Swithin Sarjeant, DSc., FRSC was both a micropalaeontologist of international repute and a very sociable eccentric with a diversity of interests. In 1956, he gained a geology degree at Sheffield University, his home town, when, because he was born on St. Swithin's Day, he added his third forename by deed poll in time for it to appear on his degree certificate. He then stayed on to gain a PhD on the topic of *An investigation of the palaeontology and stratigraphical potentialities of the micro-plankton (dinoflagellates and hystrichospheres)* in the Upper Jurassic. In his time at Sheffield, he edited the Sorby Record for the natural history society and also the Students' Union newspaper.

Academic positions followed at the Universities of Keele, Reading, Nottingham and Oklahoma, until April 1972, when he became Professor of Geology at the University of Saskatchewan in Saskatoon, where he stayed for the rest of his life.

His research work focused on the study of marine microfossils and on the history of the earth sciences, fields in which he was widely published and recognized. He later expanded his studies to include fossil footprints. Also in 1972, he was awarded a DSc by Nottingham University. His submission consisted of 119 items, including 66 papers on fossil micro-plankton and 31 papers on his other interests in mineralogy, petrology and trace fossils. A citation at the time stated that … his contribution during the last 20 years to the study of fossil micro-plankton is probably unequalled. This despite losing much of his research material in a fire at Nottingham University, which cooked his palynological samples beyond redemption. In the 1980s, he compiled a massive bibliography of the history of geology, in ten volumes.

He was a founder member of the East Midlands Geological Society in 1964. He led the Society's inaugural field excursion to the Dudley Canal Tunnel in the same year and addressed the Society on "The Geology of Iceland". He edited the Mercian Geologist from 1964 to 1970, and presented the first foundation lecture to the Society in 1971. His papers in the Mercian covered Calton Hill asbestos, Derbyshire gypsum and Triassic fossil footprints, among many others.

Bill was also a founder member of both the Peak District Mines Historical Society and the American Association of Stratigraphical Palynologists, and was a member of twelve other learned societies. In 1995 he was elected to Fellowship of the Royal Society of Canada.

Outside geology, he wrote fantasy fiction under the name of Antony Swithin and was an avid collector of books. He was an authority on Sir Arthur Conan Doyle, and published a critical analysis of the author's "The Terror of Blue John Gap", with reference to Castleton localities. Folk music was an enduring passion, and he became deeply involved in heritage preservation when in Saskatoon.

He was described in a reference in his earlier years as "A man of loyalty and wide interests (extending from poetry to mineral lore), he is a thoroughly decent chap and an asset to the department; people react differently to his marked streak of naivety and quite unconscious proneness to drop the occasional brick". He was also well known at the Miners Arms in Brassington for his ability to devour entire bowls of pickled onions.

Bill Sarjeant died on July 8th, leaving his wife Margaret "Peggy", daughters Nicola, Rachel and Juliet and two grandsons.

REVIEWS

The Pennines and adjacent areas (British Regional Geology, fourth edition) by N. Aitkenhead, W. Barclay, A. Brandon, R. A. Chadwick, J. I. Chisholm, A. H. Cooper and E. W. Johnson, 2002. British Geological Survey, Nottingham. 206 pages B5, 29 colour photos, 45 figures, 0 85272 424 1, £18.

In the mid-1900s the first 18 of the 20 very popular British Regional Geological guides were published, mostly with two or three editions and many with large numbers of reprints. The original Pennines guide was first published in 1936, with its third edition in 1954. Since then there have been many reprints but until now, no new edition. This was very unfortunate as it was in those last forty years of the century that the science of geology made significant strides with the advent of plate tectonics and many other important advances. These dramatically changed our understanding of our own regional geology. Our wait for a fourth edition of the 'Pennines and adjacent areas' has at long last been answered, and that wait has been well worthwhile.

The area covered by the guide extends from Nottingham northwards to the Stainmore gap, and from the Irish Sea coast in the west across to the Vale of York and the Trent valley in the east.

The present guide is divided into ten chapters, each with different authors who are past and present staff of the BGS. Many of those authors are well known to EMGS members as they have, in various ways, made large contributions to the activities of the society in recent years.

The opening chapter sets the scene in a review of current understanding of the broad aspects of the geology of the region resulting from research in plate tectonics, basin dynamics, sequence stratigraphy etc. This chapter is followed by seven more in stratigraphic sequence from the pre-Carboniferous to the Neogene and Quaternary. Carboniferous rocks, which crop out across a vast part of the region, are rightly afforded four of these chapters, and the considerable influence of the Quaternary on the final moulding and geomorphology of the region is given extensive coverage. All chapters are written concisely, but in a very readable way, and it is surprising how much detail is presented in a limited space. The variations of the sedimentary sequences across the region are dealt with expertly, and the palaeogeographic reconstructions help to stimulate interest in the geological history.

The penultimate chapter on the structure should enhance aspirations of gaining a well rounded knowledge of the geological events that have developed the present geology. Complementing and adding to the story of the region the last chapter is used to demonstrate how those of us who live in the region have been influenced directly or indirectly by the geology. The variety of the mineral resources, their exploitation and influence on the growth of settlements and the potential hazards resulting from the underlying geology are all developed.

This guide is an excellent update on the third edition, and enhances the literature concerning our local area. It is well written throughout, and with the numerous contributing authors it has had to be extremely well edited to make it the cohesive publication it is. The text is augmented with well chosen and numerous text figures and tables. The cover plate of Gordale Scar is most attractive and there are 28 further plates, with variable colour quality, that enhance the guide.

The BGS are to be congratulated for this publication which I thoroughly recommend. It is a quality text for background and general reading, and for those who wish to pursue aspects of the subject further there is a very good bibliography. The selling price is higher than for earlier guides, but there is a wealth of content and, with a separate solid geological map included in the back pocket, it is very good value.

Ian Sutton

Rocks and Scenery of the Peak District, by Trevor Ford, 2002. Landmark: Ashbourne. 96 pages of A5, 39 diagrams, 46 colour photos, 1 84306 026 4, £7.95.

Most EMGS members will have heard one of Trevor Ford's talks or have accompanied him on a field trip and will be aware of his great ability to convey complex scientific concepts in a way that any interested person can understand. In this concise book on the Peak District, Trevor has drawn together many strands of his work, and carried this communication skill to a wider readership. The geological processes that have shaped the area to give rise to what can be seen today are clearly explained in 18 short chapters, each dealing with a rock type, structure or event, for example, limestones, volcanics, the ice age, minerals and mines, and of course caves. This book is a valuable new overview, presenting information (much previously only available in specialist publications) in a very accessible style.

Alan Filmer

Mercia Mudstone as a Triassic aeolian desert sediment

Ian Jefferson, Mike Rosenbaum and Ian Smalley

Abstract. It has been suggested that at least parts of the Mercia Mudstone in the English Midlands are closely related to loess, or loess-like sediments. It seems likely that the Mercia Mudstone is an ancient form of parna, the aeolian desert sediment formed in the Australian Quaternary. This is essentially a form of loess having silt-sized particles and an open depositional packing. Loess-like systems tend to collapse when loaded and wetted, and this appears to have occurred in the mudstone. The collapse behaviour of the Mercia Mudstone is probably the strongest indication of a loessic origin. Study of the Mercia may throw some light on the nature of parna - the most characteristic of the Australian loesses.

The original idea appears to be due to Bosworth (1913), that the Mercia Mudstone Group (which he of course knew as the Keuper Marl) was possibly in part a loessic or loess-like deposit that had been formed by arid desert processes. In the recent report on the Mercia Mudstone prepared by the British Geological Survey (Hobbs et al, 1998) this idea is still given some credence, as one of the ways in which the Mercia Mudstone was formed. The idea deserves more discussion, from two points of view, as part of a further consideration on the mode of formation of the Mercian, and as a means of providing more data on loessic processes associated with hot deserts. The desert loess problem has been discussed for many years, in particular since the Smalley & Vita-Finzi paper of 1968. They claimed that there were no specifically desert processes which could produce the fine material needed for loess deposits - and this claim is still being discussed (Sun, 2002). Bosworth saw loess as a desert sediment. Today, loess is seen more as a glacial phenomenon, related to cold phases of the Quaternary, rather than as a desert material. The nature of 'desert' loess and the nature of desert-related loessic processes is still being questioned (Wright, 2001) and the nature of the Mercia Mudstone may throw some light on nearly contemporary processes.

Mercia Mudstone

The Mercia Mudstone Group is a sequence of predominantly mudrock strata that underlies much of southwestern, central and northern England and on which many urban areas and their attendant infrastructure are built. Although it causes few serious geotechnical problems, some difficulties do arise as a result of volume change (Popescu et al, 1998). It is significant to the construction industry because it is frequently encountered in civil engineering activities involving foundations, excavations and earthworks (Nathanial & Rosenbaum, 2000). Its nature is such that its properties may vary between a soil and a rock depending on its detailed lithology and its state of weathering. These descriptive statements are supported by the recent report by the British Geological Survey (Hobbs et al, 1998) on the Mercia Mudstone in the context of a series of monographs on the Engineering Geology of British Rocks and Soils; another excellent source of practical data is Chandler and Forster (2001).

It appears that the Mercia Mudstone was deposited in a mudflat environment in three main ways:

- settling out of mud and silt within temporary lakes,
- rapid deposition of sheets of silt and fine sand by flash floods,
- accumulation of wind-blown dust on wet mudflat surfaces.

This last depositional mode has allowed a comparison between the Triassic sediment and Quaternary loess. In fact it seems likely that parts of the mudstone, notably the outliers in Nottingham and Leicester, are like the parna deposits which are observed in south-eastern Australia (defined and named by Butler, 1956).

The overall disposition of the Mercia Mudstone across the country is controlled by the long-term tectonic trends (Smalley, 1967), and lies parallel to, and probably just to the south of, the major tilt axis. Land to the south and east of the Mercian outcrop is subsiding, largely as a result of long-term tectonic trends, but possibly with a contribution from isostatic recovery following the last glacial retreat.

Structure and nature

The Mercia Mudstone has been reported (Hobbs et al, 1998) as having a two-stage structure, formed first by the aggregation of clay-sized particles into silt-sized units, and then by the agglomeration of these when weakly bonded by various cements. The primary 'intra-ped' structure is stronger than the secondary 'inter-ped' structure. This is very like the situation in southeatern Australia where the parna consists of a silt-sized material, often found in dune structures. The silt-sized particles are aggregates of clay units. The Triassic deserts could have provided a depositional environment very similar to that in Pleistocene Australia. Parna behaves in many ways like loess, has the classic, open, airfall structure, and also mantles the landscape.

The Mercia Mudstone is a heavily over-consolidated and partially indurated clay/mudrock. It has been credited with 'anomalous engineering behaviour' and 'unusual clay mineralogy' throughout. The former is usually attributed to aggregation of clay particles into silt-sized peds or clusters. The clay mineral composition is dominated by illite (typically 40-60%) with additional mica, chlorite, and corrensite (swelling, mixed layer, chlorite-smectite), with minor smectite, palygorskite and sepiolite.

Collapse and subsidence

L. J. Wills, who devoted much time to the study of the Triassic in England, appeared to suggest that mudrocks in the Nottingham-Leicester area were perhaps the most likely to be of a loessic nature (Wills, 1970). He pointed out that the 'loess' school of thought was initiated by Bosworth in his famous monograph for the Leicester Literary and Philosophical Society in 1913, although Bosworth does not actually say much about this idea.

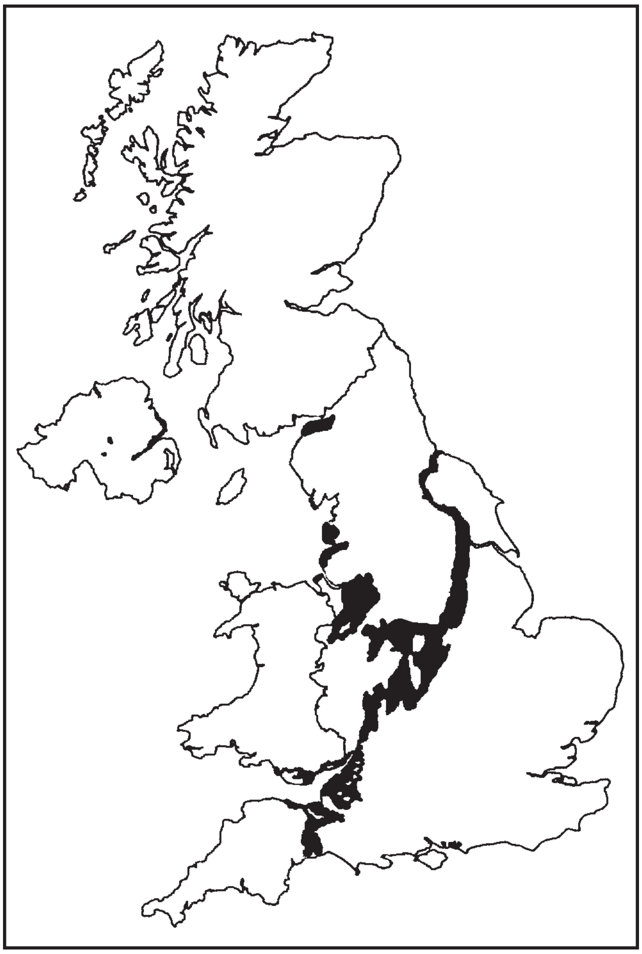


Figure 1. Outcrop of the Mercia Mudstone Group (after Hobbs et al, 1998).

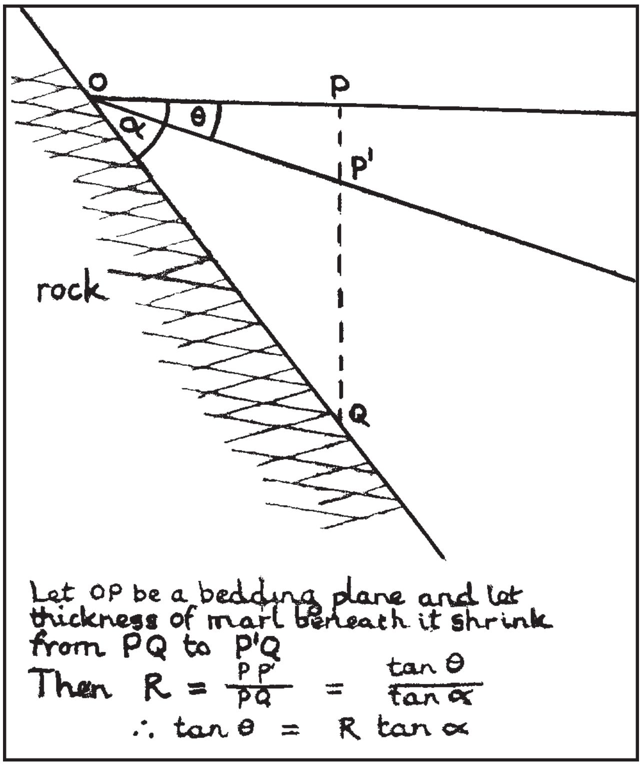


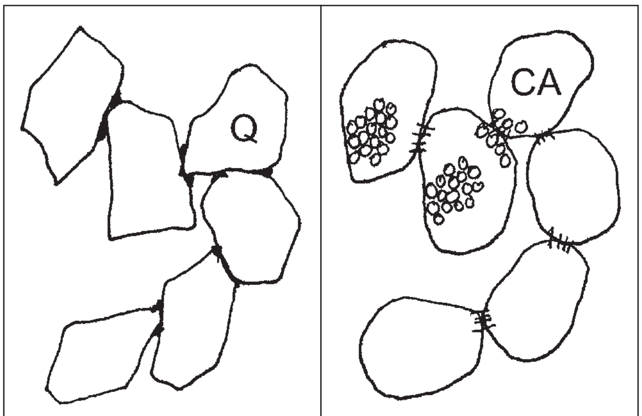
Figure 2. The original Figure 33 from Bosworth (1913) showing subsidence in the Mercia Mudstone; a rough diagram, but possibly one of key significance. Citing Bosworth - "thus taking $\alpha = 35^o$ and $\theta = 10^o$, values observed in several cases, we obtain R = 0.25".

In most parts of England and Wales the Mercia Mudstone has been subjected to only mild tectonic deformation. Dips are generally <5°, except in the vicinity of faults, though steeper radial dips occur locally around the flanks of contemporaneous landmasses such as the Mendips. Examining this aspect, Bosworth showed how the mudstone subsided after deposition (Fig. 2). The Bosworth calculation showed a structural rearrangement followed by a collapse of about 25% - which compares reasonably well with the 15% subsidence observed when classic loess suffers from hydrocompaction.

The study of the mudstone collapse may throw some light on to the nature of the collapse mechanics in loess and loess-like materials. There is still a large amount of interest in the problem of hydrocollapse and subsidence in loess soils - in particular in the Russian language literature (Trofimov, 2001). The Russian investigators see the 'development of collapsibility' as a critical problem in the study of collapsing loess, and it is possible that collapse of parna and Mercia Mudstone may provide useful additional information for this debate. Loess collapse is influenced by the clay in the system (Rogers et al, 1994). In the parna/mudstone system, where the particles are all clay mineral material (despite their aggregated silt size), the particle contacts should all be mobilizable.

The 25% collapse may be an example of the ideal collapse in aeolian silty sediments. This is a significant observation and could prove to be the critical link between the two systems (Fig. 3). The all-clay particles may behave in an interestingly different manner from the quartz silt particles; they should certainly have different shapes. The quartz silt particles are remarkably flat (Assallay et al, 1998) but the parna/mudstone particles could be much rounder - as they accumulate, no breakage is involved. These could form more collapsible structures, giving >20% collapse, rather than the normal 15% in classic loess deposits.

The Mercia Mudstone is found to be 'water-softened' where its upper boundary acts as an aquiclude below sandstone or permeable fill. Here it can be expected to have a low strength and high deformability. The factors that cause water-softening in the lithified deposit could be similar to those that cause hydro-compaction in a recent loess deposit. In each case the effect of water at the particle contacts allows strains to develop; in the Mercia Mudstone this is seen as high deformability. In the loess there is also high deformability - which takes the form of structural collapse or hydro-compaction.



loess	parna Mercia Mudstone
open airfall structure e = 1; PD = 0.5 Q = angular comminuted quartz particles ~30 μm some clay #10%	open airfall structure e = 1; PD = 0.5 CA = clay aggregate particles ~30 μm
short range bonds modified by clay at contacts linear collapse 15%	initial short-range bonds transform quickly when wet linear collapse 25%
cold formation environment periglacial, glacial source	hot formation environment desert fringe, dry lakes salt lakes, clay dunes
Quaternary - loess	Quaternary - parna Triassic - Mercia Mudstone

Figure 3. Collapsing systems in metastable airfall structures compared - loess versus parna (and possibly Mercia Mudstone).

Loess and deserts

If loess is a deposit of wind-blown dust (silt), and if deserts are places where dust-storms are observed, it seems intuitive that deserts and loess go together. But the relationship is not as close as it may appear. Since Smalley & Vita-Finzi (1968) raised the issue, there has been the large problem of 'making the material'. There are no obvious sources, in dry sandy desert regions, of the silt-sized quartz particles that constitute most of the world's loess deposits. Sun (2002) is close to solving the 'desert loess' problem by showing that the great deserts to the north and west of the Chinese loess deposits act as 'holding-areas' or large silt reservoirs. These supply silt for the thick loess deposits, but are themselves supplied with silt material from the mountains of High Asia.

If there were an alternative method of forming silt-sized particles then desert sources might look more promising; the alternative would have to provide a way of avoiding the need for large geo-energies to fracture quartz particles to provide silt. A non-comminutive method of making silt might be to agglomerate clay-sized particles; these could then be moved by the wind and deposited as loess-like sediments. It appears that this is what happens in parna deposits (the study of which is rapidly developing) and it may have occurred in at least parts of the Mercia Mudstone. The Mercian occurrence is interesting and important because it offers an extra window on to a currently important problem in loess sedimentology.

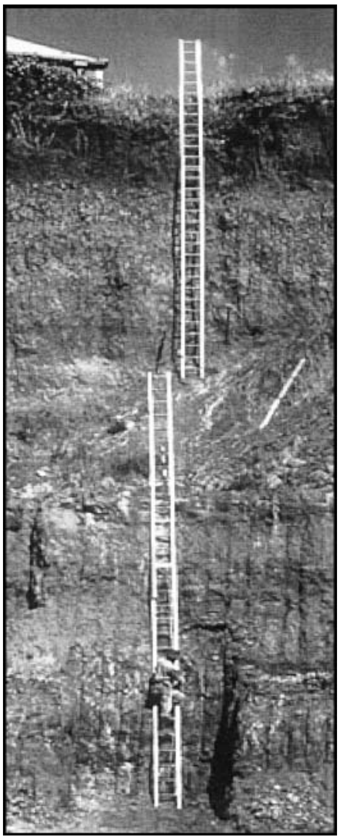


Figure 4. A classic exposure (now flooded) of parna in the Pioneer Pit in the Murrumbidgee floodplain 340 km east of Balranald. The 2 m of pale soil with blocky jointing just below the dark top layer is the Wills Parna.

Parna

We know relatively little about parna (Fig.4) - it is a late-comer among the loess-like materials. It is an aeolian loessic clay, named by Butler (1956) in Australia, and it has little local geotechnical significance. A recent study (Chen, 1997) of parna near Wagga Wagga (in S.E. New South Wales) has described the Quaternary sedimentation, landforms and soils of the region, and a large step forward has been made by the publication of a superb and timely review (which provoked this Mercian correlation) by McTainsh and Hesse (2001). These authors want to call their material 'loess', claiming that confusions over terminology have prevented Australian investigators from playing a significant role in international loess science, and the desert loess debate.

The sedimentary environment in southeastern Australia over a period of around 17000-15000 BP could have been very similar to that in parts of England during the Triassic. The Wills map (1970) of the dried-out phases of the German and English Neotrias shows salt lakes and 'loessic' regions (Fig. 5). The Bowler map (1975) shows the parna environment in part of Australia, with salt lakes and parna dunes (Fig. 6). The unconsolidated sediments of the Riverina Plain of New South Wales and northern Victoria are dominated by fluvial deposits, but interspersed through the materials, and spread extensively across the plain, Butler recognized an aeolian clay - parna. These parna deposits occur either as discrete dunes (dune parna) or as thin, discontinuous but widespread sheets (sheet parna). The principal feature of both forms is their origin as aeolian clays transported not as separate clay-sized particles but as stable clay aggregates or pellets. Dare-Edwards (1983) proposed three mechanisms for the production of clay pellets:

- deflation of the aerated clay surface of a lake floor, swamp or dune corridor, following the evaporation and efflorescence of saline water,
- aeolian erosion of pre-existing soil surfaces,
- stripping of alluvial clays.

The production of aeolian clay dunes requires the seasonal filling of lakes and swamps by saline water followed by the evaporative drying of these water bodies. The Australians would like to call parna loess, and there is no doubt that there are striking similarities (Fig. 3).

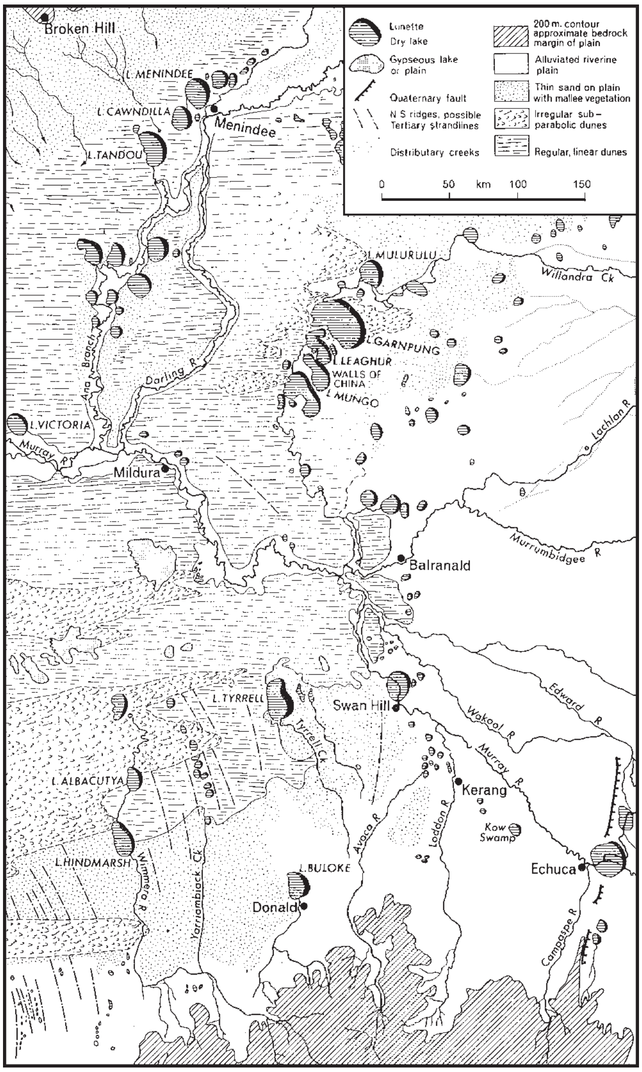


Figure 6. The landscape with aeolian loessic clays in western New South Wales and northern Victoria (from Bowler, 1975) - a possible model for parts of the Triassic in the English Midlands.

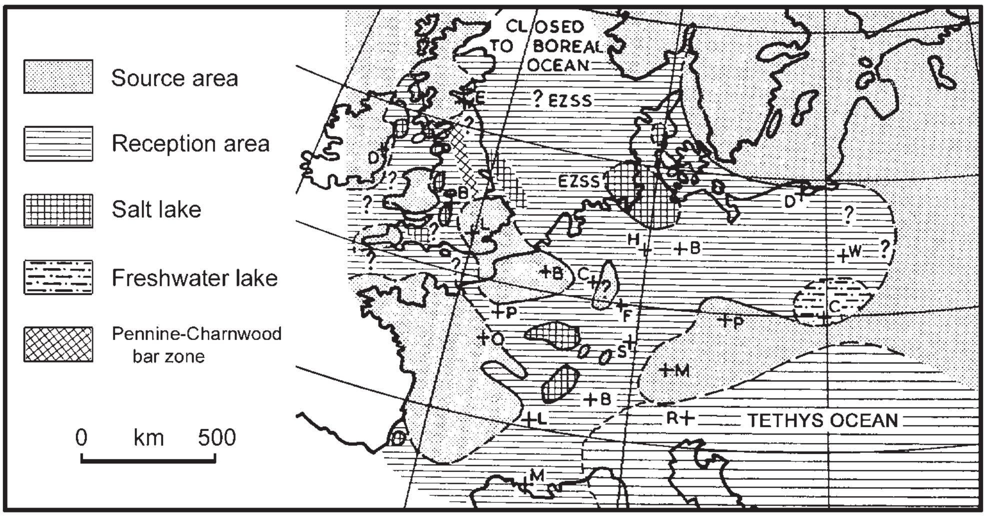


Figure 5. The Neotrias (Mercia/Keuper) in Europe (from Wills, 1970). Reception areas were described by Wills as shallow basins on the peneplain, which was largely dry and loess-covered.

Figure 7. Saltbush plains north of Balranald.

The scenario of a wind-swept, unstable landscape, in which lakes and rivers are drying up, vegetation cover is sparse, saline groundwater tables are high and episodic flash flooding occurs, corresponds with reconstructions of palaeo-environments proposed from the period 18,000 to 15,000 B.P., in southeastern Australia. It might also be viable for the English Midlands in the Triassic, and Figures 7 and 8 may therefore give some indication of the environments around Nottingham in the late Triassic.

Discussion

There is a precedent for comparing the Triassic English Midlands with Quaternary Australia. Talbot et al (1994), looking at problems of sedimentation in low-gradient desert-margin systems, compared the Late Triassic of northwest Somerset to the late Quaternary of east-central Australia. This comparison appears to be valid, and it allows examination of a sedimentary system that delivers silt-sized clay agglomerate particles. Bowler (1975) records the first appearance of clay pellets in aeolian sediments on the Walls of China (a lunette - a crescentic ridge of aeolian sediment on the lee-side of a salt lake - located on figure 6) at about 26 000 BP. The appearance of the clay pellets is related to a phase of increasing aridity and the drying out of the salt lakes in the landscape. The link between salt lakes and Mercia Mudstone is also shown on the Wills map (Fig 5).

Comparisons between Mercia Mudstone and parna are made somewhat difficult by the variation in lithology in the former. We can recognise, in the East Midlands, five main lithofacies in the Mercia Mudstone Group:

- Laminated silty mudstone - very finely laminated, with ripple marks, shrinkage cracks and planar lamination. Notably the Radcliffe Formation and parts of the Gunthorpe Formation. Definitely water deposited, possibly lacustrine.
- Deformed mudstone - as above, but with lamination highly disrupted by shrinkage cracks, soft sediment deformation, and growth and dissolution of evaporitic minerals, though traces of lamination remain. Common in the Gunthorpe and Edwalton Formations. Definitely water deposited.

Figure 8. Eroded remnants of a lunette, dated from about 65 000 BP, overlie lacustrine sediments on the margins of the Mungo salt lake.

- Thin beds of dolomitic or siliceous, fine sand or coarse silt, often occurring in units of several beds separated by mudstone partings - giving rise to the so-called 'skerries'. Abundant laminations, with ripples and slumped laminae. Common throughout the Gunthorpe and Edwalton Formations. Definitely water deposited, probably by flash floods.
- Fine sandstone, in beds up to 400mm thick, well laminated, interbedded with mudstone of the first two types, containing common mudstone rip-up clasts. The Sneinton Formation, Cotgrave Sandstone Member and Hollygate Sandstone Member (= Dane Hills Sandstone) fall into this category. Definitely water deposited, probably on distal alluvial plains with periodic floods.
- Structureless mudstone. Most of the upper 40m of the Mercia Mudstone Group (Cropwell Bishop Formation, above the Hollygate Sandstone, below the Blue Anchor Formation) is of this lithofacies, the best examples being associated with the more gypsiferous levels mined at East Leake and Barrow on Soar. There is another 5m of this facies at the top of the Gunthorpe Formation. It occurs in thin beds elsewhere in the Mercia Mudstone Group, but is minor compared to the other types. This seems to be the strongest candidate for a parna-type deposit; if our concept is going to work, this appears to be the material to be compared to the parna.

The original Bosworth proposal still has merit; the only change required is to replace loess with parna - then the fit appears to be reasonable. We need to know more about the lithology of parna before more exact comparisons can be made; the Mercia Mudstone has been studied for generations but the parna is new on the scientific scene.

The most interesting aspect of the Mercian material could be its capacity for subsidence. This is one of the defining parameters for loess and loess-like materials, the one that gives them their major geotechnical interest, and in this sense parna and classic loess behave in similar fashion. Bosworth's rough calculation yields a 25% linear collapse; the usually cited figure for loess collapse is 15%. There is a critical value of clay mineral content that allows a loess to collapse efficiently, and it appears to be about 20%. This 'small clay' system (Rogers et al, 1994) allows deformation at the particle contacts when the system is loaded and wetted, with the initial requirement being an open, metastable structure for the structure-forming primary mineral units. More effective compaction might occur in the Mercia Mudstone due to higher loads over longer times. The observation of structure collapse and subsidence is the best evidence that Mercia Mudstone initially had an open metastable structure, and the parna seems to be a likely analogue.

Acknowledgements

We thank the organisers and leaders of the INQUA Loess Commission Western Pacific Working Group field trip to S.E.Australia for demonstrating the realities of the Australian Quaternary and the possibilities of the English Triassic. We thank in particular Prof Jim Bowler of the University of Melbourne, and Dr David Gillieson for providing photographs. We thank the BGS for bibliographical assistance, and particularly Dr Andy Howard for guidance on the lithologies of the Mercia Mudstone.

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I. F. Jefferson, M. R. Rosenbaum and I. J. Smalley
GeoHazards Group, School of Property and Construction,
Nottingham Trent University, Nottingham NG1 4BU

Dolomitization of the Carboniferous Limestone of the Peak District: a Review

Trevor D. Ford

Abstract. Large areas of the Carboniferous Limestone of the southern Peak District have been dolomitized, particularly the more coarse-grained calcarenitic facies. After a summary of the physical features of dolomitized limestone, its stratigraphic distribution and relationship to mineralization, the evidence points to a late Carboniferous date of dolomitization. Possible sources of the magnesium are from buried shales in adjacent basins, effectively as an early flush of hydrothermal fluids, from altered mafic minerals in volcanic rocks or both. It is proposed that a magnesium-rich fluid moved ahead of the hydrothermal mineral fluids and was exhausted before the mineral veins were infilled.

Some 50 km^2 of the Carboniferous Limestone outcrop in the southern half of the Peak District shows evidence of alteration of the original limestone to dolomite, locally known as dunstone from its dull brownish grey colour on weathered surfaces. The dolomitized area (Fig. 1) is less than a tenth of the total White Peak limestone outcrop, but the alteration has produced both distinctive rocks and landforms such as dolomite tors (Ford, 1963). Magnesium was introduced in mobile groundwaters long after sedimentation and resulted in the metasomatic growth of dolomite crystals within the limestone, so progressively obscuring the sedimentary fabric and fossils (Parsons, 1922).

While the character of the alteration and the distribution are well known, there has been little study of the cause of dolomitization or the processes that might have been involved. Furthermore, two schools of thought have emerged concerning the date of dolomitization, broadly late Permian or late Carboniferous: each would imply the operation of a different mechanism for dolomitization.

Dolomites also occur amongst the lowest beds seen in the Wye Valley and were penetrated in the few deep boreholes sunk towards the sub-Carboniferous basement (Cope, 1973; Dunham, 1973; Chisholm & Butcher, 1981; Chisholm et al. 1988). These dolomitic beds are associated with other evidence of sabkha-shoreline conditions to be expected at the start of an early Carboniferous marine transgression and are not regarded as part of the high-level dolomitization discussed here.

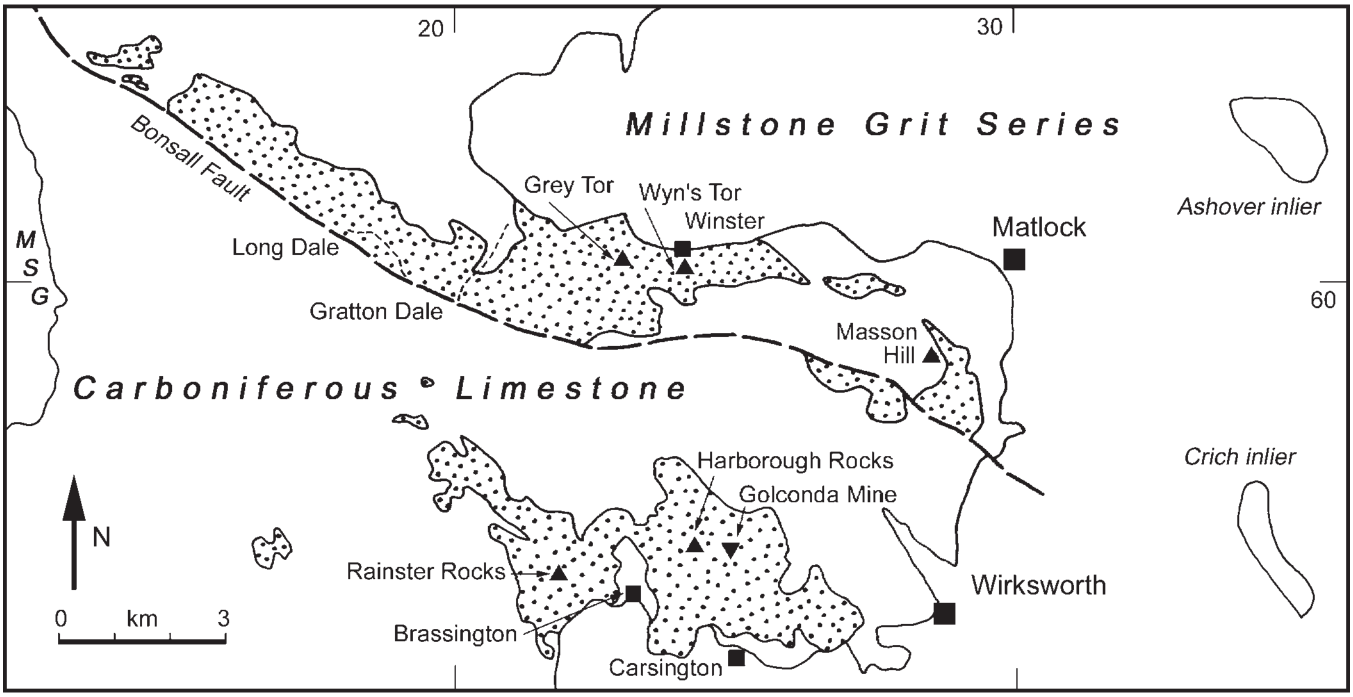


Figure 1. The southern White Peak showing the dolomitized limestone areas (stippled).

The Carboniferous Limestone inliers of Breedon on the Hill in Leicestershire have also been dolomitized (Parsons, 1918) but these are directly overlain by the unconformable Mercia Mudstone of late Triassic age. It seems that a different process has operated there: it is not considered further herein.

The aims of this communication are to review the constraints on the process of dolomitization in the Peak District and to discuss possible mechanisms.

Petrography

Dolomite is the double carbonate of calcium and magnesium, $CaMg(CO_3)_2$ (Deer, Howie and Zussman, 1992). It was named after the 18th century French geologist D. G. de Dolomieu (King, 1995). In the Peak District it has developed as euhedral to subhedral crystals within the coarser-grained limestones of the southern half of the White Peak (Parsons, 1922). The Limestone and Dolomite Resources Reports produced by the British Geological Survey in the 1980s gave many analyses and several photomicrographs (Bridge & Gozzard, 1981; Bridge & Kneebone, 1983; Cox & Bridge, 1977; Cox & Harrison, 1980; Harrison & Adlam, 1985) but most did not discuss the dolomitization process. Indeed, Cox & Bridge (1977) simply commented that the cause was unknown and that magnesian fluids could have moved downwards from the Permian or upwards from below.

Together these reports show that the dolomitized limestone is never pure dolomite (dolostone in American terminology) but that the degree of alteration is generally around 50-80% with the remainder of the rock as interstitial calcite. The content of MgO does not reach the theoretical maximum of 21%, and maxima are generally below 20% (Cox & Harrison, 1980). This degree of alteration, though incomplete, is enough to yield the textures and colour of dunstone. Surface weathering gives a very porous appearance but at depth interstitial calcite reduces the porosity. Boreholes reported in the BGS resources surveys have shown that the degree of dolomitization is highly variable both vertically and horizontally, and that the coarser calcarenites have usually been altered most.

Dolomitization has taken the form of the growth of euhedral to subhedral dolomite crystals in the body of the rock (Fig. 2). Their growth has resulted in partial or almost complete loss of original textures; fossils were destroyed or left as ghost outlines. Some beds contain silicified fossils and chert nodules and these are unaffected, being left surrounded by dolomitized limestone.

With the dolomite molecule being smaller than that of calcite, there is only a little loss of calcium, which has apparently been redeposited elsewhere, such as in mineral veins. The remaining calcite is usually recrystallized in the interstices. However, calcite is more soluble and weathering processes tend to remove it preferentially, eventually leaving a loose dolo-sand residue. Periglacial sludging takes the dolo-sand away leaving upstanding cores of still-solid rock known as dolomite tors: Grey Tor and Wyn's Tor near Winster provide good examples (Ford, 1963).

Distribution

As noted by Parsons (1922) and in the various Geological Survey Memoirs (Frost & Smart, 1979; Aitkenhead et al., 1985; Chisholm et al., 1988; Smith et al., 1967), dolomitized limestone is largely confined to two strips of country in the southern White Peak, one from Long Dale to Winster and the other around Brassington and Carsington on the south flank. Well-known occurrences in the former area are Wynn's Tor and Grey Tor above Winster, and in the latter area are Harborough and Rainster Rocks. Each of these areas totals around 20-25 km^2. A detached area of about 2 km^2 caps Masson Hill above Matlock, and there are a few scattered outliers.

A few old quarry faces and several lead mines show that the dolomitized limestone lies on top of unaltered limestone. The depth to the base of the dolomite is highly variable, but is usually not more than 40 m. The deepest dolomitization base recorded is in Golconda Mine (Ford & King, 1965) at about 120 m. Here it undulates along a NW-SE axis in flat-lying beds, and gives rise to a false concept of an anticlinal disposition of the mineral deposits that lie on the flanks of the "high" of unaltered limestone. In Masson Hill, Matlock, the base of dolomitization is generally along the line of the Masson, Rutland and Wapping Mines, but descends sharply almost to river level in Temple Mine (Ford, 2002).

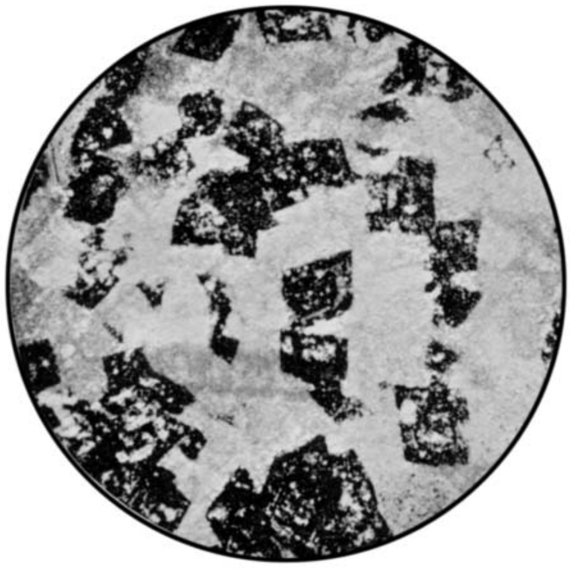


Figure 2. Photomicrograph of dolomitized limestone with dolomite rhombohedra, from Rainster Rocks (photo: G S Sweeting).

Dolomitization does not normally extend beneath the Namurian shale cover to the east, indeed the rather shaly facies of the highest limestone beds (the Eyam Limestones) are generally not altered. Only in the vicinity of Winster is dolomitized limestone known to extend beneath the shale cover for about 1.5 km (Aitkenhead et al., 1985). However, the stripping back of the shale cover to its present position around Winster and Brassington is a Pleistocene feature and the Millstone Grit cover with the thick Edale Shales at its base extended over the whole dolomite outcrop in pre-Pleistocene times.

The stratigraphic relationships of dolomitized limestones are shown in Table 1. In the Long Dale and Gratton Dale area, dolomitization has altered the Bee Low Limestones of Asbian age. Further east, around Winster, it is mainly the Monsal Dale Limestones of Brigantian age which are altered, but the alteration extends upwards into the Eyam Limestones where the more massive limestone beds of reef facies are present. Both Asbian and Brigantian beds have been dolomitized around Brassington. The presence or absence of lavas within the limestones sequence appears to have had some influence, as lavas are few and far between in the Long Dale and Brassington areas, where Asbian beds are affected. On Masson Hill, where there are two thick lavas and several clay wayboards in the Brigantian Monsal Dale Limestones, dolomitization rarely extends downwards into the underlying Bee Low Limestones. The distribution along the two flanks of the western extension of the Masson anticline raises the question as to whether the eroded upper limestones between the two areas might have formed a dolomitization cap to the upwarp but no clear evidence of this has been found.

On Masson Hill, dolomitization is largely confined to the more massive limestone beds between the two main lavas. These beds are about 40 m thick, with several clay wayboards. Dolomitization is confined to the beds above the “Little Toadstone” wayboard, some 6 m above the Matlock Lower Lava (Ixer, 1978). Both the limestones below the Little Toadstone and the dolomitized limestones immediately above have been mineralized with fluorspar replacements, pipe-vein cavities lined with minerals, and minor scrins (Ixer, 1974, 1978). An up-dip fault postulated by Ixer seems to have little effect on dolomitization, but the alteration dies out suddenly down-dip of the Masson Pipe mineral deposit (Ford, 2002).

The boundary of dolomite on limestone is usually sharp, with the transition taking place in a few millimetres. The boundary is often along clay wayboards, but Ixer (1978) noted that the ratio of MgO fell to a minimum immediately above and below wayboards in the Masson opencast, implying that the reduced permeability either side of the wayboards restricted fluid migration. Manystones Quarry, near Brassington (now partly back-filled with mineral processing waste), showed a dolomite/limestone contact undulating across the face with downward prolongations of dolomite on major joints (Fig. 3). Within a short distance to the east the base of dolomitization plunges more than 120 m to the main levels in the Golconda Mine. Together with the dolomitized Harborough Rocks, the total thickness of dolomitization there is around 150 m - rather less than the estimate of 200 m given by Harrison and Adlam (1985). A kilometre further east, an irregular dolomite/ limestone contact is visible outside the Gallows Knoll tunnel on the High Peak Trail. Elsewhere a few sections show a gradation from dolomite to limestone, apparently as grain-size decreases. Locally there is an alternation of dolomite and limestone along the contact, where only the coarse-grained limestones have been dolomitized. The fine-grained facies, with much less porosity, remains largely unaltered. Some contacts are nearly vertical and follow joints, demonstrating that the limestones were sufficiently lithified to have developed a joint system before dolomitization. Details of other contacts are to be found in Parsons (1922) and in the BGS resources reports.

stratigraphic unit	dolomitization
Brigantian	
Eyam Limestones	limited
Monsal Dale Limestones (Upper)	extensive
Matlock Upper Lava	
Monsal Dale Limestones (Lower)	extensive
Matlock Lower Lava	
Asbian	
Bee Low Limestones	patchy
Holkerian	
Woo Dale Limestones	contemporary

Table 1. Stratigraphy of the dolomitized limestones.

The strip of dolomitization from Long Dale to Winster is roughly parallel to but not always in contact with the Bonsall Fault. The latter cuts off the dolomitized limestone along part of its length, demonstrating that at least the later fault displacements were post-dolomitization. Neither the Brassington nor Masson Hill areas of dolomitization are juxtaposed to the Bonsall Fault.

The distribution of dolomitized limestone outcrops is similar to but not identical with that of the Neogene (Brassington Formation) silica-sand pocket deposits (Aitkenhead et al., 1985). As these two phenomena are separated by some 270 million years the process of dolomitization is not thought to be associated with the deposition of the Brassington Formation.

Relationship to mineralization

Previous researchers are agreed that dolomitization preceded mineralization. Large and small veins (rakes and scrins) pass from one host rock to the

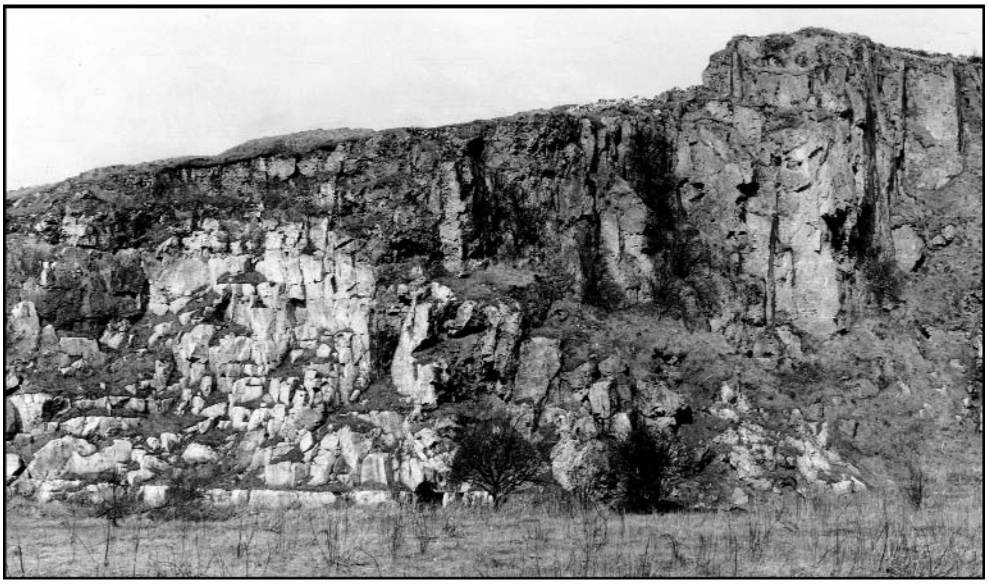


Figure 3. An old face in Manystones Quarry, near Brassington showing the irregular contact of darker dolomitized limestone above and paler unaltered limesone below. The lower part of this section is now buried by waste material.

other without any substantial change. Perhaps the most obvious example is the Great Rake on Masson Hill and High Tor, extending from limestone host rock in Riber Mine to dolomite above Masson Mines (Ford, 2002). Flat, pipe and replacement mineralization is common at or just below the contact of dolomitized and unaltered limestones, particularly along the Little Toadstone wayboard, as in parts of the Masson Mines (Dunham, 1952; Ixer, 1974, 1978; Ixer & Vaughan, 1993; Jones et al. 1994; Ford, 1999; 2002). In the Black Ox workings of the Masson Mines, thin layers of galena partially fill bedding planes and micro-joints in pre-existing dolomite. In the Golconda Mine, near Brassington, the base of dolomitization also follows a clay wayboard in places (Ford & King, 1965). It is notable that the mineral veins do not include dolomite as a primary mineral though it is occasionally present as adventitious lumps or dolo-sand derived from the walls. Dolo-sand in the centre of a baryte-lined vug in Golconda Mine post-dates galena-barytes mineralization (Ford & King, 1965).

Studies of successive generations of cementation of limestones by Hollis (1998) and Hollis & Walkden (1996) have shown that the calcite cement was deposited in four layers which they named Zones, each characterized by different trace element chemistry. Both magnesium and the elements of the ore minerals increase in late Zone 3 and in Zone 4 - which those authors regard as having been deposited during deep burial in late Carboniferous times, at much the same time as the main mineralization phase. While their studies hint at dolomitization being partly contemporary with mineralization, they did not discuss the relationship of their findings to the dolomitized limestones discussed herein.

An attempt to obtain magnesium metal from dolomite near Hopton in the 1960s proved uneconomic, as only about half the anticipated yield could be obtained. One of the factors is thought to have been the minor lead-zinc mineralization on the many joints interfering with the extraction process.

The date of dolomitization

As dolomitization preceded mineralization, the real question is - when did mineralization take place? Also, in turn, did mineralization precede or follow the folding of the Matlock anticline? Dunham (1952) argued, briefly, that dolomitization had occurred as a result of downward percolation of magnesian brines from a late Permian Zechstein marine transgression across the South Pennine region, and several authors have accepted this argument uncritically. However, among others, Frost & Smart (1979) and Cope et al. (1992) thought it unlikely that the Permian transgression had extended over the South Pennines. If dolomitization was late Permian, then the subsequent mineralization must have been very late Permian or Triassic in age. An alternative possibility that dolomitization might have been due to Triassic groundwaters (Aitkenhead et al., 1985) would necessitate mineralization having been post-Triassic, for which no evidence has been presented.

Dolomitization clearly followed lithification of the limestones sufficient for them to have a joint and fracture system. The distribution of dolomitization suggests that it was later than the folding of the Matlock anticline. The latter had been growing since Dinantian times as shown by facies changes in the Eyam Limestones and the thinning of the Edale Shales over the Matlock anticline (Smith et al., 1967; Ford, 2002). Upfolding culminated in the Westphalian, as part of the Variscan orogeny at the end of the Carboniferous, demonstrating a fairly rapid sequence of events at this time – folding and fracturing - dolomitization – renewed fracturing – vein formation. Without reliable means of dating these episodes, it is difficult to constrain the sequence in a definite chronological framework but a sequence of events in late Westphalian to Stephanian times, i.e. part of the Variscan orogeny, is logical.

Burial history curves presented by Hollis (1998) (after Colman et al, 1989) show that maximum depth of burial of the limestones at about 2500 m was reached in late Westphalian times and that mineralization reached a climax then. From Stephanian times (latest Carboniferous) onwards, there was a steady reduction in the cover with waning mineralization. Though Hollis did not discuss dolomitization, there is a clear implication that it preceded mineralization at some stage in the Westphalian.

Fluid inclusion temperatures generally ranging around 100-120°C have been obtained mainly from fluorite crystals in the veins (Atkinson et al., 1982; Colman et al., 1989). They indicate that there was a cover of around 2000 m of Upper Carboniferous strata on top of the limestone at the time of mineralization. Projection of the Permian base from the Mansfield area suggests that most of the Coal Measures and Millstone Grit had been eroded off the limestone by late Permian times, so the depth of burial necessary for the fluid inclusion temperatures was not available then. These stratigraphic arguments confirm the burial histories deduced from cementation generations by Hollis (1998) and Hollis & Walkden (1996). Furthermore Triassic rocks lie unconformably on the limestone around Ashbourne and Snelston, indicating complete removal of the cover over at least that small area. How much cover remained on the dolomitized areas in the late Permian and Triassic may be uncertain, but it is difficult to argue for enough to account for the depth of burial sufficient for the formation of the mineral veins.

An as-yet unsubstantiated report (Willies, pers. comm.) of pebbles of vein-stuff in the Sherwood Conglomerate of the Trent Valley region may indicate that vein minerals were available for erosion from an unknown mineral deposit in the southern Peak District by Triassic times, again indicating that much if not all of the Upper Carboniferous cover had then been eroded away. .

In addition, if there had been a thick cover of Coal Measures and Millstone Grit in late Permian times, their thick shales would have obstructed downward percolation of magnesian brines to the limestone. And why would such percolation have occurred in such limited areas?

On the basis of alteration of wayboard clays adjacent to mineral veins, Ineson & Mitchell (1972) applied the K-Ar isotope dating method and deduced that there had been episodic mineralization from mid-Carboniferous to Triassic, with a climax in the late Carboniferous. However, the dating method has its critics and perhaps not too much significance should depend on these results.

On structural grounds, it seems that mineralization was an episodic process culminating in mid to late Carboniferous times (Quirk, 1986, 1993). He argued that the changing directions of stress fields from late Dinantian to end Westphalian yielded fracture systems with varying orientations as a form of ground preparation. Mineral infill of the fractures could have been contemporaneous or later. Plant & Jones (1989) regarded the main episode of mineralization as being in a short period in the late Westphalian (upper Coal Measures). This is consistent with the timing of the "inversion" of the South Pennine sedimentary basin to an area of uplift as a result of the Variscan orogeny. The hydrothermal fluids responsible for both the dolomitization and the mineral vein infills would have been able to migrate from the basin into the growing upwarp before too much cover had been removed.

The argument that dolomitization was pre-Triassic because the fill of the silica-sand pockets was Triassic (Kent, 1957) has been negated by dating of the latter as Neogene.

Source of the magnesium

Discounting the Upper Permian Zechstein sea brines as a source of magnesium on chronological grounds, as discussed above, a possible source or sources must be sought elsewhere in the South Pennine region. There are several possibilities, all with problems arising.

As with hypotheses concerning the origin of the solutes in hydrothermal fluids resulting in mineralization, a potential source of magnesium

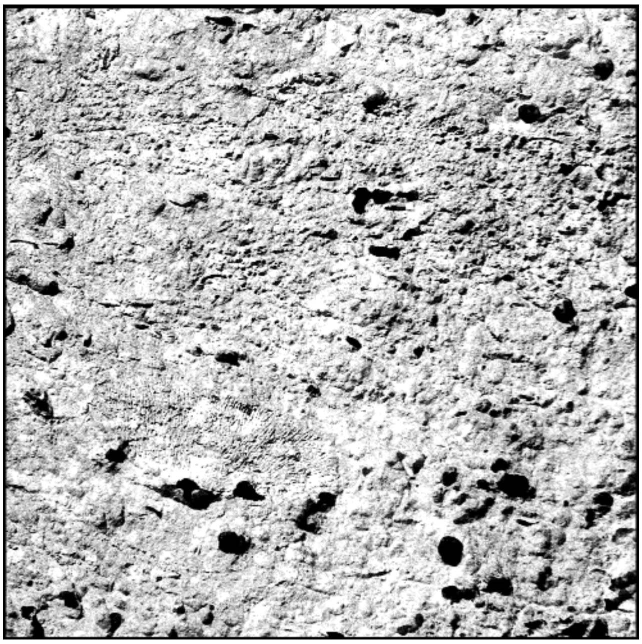


Figure 4. A dolomitized limestone surface on Rainster Rocks. The shadowed hollows are probably where calcite fossils were preferentially dissolved out, though a colonial coral survives in the lower left.

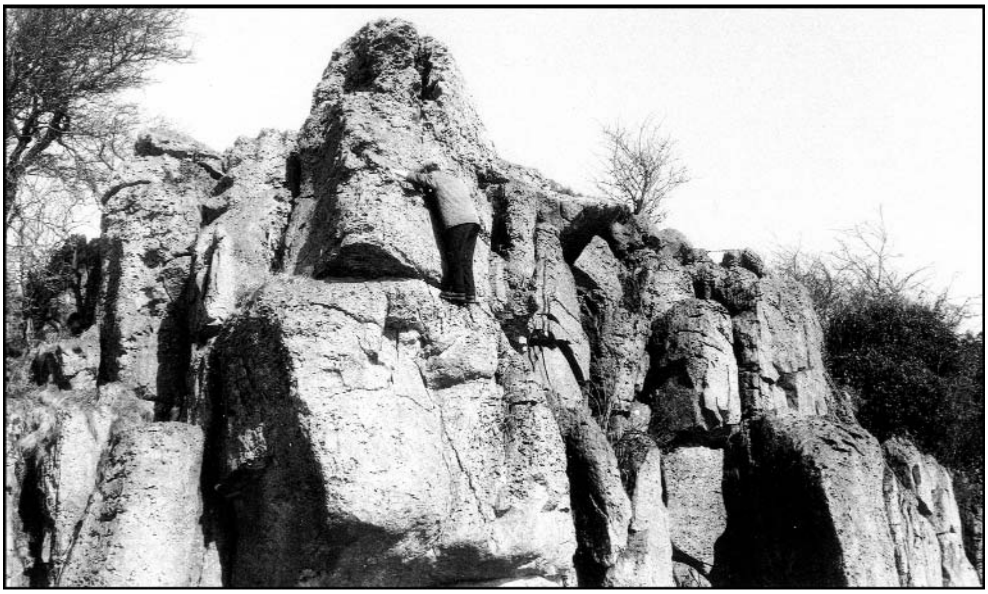
Figure 5. Wyn's Tor – a crag of dolomitized Brigantian limestone crag near Winster.

could be in the Dinantian/Namurian shales of adjacent basins. Few analyses of the clay minerals of the shaly basinal equivalent of the Dinantian limestones and the overlying shales of Namurian age anywhere in the Pennines have been published (Plant & Jones, 1989), and no significant figures for magnesium have been traced for shales in the South Pennine basins. As with the deltaic sandstones of the Millstone Grit, the clay minerals there have been derived from parent rocks in the Caledonian mountain belt containing some mafic minerals, so a small proportion of magnesium could be expected. If this was expelled as an early fluid pulse during burial diagenesis, a magnesium-rich fluid could have migrated into the Peak District limestones ahead of the main hydrothermal fluid. Such a flush of magnesium-rich fluid could have penetrated the coarser-grained limestones and given rise to dolomitization before being exhausted; later pulses of hydrothermal fluid then yielded the vein minerals that filled the fracture systems. It is thus possible to visualize a magnesium-rich front travelling through the limestones and causing dolomitization. Once the magnesium source was exhausted, dolomite was not available to fill fractures and so does not occur in the vein mineral assemblages.

A second possible source of magnesium could be the dolomites of the Woo Dale Limestones (the lowest exposed beds in the Wye Valley) (Aitkenhead et al., 1985) or the deeply buried dolomites found in the few boreholes to the base of the Carboniferous Limestone at Woo Dale (Cope, 1973), Eyam (Dunham, 1973), Via Gellia (Chisholm & Butcher, 1981) and Cauldon Low (Chisholm et al., 1988). The first two boreholes encountered some 50-100 m of dolomites at the base of the Carboniferous sequence resting on a basement of Precambrian or Lower Palaeozoic rocks, and the others were thought to be close to basement before being terminated. However, as these concealed beds near the base of the limestone sequence are still dolomites, it is difficult to see how they could have provided sufficient magnesian fluids while still remaining dolomite. It is probable that the early Carboniferous marine transgression started with a sabkha shore-line phase on the South Pennine block, so any adjacent basins could have had a thicker sequence of dolomites, but these have yet to be proved by deep boreholes.

The third possible source of magnesium is from altered volcanic rocks. The exposed lavas are basaltic, containing a large proportion of mafic minerals, principally augite with subsidiary olivine. Alteration by hydrothermal fluids and by weathering converts these to clay minerals, mainly chlorites, releasing magnesium. But was there enough magnesium released to account for all the dolomitization? From the visible altered portions of the lavas probably not, but there is evidence of considerable amounts of concealed basaltic volcanics further east. At Ashover, some 200 m of basalts and basaltic breccias were found in boreholes without reaching their base (Ramsbottom et al., 1962). There was much alteration in what was thought to be a vent beneath the Ashover anticline, and magnesium could have been released from mafic minerals therein. Much further east, a substantial volume of concealed volcanics was found in the Coal Measures of the N. E. Leicestershire coalfield, but having these as a source would require a mechanism to transfer the magnesian brines, both down to the limestone through the Coal Measures and Millstone Grit with their thick shales, and for a considerable distance to the Peak District. Taken together with other as yet unknown concealed basalts, the volcanics could have been a source of magnesium distinct from the usual hydrothermal mineral source in shales, but no mechanism for transfer of magnesian fluids from the basalts to the limestones has yet been proposed.

Figure 6. Rainster Rocks – dolomitized limestones of Asbian age.



Quantification of how much magnesium could be obtained from these sources and how much has been deposited in the partially dolomitized limestones is impossible owing to lack of knowledge of the efficiency of extraction and migration and the quantities of the potential source rocks. On balance it seems that the shales must be the preferred source, with a possible contribution from altered volcanics.

The apparent restriction of dolomitization to the present limited areas of outcrop may be misleading, as a dolomitized limestone crest to parts of the Matlock anticline and its western extensions has been eroded away.

Dolomitization in other areas

No comparable large-scale post-depositional dolomitization of the Carboniferous Limestone has been found in other British orefields (Ixer & Vaughan, 1993). Limited areas of contemporary fine-grained dolomite are present in the North Wales and Mendip successions of the Carboniferous Limestone, but no such dolomite has been recorded in the North Pennines. Dolomite is present as a vein mineral in the latter though it is not known as a vein mineral in the South Pennine orefield. Widespread dolomitization of the Waulsortian mud-mound facies of the Carboniferous Limestone in southeast Ireland has been taken to indicate a magnesium-rich fluid front moving upwards from the adjacent Munster Basin (Hitzman et al., 1998). The fine-grained character of the limestone apparently formed no obstacle, as the mud-mounds have abundant stromatactis cavities providing permeability. While the general setting is comparable to the Peak District, the limestone facies and tectonic setting in Ireland are different. A broadly comparable situation to that in Ireland has been described in Cambrian rocks in Missouri (Gregg & Shelton, 1989).

That there is no comparable dolomitization in other British orefields suggests a distinctive source or mechanism in the Peak District, but none has been determined. However, it should be noted that none of the other orefields has lavas interbedded with the limestones. While these may not have been the main source of magnesium they certainly were guiding horizons with limited permeability which could have concentrated magnesian brines at certain limestone horizons, as they did the mineralizing fluids later.

Conclusions

Dolomitization affected some 50 km2 of the Carboniferous Limestone in the southern Peak District. The coarse-grained calcarenite facies seem to have been most altered with generally sharp but transgressive boundaries, often guided by joints. Dolomitization penetrated to depths averaging around 40 m with a maximum of around 150 m, with unaltered limestone below. Dolomitization is rarely complete but has resulted in the distinctive brownish dunstone. Both Asbian and Brigantian beds are affected, with the distribution guided to some extent by lavas and clay wayboards. Dolomitization was post-folding but pre-mineralization and, as the latter is now generally regarded as late Carboniferous, so dolomitization must also have been late Carboniferous in date. Sources of magnesium are likely to have been the Dinantian and Namurian shales of adjacent sedimentary basins, effectively providing an early flush of magnesium-rich hydrothermal fluids, but a contribution from altered basaltic volcanics is possible.

Acknowledgments

Thanks to Bob King, Lynn Willies, Nick Butcher, Noel Worley, Kip Jeffrey and others for useful discussions over the years and to Tim Colman for his helpful reviewer's comments.

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Trevor D. Ford, Honorary Research Fellow,
Geology Department, University of Leicester, LE1 7RH

The late Triassic and early Jurassic succession at Southam Cement Works, Warwickshire

Jonathan D. Radley

Abstract. Southam Cement Works Quarry, Long Itchington, exposes beds ranging from the Cotham Member of the late Triassic Lilstock Formation up into the Rugby Limestone Member of the early Jurassic Blue Lias Formation. The lithologies and fauna are described and interpreted in the context of Triassic and Jurassic palaeoenvironmental change.

Warwickshire's Jurassic outcrop is dominated by a broad low-lying terrain formed by argillaceous rocks of the early Jurassic (Hettangian up to Pliensbachian) Blue Lias and Charmouth Mudstone formations. The Charmouth Mudstone Formation is poorly exposed, however the upper part of the Blue Lias Formation (Rugby Limestone Member; Ambrose, 2001) has been extensively quarried for the cement industry. Largely inaccessible sections occur in several disused pits, as at Rugby and near Harbury.

Currently (2002) the only working quarry is at Long Itchington, [NGR SP420630] 10 km E.S.E. of Leamington Spa (Fig. 1). Here, the deep, extensive excavation at Southam Cement Works exposes early Jurassic mudstones and limestones of the Blue Lias Formation (Saltford Shale and Rugby Limestone members; Hettangian up to Sinemurian; *liasicus* up to *bucklandi* Zone). Limestones of the underlying latest Triassic (Rhaetian) Langport Member of the upper Lilstock Formation ('White Lias') are also exploited and are crushed for roadstone. The quarry originated in the latter part of the nineteenth century (Woodward, 1893) and has been identified as a RIGS (Regionally Important Geological Site) by the Warwickshire Geological Conservation Group. Access is restricted since the closure of Rugby Cement's adjacent factory.

Partial descriptions of the succession have been given by Clements (1975), Old *et al* (1987), Swift (1995) and Ambrose (2001). Swift (1999) provided photographs of the Langport Member succession in the quarry. The sedimentology of the Blue Lias was investigated by Weedon (1986) and Wignall and Hallam (1991). Aspects of the palaeontology and ichnology have been documented by Clements (1975), Gilliland (1992) and Swift and Martill (1999). Jones and Gould (1999) featured Long Itchington material in their important study of oyster (*Gryphaea*) growth and evolution. Additionally, the site has been mentioned by several other workers including Nuttall (1916), Arkell (1947) and Hallam (1968). Rocks and fossils from the site are held in the collections of Warwickshire Museum.

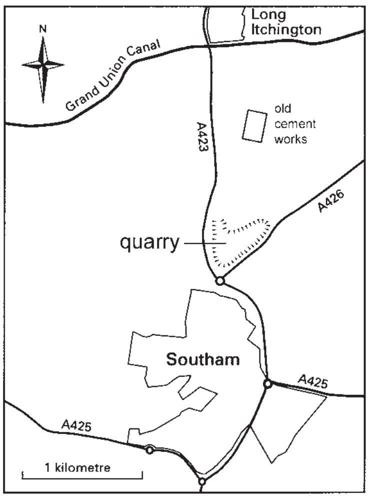

Figure 1. Location of Southam Cement Works Quarry

Lilstock Formation (Langport Member)

The main quarry floor is a broadly planar (but in places hummocky) iron-stained surface, marking the eroded top of the Langport Member. Various pits and trench sections within the quarry floor expose the full thickness (about 2.5 m) of the Langport Member, below which lies an unknown thickness of grey-green mudstones of the Cotham Member (lower Lilstock Formation). Only the topmost 0.5 m or so of this latter member is exposed at present but a sump opened in the base of the quarry some years ago showed at least 7 m of the Cotham Member (A. Swift, *pers comm*).

The base of the Langport Member is marked by a seam of the oyster-like bivalve *Atreta intusstriata* (Emmrich). This shell bed encloses bored and *Atreta*-encrusted limestone pebbles; some of cryptalgal appearance and resembling the stromatolitic 'landscape marble' of the Bristol area. Grazing traces attributable to regular echinoids (*Gnathichnus pentax* Bromley) have been identified on several pebbles. Above the *Atreta* shell layer, the lower half of the member is dominated by pale-grey to cream coloured, irregularly bedded, stylolitic, fine-grained limestones (micrites) with a few thin shale seams. Many of the beds are burrowed, and recognisable trace fossils include small U-burrows (*Arenicolites*). Some units are quite fossiliferous, yielding small bivalves (including *Gervillella* sp., *Plagiostoma* sp. and *Plicatula* cf. *hettangiensis* Terquem), gastropods, echinoid spines and occasional solitary corals (*Montlivaltia rhaetica* Tomes). The top metre of the member is largely a poorly sorted breccio-conglomerate of micrite/bioclastic limestone blocks in a cemented micritic matrix (Fig. 2). Shallow, channel-like structures occur in this upper division.

Blue Lias Formation

The benches and walls of the main quarry expose the Saltford Shale Member (c. 15 m), overlain by the lower part of the Rugby Limestone Member (*c*. 25 m) (Fig. 3). The basal Hettangian *planorbis* ammonite zone is unproven (Old *et al.*, 1987) and the Saltford Shale Member (*liasicus* up to *angulata* Zone) rests sharply on the eroded surface of the Langport Member. Runnel-like depressions on this surface preserve a veneer of black mudstone containing oysters, echinoid spines and bored limestone pebbles. Above, the Saltford Shale is dominated by dark grey laminated mudstone with a few beds, lenses and nodules of fine-grained limestone. Sharp-based siltstone lenticles about 7.5 m above the base of the shale preserve arthropod 'resting' and burrow traces (*Isopodichnus*). A layer of small oyster and serpulid-encrusted limestone nodules occurs about 2.5 m higher. Nodules and lenticles of laminated silty limestone towards the top of the member occasionally preserve concentrations of spar/sediment-filled schlotheimiid ammonites (including the zonal species *Schlotheimia angulata* (Schlotheim)), together with small bivalves (?nuculids), fish scales and other fine-grained skeletal debris. The ammonites are commonly imbricated (Fig. 4). Some are encrusted with oysters that display xenomorphic sculpture. Warwickshire Museum's holdings of Saltford Shale material from this site also include nautiloids and partly articulated ichthyosaur, plesiosaur and fish remains. Wignall and Hallam (1991) recorded minute high-spired gastropods.

The overlying Rugby Limestone Member marks the development of typical 'Blue Lias' facies - regularly alternating limestone, marl and shaly mudstone beds (Fig. 3). The limestones are mostly pale grey in colour, laterally persistent and seldom more than 0.25 m thick. They are fine-grained, commonly sharp-based, bioturbated, and often highly fossiliferous. Enclosed fossils are largely uncrushed. Among the ammonites, schlotheimiids dominate the lower beds (*angulata* Zone) and are replaced upwards by species of *Vermiceras* and *Coroniceras* (*bucklandi* Zone; Clements, 1975). Nautiloids (*Cenoceras* sp.; commonly oyster encrusted) are common. The bivalve fauna is dominated by *Plagiostoma giganteum* J. Sowerby and *Antiquilima succincta* (Schlotheim) (sometimes disarticulated and oyster-encrusted), together with small *Gryphaea arcuata* Lamarck and *Liostrea* sp.. Pleurotomariid gastropods are recorded. Rhynchonellid brachiopods (*Calcirhynchia calcaria* S.S. Buckman) are abundant in the so-called Rhynchonella Bed, approximately 8 m above the base of the member. Crinoid debris and fossil wood occur in some beds. Clements (1975) provided additional details of fossils. Trace fossils in the limestones include *Chondrites*, *Thalassinoides*, *Kulindrichnus* and *Diplocraterion*. The latter are very common at several levels, notably within the Worm Bed (Clements, 1975) some 10 m above the base of the member. The dark grey marls and mudstones yield rich microfaunas dominated by ostracods, foraminifera, echinoid debris and holothurian sclerites (Clements, 1975). The true shales tend to be poorly fossiliferous.

Figure 3. Southern end of Southam Cement Works Quarry. Sections in the foreground are about 2.5 m high and expose pale limestones of the Langport Member. The main cliff exposes alternating pale limestones and darker mudstones of the Rugby Limestone Member, above dark mudstones of the Saltford Shale Member. This is nearly 40 m high.

Figure 2. Loose block of conglomeratic Langport Member limestone. Ruler is 15 cm long.

Interpretation of environments

The succession was deposited near the south-western end of the East Midlands Shelf, north west of the partly emergent London Platform. The Vale of Moreton Axis lay a few tens of kilometres to the southwest of Long Itchington (Ambrose, 2001), marking the eastern margin of the Severn Basin. The Langport Member is largely absent in the Severn depocentre, suggesting emergence in latest Triassic times (Swift, 1995). Thus, the Warwickshire outcrop may equate to part of a central English embayment. The basal *Atreta* bed marks the establishment of a mollusc-dominated fauna during the initial stages of the transgression recorded by the Langport Member. Above, the *Arenicolites*-burrowed surfaces and corals indicate shallow-water conditions. While of marine aspect, the low faunal diversity may suggest slightly abnormal salinities. The micrites may signify that warm, calcium carbonate-rich, predominantly low-energy Bahamian-type environments prevailed during deposition of the Langport Member (Hallam, 1960).

The matrix-supported conglomeratic limestones within the higher part of the Langport Member succession resemble muddy debris flows. Similar beds in the Langport Member of S W England signify reworking of partly lithified rock in a shallow marine or emergent setting, attesting to late Rhaetian eustatic sea-level fall (Wignall, 2001). Long Itchington material may have a similar origin, but requires further investigation.

Deposition of the Blue Lias Formation was initiated during a phase of eustatic sea-level rise (Hallam, 2001), marking establishment of the shallow, epicontinental Jurassic sea over extensive areas of southern Britain. Following localised sediment starvation (*planorbis* Zone) and generation of a basal shell/pebble bed, the Saltford Shale Member of eastern Warwickshire marks a mid-Hettangian transgressive pulse onto the London Platform (Donovan, Horton and Ivimey-Cook, 1979). Its dark, laminated and poorly fossiliferous character indicates deposition in generally anoxic environments, punctuated by brief oxygenation events. Wignall and Hallam (1991) attributed the anoxia to rapid deepening, resulting in poor circulation beneath a stratified water column. Siltstone lenticles, reworked limestone nodules and imbricated ammonite concentrations (Fig. 4) demonstrate weak current influence and a possible mechanism for periodic oxygenation. Storm generation is supported by the abundance of comparable storm beds ('tempestites') in shallow water facies of the British Lower Jurassic (Hallam, 1997).

Sedimentary environments of the present day German Bight (North Sea) were taken as a reasonable analogue for those of the British early Jurassic by Elliott (1997) and Hallam (1997). In the German Bight, thin, silty, storm-flow deposits are well developed within mud facies slightly below maximum storm wave base, at depths of around 20-30 m (Aigner, 1985). A comparable bathymetry seems plausible for the deposition of the Saltford Shale at Long Itchington.

The rapid transition to the relatively fossiliferous and calcareous beds of the Rugby Limestone Member marks overall increased benthic oxygenation. Relative shallowing is supported by the cessation of sediment onlap onto the London Platform at this time (Donovan *et al.*, 1979). The cyclic alternations of limestone, marl and shale constitute the well-known 'Blue Lias' facies of the British early Jurassic. Weedon (1986) studied the petrology of these beds at several sites including Long Itchington. He concluded that the limestones are diagenetically 'overprinted' calcareous, marly sediments (also see Hallam, 1964). Darker marls and shales were taken to signify periodically increased terrigenous mud influx, that drowned carbonate production and resulted in poorer oxygenation at the sea floor.

Weedon (1986) presented evidence to suggest that the rhythms resulted from changes in orbital precession and obliquity, affecting climate (Milankovitch cyclicity). He took the shaly intervals to signify wetter phases and increased runoff.

Figure 4. Fragmented limestone nodule from the Saltford Shale Member enclosing imbricated schlotheimiid ammonites (Warwickshire Museum Collection). The pencil provides scale.

However, Hallam (1986) drew attention to the wholly diagenetic origin of at least some Blue Lias limestones, potentially weakening the case for Milankovitch cyclicity. Interestingly, Elliott (1997) established the presence of taphonomic and palaeoecological rhythms in the Blue Lias, which are out of phase with the lithological cyclicity. He also documented several previously undetected sedimentary hiatuses, further weakening the Milankovitch model. Elliott's work did not extend to Long Itchington, where there is scope for further investigation along these lines.

The rich ichnofauna and macrofauna of the Rugby Member limestones at Long Itchington indicate greater benthic oxygenation. The dominant epifauna suggests that the calcareous substrates were firm and cohesive. The abundance of bivalves is consistent with a generally shallow marine environment (Hallam, 1997), although common ammonites and absence of micritisation suggest an offshore, possibly subphotic setting. Oxygen isotope profiles obtained from growth increments on *Gryphaea* shells indicate an annual temperature cycle of warmer and cooler conditions (Jones and Gould, 1999).

Acknowledgments

The staff of Rugby Cement (Southam Works) are thanked for access to the Long Itchington Quarry. Andrew Swift (Leicester University) and an anonymous referee kindly provided comments on the manuscript.

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Jonathan D. Radley
Warwickshire Museum, Warwick CV34 4SA
and School of Earth and Environmental Sciences,
University of Portsmouth, PO1 3QL

REPORT

Edgehill Quarry, Warwickshire

The Lower Jurassic escarpment of Edge Hill, in southeastern Warwickshire is capped by the Marlstone Rock Formation. Here, this unit consists of about 8 m of unusually pure calcitic chamositic ironstone, weathering to limonite (Whitehead *et al*, 1952). It thins to the northeast and southwest, accompanied by increasing sand content. Rare ammonites collected from the Marlstone prove a late Pliensbachian to early Toarcian (*spinatum* up to *tenuicostatum* Zone) age (Howarth, 1980). It has been quarried around the scarp-top settlement of Edgehill since mediaeval times for building stone, ornamental stone and aggregate (Edmonds *et al*, 1965).

Hornton stone is now quarried at just one site, on the crest of Edgehill about 700 m north of the A422 road, at SP372468. This site has recently been deepened, and has an active face over 100 m long. Old quarries northwards along the escarpment are now backfilled, but other exposures survive nearby, notably within the former Banbury Ironstone Field to the southeast, and on the Burton Dassett ridge to the northeast. The active Edgehill quarry section has been selected as a RIGS (Regionally Important Geological Site) by the Warwickshire Geological Conservation Group. Permission to visit the site should be sought from Hornton Quarries Limited at their Edgehill works.

Lithologies and palaeontology

Excavations within the quarry floor have recently provided sections down to the uppermost part of the underlying Dyrham Formation (formerly Middle Lias Silts and Clays; Cox *et al*, 1999), seen to a thickness of approximately 0.5 m. Iron-stained clays were exposed, grading up into marl and richly fossiliferous bioclastic and oolitic ferruginous limestone. These beds are rich in pectinid bivalves and worn belemnite rostra. One particular clay-limestone interface preserves a ‘belemnite battlefield’ (Doyle & Macdonald, 1993). This comprises a dense accumulation of variably worn belemnite rostra interspersed with crushed bivalves (Fig. 1).

Overlying these beds, the widely distributed pebble bed at the base of the Marlstone Rock Formation (Edmonds *et al.*, 1965) is developed as a 10-15 cm hard shelly pebbly ironstone bed, containing numerous pebbles and flattened cobbles of claystone, siltstone and shelly ironstone, up to 20 cm in length. The pebble bed matrix yields a well preserved fauna of disarticulated pectinid bivalve shells (including large *Pseudopecten equivalvis*), oysters (including bilobate *Gryphaea sportella*), fully articulated deep-burrowing bivalves in life position (*Pholadomya ambigua*), abundant belemnite rostra (*Passaloteuthis* and *Parapassaloteuthis*) and ‘nests’ of fully articulated rhynchonellid and terebratulid brachiopods (*Tetrarhynchia tetrahedra* and *Lobothyris punctata*). Many oysters and belemnite rostra are serpulid-encrusted and extensively bored. Some bear grazing traces attributable to regular echinoids and gastropods (ichnofossils *Gnathichnus pentax* and *Radulichnus*).

Above the quarry floor, the Marlstone Rock Formation is seen in low faces up to 5 m in height, grading up into stony subsoil (Fig. 2). The lower part of the ironstone is intensely weathered and argillaceous, yielding scattered disarticulated bivalves and further accumulations of fully articulated, well preserved *Lobothyris punctata*. The main mass consists of the typical finely bioclastic, jointed, locally cross bedded oolitic ironstone, containing scattered wood fragments and a few other fossils including the body chambers of large nautiloids. Much of the rock is rusty and limonitic, with sporadically distributed blue-green, chamositic ‘cores’. Cross sections through bundled, tube-like burrows are seen on loose blocks. The quarry workshops provide an opportunity to inspect sawn slabs of the ironstone from several sites in the Edgehill-Hornton area. These show that the rock is extensively bioturbated. Recognisable trace fossils including dumb-bell shaped cross sections through *Diplocraterion* and/or *Rhizocorallium*.

Figure 1. A belemnite rostral accumulation (known as a ‘belemnite battlefield’) at the top of the Middle Lias Dyrham Formation.

Palaeo-environments

The onshore, British, mid to late Pliensbachian is represented by a shallowing-upward marine succession in both basin and shelf settings (Sellwood & Jenkyns, 1975; Hesselbo & Jenkyns, 1998). Situated at the south-western end of the East Midlands Shelf (Cox *et al.*, 1999), southern Warwickshire clearly demonstrates this regional pattern. The higher slopes of the Edge Hill escarpment are formed by the silty clays, silts, sands, and impure limestones of the Dyrham Formation, 'coarsening up' from the Lower Lias clay lowlands of the Warwickshire Feldon. This episode of shallowing has been attributed to regional hinterland and/or sea-bed uplift (Hallam & Sellwood, 1976; Hallam, 1988). The fauna of the uppermost Dyrham Formation at this site points to a well oxygenated marine environment. The worn belemnite rostra (Fig. 1) accumulated during a phase of low sedimentation.

Capping the Dyrham Formation, the pebble bed at the base of the Marlstone is taken to represent the culmination of the shallowing episode. Its generation appears to have involved wave and/or current erosion of bedrock, followed by and perhaps concurrent with, concentration of worn lithoclasts, shells and belemnite rostra in an intermittently high-energy environment. The hard substrate grazing traces are significant in this respect, suggesting widespread growth of algae and cyanobacteria in a shallow-water, photic setting (Bromley, 1994).

Thereafter, the Marlstone apparently signifies slight deepening, allowing net accumulation of bioturbated chamositic oolitic sediment. Localised cross-bedding indicates wave and/or current activity above storm wave base. The brachiopod accumulations are comparable to the life assemblages documented from the Marlstone of Leicestershire by Hallam (1961). These may have been preserved by rapid burial beneath ooid bedforms. Historically, the Marlstone has been central to a debate concerning the origin of oolitic ironstones. It is now generally thought that the abundant iron was derived from terrestrial laterite soils, indicating a warm, humid Pliensbachian climate (Hallam & Bradshaw, 1979). The fossil driftwood confirms the influence of nearby land, probably the western margin of the London Platform (Cox *et al.*, 1999). The unusually pure, relatively thick ironstone development at Edgehill suggests deposition in a semi-isolated basin, broadly coincident with A.H. Cox and Trueman's (1920) Edgehill syncline.

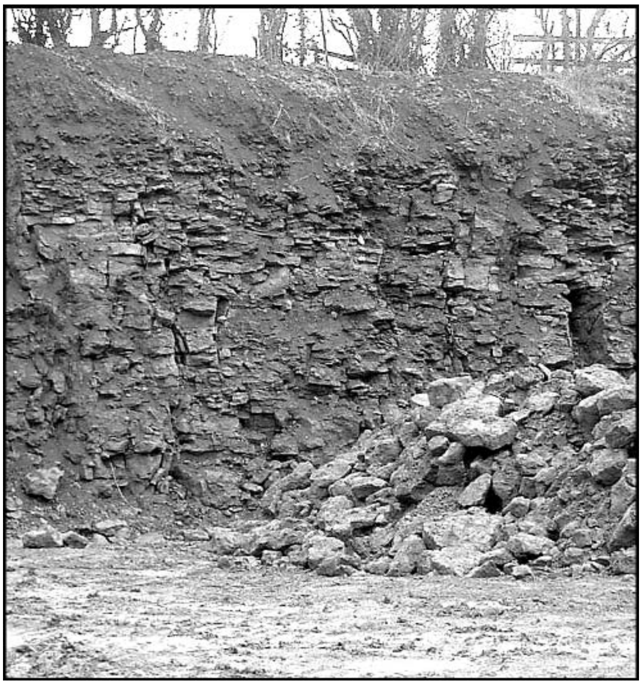

Figure 2. Exposure of the Marlstone Rock Formation in the Edgehill quarry.

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Jonathan Radley
Warwickshire Museum and Portsmouth University

HOLIDAY GEOLOGY

Réserve Géologique de Haute Provence

The Provence region of southeast France receives many British visitors who enjoy the weather, the perched villages, the lavender fields and the delightful ambience. Haute Provence is less visited and lies northeast of Provence, bounded to the north by the Dauphine Alps. It is an area of rugged high country dissected by many gorges.

The Réserve Géologique de Haute Provence occupies 190 000 ha. Its aims are to conserve the geological assets of the area while making a selection of them available to visitors. Entry points are marked by large coloured road-side signs that show an ammonite. The two main towns of the reserve are Digne les Bains and Castellane, each of which has a large geological museum devoted to different aspects of the reserve. There is also a more modest museum in the small town of Barrême (of the Lower Cretaceous Barrêmium).

The rocks of the reserve are mainly limestones and shales from the Upper Jurassic, Cretaceous and Tertiary. All have been folded on a grand scale by the Alpine orogeny.

The museum at Digne les Bains is built on a cliff faced with tufa, above the river just to the north of the town. From the car park, three trails lead up through woodland to the museum, and these pass by sculptures on the theme of rocks and water by past artists in residence. At the museum, the stream that pours down the hillside is actively depositing tufa, and also provides the water element in the theme of the reserve. Each gallery in the museum attempts to relate modern living plants and creatures with those in the fossil record. There is a room with walk-through aquaria and fossil fish displays, and another for plants old and new. The gallery devoted to ammonites themes on modern paintings that are inspired by the fossils on display.

The minor road heading due north out of Digne, close to the museum, reaches 23 km to the village of Barles. It passes several geological localities, each a few kilometres apart, and each with the familiar ammonite sign, a small car park and interpretative notices (that are mostly bi-lingual).

The first geology-stop, maybe 5 km out of Digne, is a spectacular roadside exposure of a large bedding plane, dipping at about 40°, that contains countless large ammonites.

The next signed stop, a few km further on, has a trail 2 km long through an attractive gorge and up a hillside to an in situ fossil ichthyosaur exposed on a bedding plane. The fossil is protected by a glass box, and has a diorama worthy of Alan Dawn behind it.

The third site is at the roadside and has bird footprints in Tertiary sediments (though close inspection reveals that this is a glass-reinforced plastic replica of the real material that is now safely in a museum). The road lies in the Clues de Barles gorge, which cuts through vertical beds so that tops and bottoms are exposed for inspection.

The next locality offers a short walk on the dry bed of the Bes River, to reach some infilled paleo-channels that are now tilted to the vertical; the site reveals small-scale depositional features.

Overall and close-up views of the roadside ammonite-rich bedding plane north of Digne les Bains.

The last site on the road to Barles has a short circular path through woodland, where a number of replica plant fossils have been mounted adjacent to living trees that are considered to have some connection.

The road south from Digne les Bains is the N85 to Castellane, 54 km away. It passes through the village of Barrême, where signs point to the geological museum, housed in the waiting room of the station on the narrow gauge line from Digne to Nice. There are various interpretative boards and lots of fossils (mainly ammonites, needless to say). So abundant are large specimens of the partly uncoiled type that some villages along the route have mounted them on plinths on road roundabouts.

At the Col de Leques, 10 km short of Castellane, there is a sign to the Sirènes. A walk of 2 km leads to a valley where the fossilised remains of numerous ancestral manatees (sirènes in French) have been found. These animals, which today are best known in Florida, probably gave rise to the mermaid legend that has its counterparts in many other cultures. About 40 million years ago, a large number of manatees died and sank to the sea bed - which was a surface of Jurassic rocks. The bodies were buried in mid-Eocene sediments, which therefore lie unconformably on the Jurassic rocks, and the whole sequence was uplifted and tilted to about 40° during the Alpine orogeny. After the last ice age a small stream has cut a valley by exploiting this unconformity, and has gradually removed a section of the Tertiary sediments - to leave the fossil manatees lying on the old Jurassic sea bed just a few metres up the valley side. An elevated boardwalk gives access to the exposure, and the fossils are protected behind glass screens. Two notice boards describe the life and death of the sirènes, and also the legends around them and the wider geological framework.

The road from the col continues south to Castellane, where the museum (which we did not visit) concentrates on the manatee fossils, with reconstructions of the creatures, and a feature on their associated legends.

Alan Filmer

HOLIDAY GEOLOGY

Wieliczka Salt Mine, Krakow

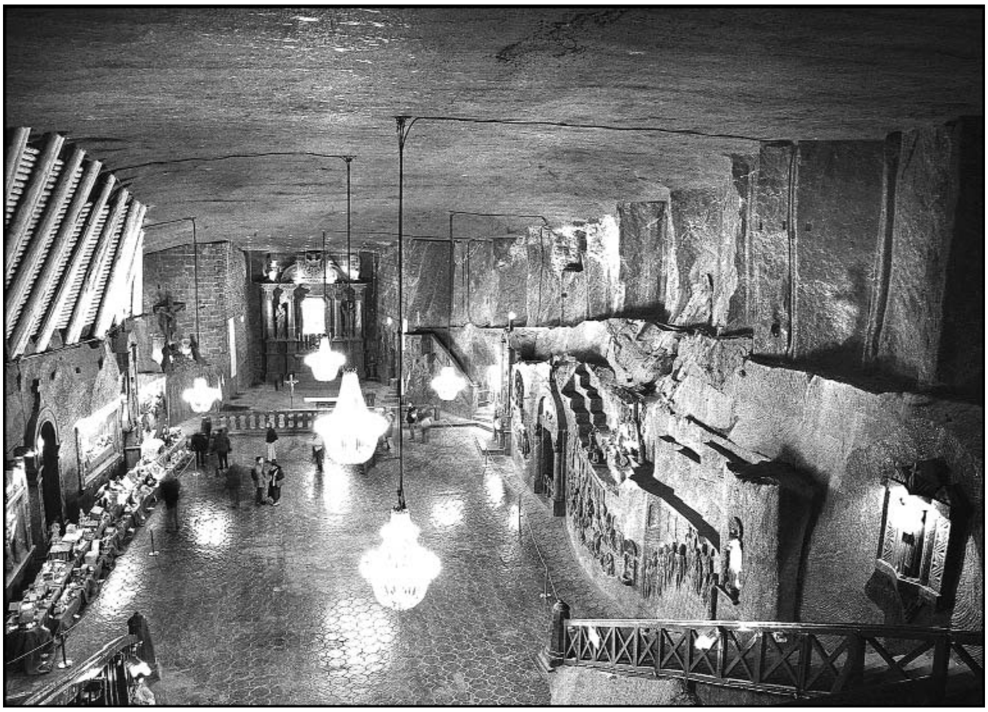
Krakow draws the lion's share of visitors to Poland, and justifiably so. The old city has a splendid collection of fine buildings that suffered very little damage during the wars of the last century. It is a lovely place to visit, and also has the perfect escape from the urban world in the Tatras Mountains just to the south. The geologically minded visitor has an added attraction in the Wieliczka salt mine, tucked away in the suburb of the same name on the southeast side of the city. This has been developed for tourist access on a grand scale, and it offers a spectacular and fascinating underground tour.

Miocene salt stretches for about 10 km beneath Wieliczka, roughly east-west in a nappe structure parallel to the Carpathian front (just to the south). Within this length, the salt is 500-1500 metres thick. Any traces of an early classic diapiric salt dome (formed simply by overburden stress) are now well hidden in a structure that is thickened by spectacular plastic flow under tectonic lateral compression. The lower part of the orebody is bedded and folded, but is nearly solid pure salt, except for some interbedded clay, siltstone, gypsum and anhydrite. The upper part is a large-scale breccia, a classic residual deposit left by partial dissolution and extensive collapse; blocks of salt many tens of metres across have survived within it. Over the salt, a cap of gypsum and clay appears to be a recent dissolution residue as typically occurs on salt domes at outcrop.

Brine springs at Wieliczka were exploited more than 5000 years ago, but it was only in 1250 AD that the source rock salt was first seen during the digging of a new brine well. Rock mining soon started and the first deep shaft was sunk before 1500. The industry expanded, and there are now 2000 mined chambers, reached by 200 km of tunnels, beneath 26 shafts, that descend to a depth of 327 m. Mining ended in 1997, and the site is now just preserved for its underground visitors.

The tour route starts with a spiral staircase for 45 m down the Danilowicz Shaft. Many of the tunnels from there on are lined with old or new timbers or colliery arches, but some have bare walls of clean salt. They break out into a succession of chambers, each of which exploited a single massive block of salt within the breccia zone. The first notable room was one of many turned into a chapel by the miners. It has some excellent statues, arched doorways and tall pillars, all carved out of solid salt - the salt statues are a much-lauded speciality of Wieliczka. One of the bedrock pillars is out of true, and looks to be the only sign of salt squeezing along the tourist trail. Another large room has a flat roof, stabilised with rock bolts, with long straw stalactites of pure salt, comparable to those of calcite in a natural limestone cave.

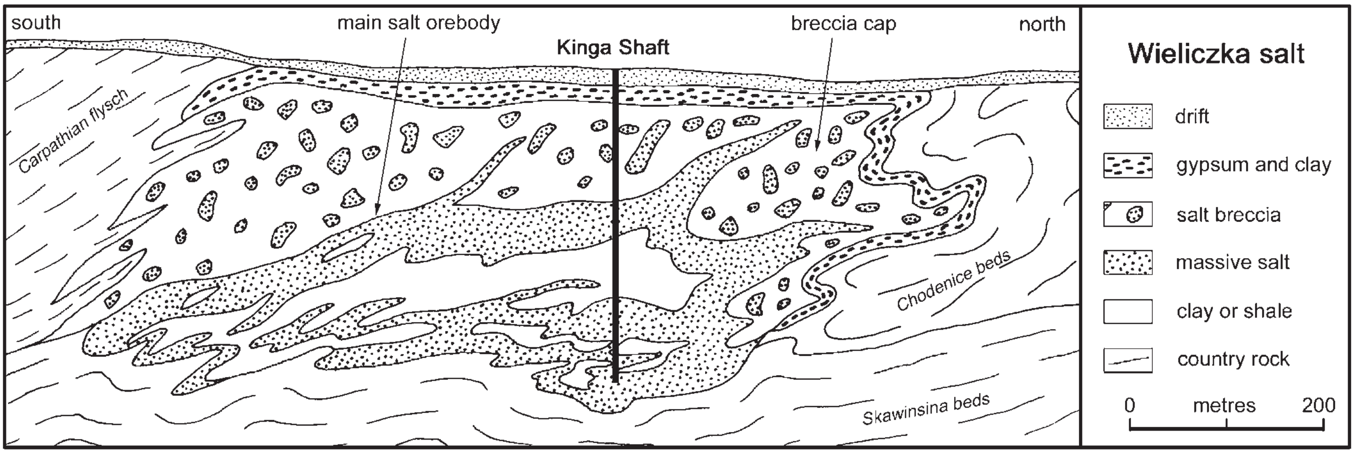
The Chapel of the Blessed Kinga in the Wieliczka salt mine, with walls, floor, roof, carvings and chandeliers all made of salt.



The highlight of the tour is the Chapel of the Blessed Kinga, a room 54 m long. It was excavated in 1862-1880 by working over 20,000 tonnes of salt from a single block in the breccia zone. Now it is has a salt floor, a huge salt altar at one end, bas-relief carvings in walls of translucent salt, and brilliant chandeliers of salt crystals. Coal mines were never like this. The tunnel beyond cross-cuts down through beds of salt dipping at 50° and impure with clay and gypsum. The walls also expose some excellent breccia beds, each only 2 m thick, with salt fragments each 50 mm across. They would appear to be left from phases of Miocene dissolution and collapse that interrupted salt precipitation.

The tour continues down through spacious chambers floored with deep brine lakes, and then through rooms with monumentally massive timber roof supports. Brine streams still flow in channels through and along some galleries; they were an important part of the mine production, but now are just a source of beautiful cubic salt crystals. An underground restaurant occupies one of the chambers, and there are yet more large rooms with museum displays that are not always open. From the restaurant room, it's 135 m straight up the Kinga Shaft in an original triple-deck miners' cage - back to daylight.

Tony Waltham



A simplified geological cross section through the Wieliczka salt body.

LECTURE

Gold in Britain and Ireland

Summary of lecture presented to the Society on Saturday 8th December 2001 by Dr Bob Leake, of B.G.S.

Finding gold by panning alluvial sediment has often been the first step in exploration that eventually led to the discovery of gold-bearing mineralisation. Systematic study of alluvial gold grains began at BGS in the mid-80s after the acquisition of an automated electron microprobe machine capable of mapping the distribution of elements within individual grains. Initial work on alluvial gold from South Devon showed a great deal of internal compositional heterogeneity to be present, particularly in palladium and silver contents, which often revealed how the grain had grown over time. In addition, microscopic inclusions of different varieties of selenide mineral were observed to be associated with some of the types of gold.

The interpretation of the chemical characteristics of the South Devon alluvial gold provided the crucial clues that show that oxidising solutions circulating within Permian red beds were responsible for transporting gold, palladium, platinum and other elements. Deposition then occurred when these fluids penetrated into more reducing rocks below the Permian unconformity, or where they became mixed with more reduced fluids. On the basis of this model, exploration was switched from South Devon, where the Permian cover had largely been removed by erosion, further north to the Crediton Trough, filled with a thick sequence of Permian red beds. Alluvial gold similar to that in South Devon was found at many localities, and gold mineralisation was found subsequently in situ in association with alkali basalt within the Permian red bed sequence. Further application of the model also led to similar gold being found in association with the Mauchline and other Permian red bed basins in Southern Scotland.

Following the success in studying alluvial gold from Devon, BGS began a similar study of material from other parts of Britain and Ireland in collaboration with Rob Chapman of Leeds University. Internal chemical heterogeneity was found in gold from other localities, but not to the extent of that present in Devon gold. However, a whole range of other opaque inclusions comprising various sulphides, sulpharsenides, arsenides, sulphosalts, tellurides and other minerals were found to differ from area to area. The nature of these inclusions together with the general chemistry of the gold grains reflected different styles of host mineralisation and different geological environments. Gold from one particular site or area usually has a definite signature with a distinct range of composition and a constant inclusion assemblage.

There are three main types of alluvial gold in the Southern Uplands of Scotland, the silver contents of which are plotted in the graph below, together with some minor types. The Shortcleugh type is characterised by its common arsenopyrite inclusions; it is dominant in the Leadhills district and also in Galloway, where it has some connection with centres of minor igneous activity. Similar gold also occurs within a comparable geological environment in the Mourne Mountains of Northern Ireland. The Megget type occurs over a wider area of the Southern Uplands, and is characterised by inclusions of base metal sulphides and minor tetrahedrite. but little arsenopyrite. Similar gold occurs in South Mayo, Ireland, associated with shear zones in rocks similar in age to those of the Southern Uplands. The third type is characterised by inclusions of selenides but not sulphides, and is associated with red bed basins and their immediate contact rocks.

Establishing the nature of the different types of alluvial gold to be found in Britain and Ireland is also vital in solving the old archaeological problem of the likely sources of gold used to make the many early Bronze Age artefacts that have been found, particularly in Ireland. Similarly, comparison of artefact and natural gold may reveal the nature of processes used in the Bronze Age to extract and refine gold prior to working.

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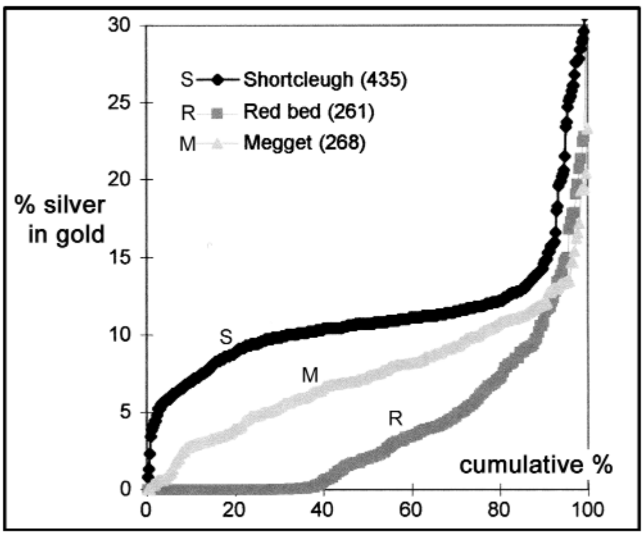

Silver content of the three major types of gold in southern Scotland (numbers of grains in brackets)

LECTURE

Deep geology of Britain

Summary of lecture presented to the Society on Saturday 12th January 2002 by Dr Alfred Whittaker, formerly of British Geological Survey.

The deep subsurface geology of Britain was a major research topic of the last two decades of the 20th Century. New and improved types of relevant data from British and international deep drilling projects, in combination with related ultra-deep seismic reflection profiling, led to the development of various national programmes and much international discussion and collaboration.

The UK programme was initiated by the British Geological Survey whose Deep Geology Unit carried out onshore seismic reflection surveys recorded to 12 seconds of Two Way Travel Time and giving data to the base of the continental crust. The seismic programme was later extended considerably by the offshore seismic surveys carried out by the BIRPS group at Cambridge. Interpretations divided the British crust vertically into three zones of different reflection character. The lowermost crustal zone was characterised by laterally persistent strong reflections, and was interpreted as comprising rock material subjected to ductile types of deformation, while the two overlying (and probably seismogenic) middle and upper zones show brittle deformation characteristics. The upper (sedimentary, 'layer cake') zone displays many normal growth faults that commonly overlie low-dipping seismic reflection features of the middle zone (in turn interpreted as important thrust faults and detachment surfaces). The structural relationships in the upper and middle zones indicate reactivation of faults in both normal and reverse senses following successive periods of tectonic compression and tension during Phanerozoic time.

In addition, many boreholes (in the depth range 2-3 km) were sited, prognosed and managed by the Deep Geology Unit, sometimes as stratigraphic 'step-out' wells to encourage oil prospection in parts of Britain and funded by the Department of Energy. Also drilled were geothermal exploration and production wells as part of the UK Geothermal Programme. The development of an international programme of continental scientific drilling in the 1980s and 1990s brought about much scientific collaboration and ultimately proposals for a British programme discussed in depth at a Geological Society meeting in London in 1987.

Related projects, now belonging to the current International Continental Scientific Drilling Program (ICDP), were the 12km-deep Soviet/Russian borehole in the Kola peninsula, which proved unexpected mineralisation and hydrological activity at much greater depths than was previously thought possible, and the German deep drilling project (KTB) which drilled to 9 km depth in the early 1990s. The lecture ended with a brief description of the Chicxulub ICDP drilling project (which began in December 2001) located in the Yucatan peninsula of the Gulf of Mexico. At the time of writing the Chicxulub borehole was at a depth of 500m, about half way to the expected Cretaceous-Tertiary (KT) boundary, rich in the platinum-group mineral iridium. The drilling target is a well-defined impact crater presently considered to be the site where a major asteroid or meteorite fell to Earth 65 million years ago and caused the mass extinction at the KT boundary.

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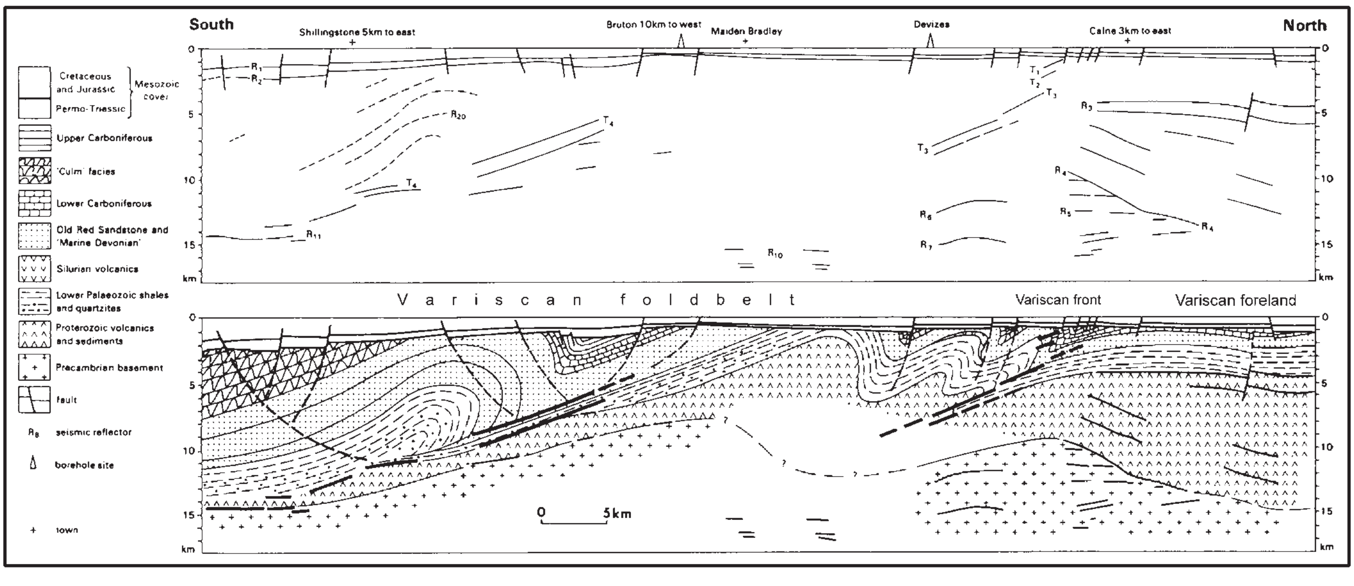
A north-south geoseismic crustal section across the Variscan fold belt of southern England to 18 km deep.



LECTURE

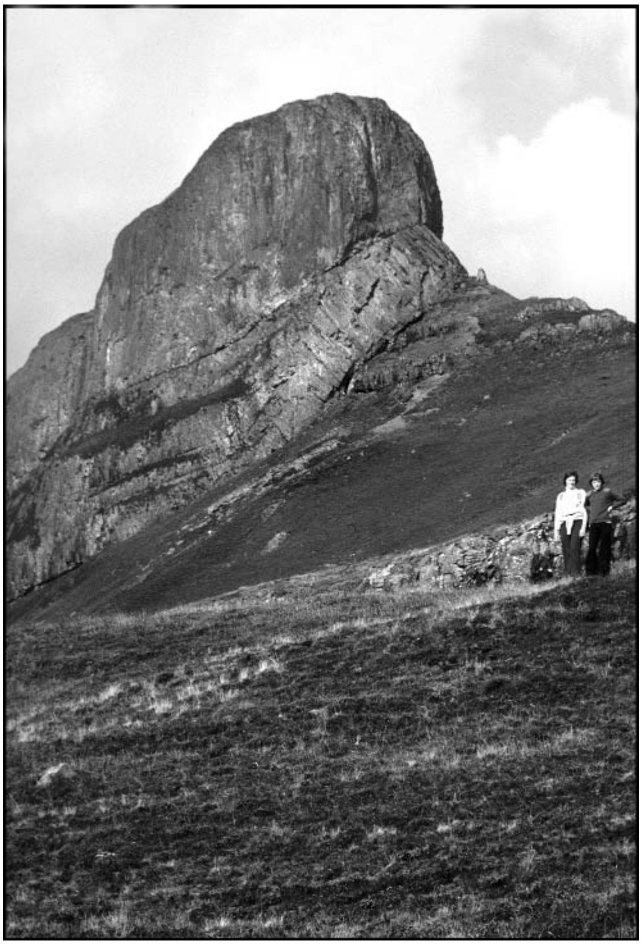
The Isle of Eigg: its geological history and the history of its geology

Summary of lecture presented to the Society on Saturday 7th April 2001 by Prof. John Hudson of Leicester University.

In the late 19th and early 20th centuries, the island of Eigg, in the Hebrides, was famous in British geological discourse, out of all proportion to its size. Fossil wood, the "Eigg Pine", had been described from there as early as the 1830s. In the 1840s, Hugh Miller discovered the first Scottish plesiosaur and graphically described his visits in his posthumous "Cruise of the Betsey" of 1858. Then Archibald Geikie, in 1865, interpreted the dramatic pitchstone rock of the Sgurr of Eigg as the fill of a pre-existing valley, carved in the underlying basalts, and now standing proud of its surroundings. This provided him with an object lesson in the power of erosion at a time when the erosional origin of valleys was not universally accepted. In 1906 Alfred Harker challenged Geikie's interpretation, claiming that the pitchstone was a transgressive sill, not a lava flow; Geikie was outraged, and in 1914 E.B. Bailey sided with him. But perhaps because of this clash of the geological titans of the day, the Sgurr lost its textbook popularity, and petrologists who studied its mineralogy and geochemistry were reluctant to comment on its field relations.

In more recent times, these 19th century discoveries and controversies have been re-investigated. Geikie's interpretation of the Sgurr pitchstone has been vindicated. Ann Allwright's mapping has revealed a buried landscape, not just a single valley, beneath the pitchstone. At its base the pitchstone contains pumice-shards, showing that explosive eruptions preceded the lava flow. Fossil wood occurs partly in the basal pitchstone but mainly in underlying conglomerates in the base of the old valley system, attesting to a vegetated landscape. Some of the wood occurs as charcoal from wildfires, perhaps started by volcanic activity.

The Jurassic rocks, especially those now known as the Kildonnan Member, contain remarkably well preserved fossils, ranging from protists to Miller's plesiosaur. Visitors are often surprised by the occurrence of mollusc shells of pristine aragonite beneath a substantial pile of basalt lava flows. This excellent preservation has enabled the author and colleagues to use isotopic geochemistry, as well as more traditional palaeontology, to interpret the environment of deposition, which we believe to be shallow, brackish lagoons, fed mainly by freshwater inflow, close to the coast and subject to occasional invasion by seawater and marine fauna. The Valtos Sandstone, forming the cliffs on the west coast of Eigg, contains remarkable concretions cemented by calcite. These developed in the subsurface, and the larger ones took millions of years to grow. Erosion of the sandstone contributes sand to the present beaches, especially the famous "singing sands".



The Sgurr of Eigg with the unconformity clearly visible where the massive pitchstone fills in the valley that had been cut into the horizontal basalts.

These sandstone cliffs, and the gleaming white sand, form an unforgettable picture as the foreground to the view of the mountains of Rum. The top of the Sgurr is one of Scotland's supreme viewpoints; the whole framework of northwestern Scotland, from the Outer Hebrides, via the Minch, Skye, Mull and the Small Isles, to the Caledonian mountains of the mainland, is laid out before you. The island of Eigg has much to offer geologists, and it is a delightful place to visit.

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LECTURE

Is the past the key to the future?

Summary of lecture presented to the Society on Saturday 10th February by Dr Chris Lavers, of Nottingham University.

The principle of uniformitarianism - that the present is the key to the past - has served earth scientists well for many years. The philosophy is quite odd, however, in the sense that it became entrenched at a time when geologists were beginning to suspect that the earth must be immensely old. It follows from this that the present must be no more than the finest shaving from the tip of geological time. Can we really understand and interpret 4.6 billion years of history using the present, any more than we can understand the Eiffel Tower by examining a sliver of paint from the top? Of course we must learn about the past by studying the present, but we may also learn about the present, and perhaps also the future, by studying the past.

For example, two of the most pressing environmental problems that we currently face are global warming and biological invasions (the latter sometimes referred to as 'global mixing'). How may we judge the likely impact of these processes on the biosphere? Computer modelling is one way but, different models yield different predictions, and the questionable reliability of such techniques, particularly in relation to climate, is widely acknowledged.

Another approach is to look to the past for guidance. In the case of global warming and mixing the best analogue is arguably the Permian-Triassic transition. The potential for global mixing at the end of the Permian was great because the earth's continental landmasses had all coalesced to form the supercontinent of Pangea. Recent research also suggests that a 6oC rise in temperature at equatorial latitudes occurred at this time, a figure at the upper end of the prediction for average global warming by 2100 by the Intergovernmental Panel on Climate Change. Warming at higher latitudes is thought to have been even greater, leading to the establishment of a relatively uniform warm to hot climate across Pangea. The change is thought to have been brought about by the release of carbon dioxide from the oxidation of coal-bearing deposits in the southern part of Pangea, and latterly from the eruption of the flood basalts of the Siberian Traps.

The Permian-Triassic transition was marked by the largest mass extinction in the history of life. The bulk of extinctions on land probably resulted from the homogenisation of habitats across Pangea as the pole-to-equator temperature gradient flattened. This gradient also drives the circulation of the oceans, and it seems likely that circulation slowed so much at the end of the Permian that the world's oceans became catastrophically depleted in oxygen and nutrients. The most extraordinary aspect of both terrestrial and oceanic ecosystems in the earliest Triassic was the ultra-low diversity and extreme cosmopolitanism among the survivors. Ninety per cent of all terrestrial tetrapod assemblages at this time, for example, consist of the remains of just one type of animal: the dicynodont Lystrosaurus.

Although global warming has been cited as the deadly *coup de grâce* for Palaeozoic life, it is inconceivable that global biodiversity would have fallen so low at the end of the Permian had continents and oceans been separated as they are now. Isolation acts to protect and generate biodiversity whatever the extraneous circumstances. We may not today be pushing the continental landmasses together in a physical sense today, but our transportation of species around the globe is having much the same effect. In fact the rate of global mixing is higher today than at any time in Earth's past.

To contend that we are currently heading for a Permian-like environmental catastrophe would be too extreme, but the parallels are clearly evident. The same processes, of global warming and global mixing, are certainly in operation, and are widely acknowledged to be key threats to the biosphere. As such, even if the late-Permian is rejected as an analogue for our current environmental predicament, it at least seems sensible to take this fascinating time in Earth's history as a warning.

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EXCURSION

Millstone Grit of South Derbyshire

Leader: Keith Ambrose (BGS)

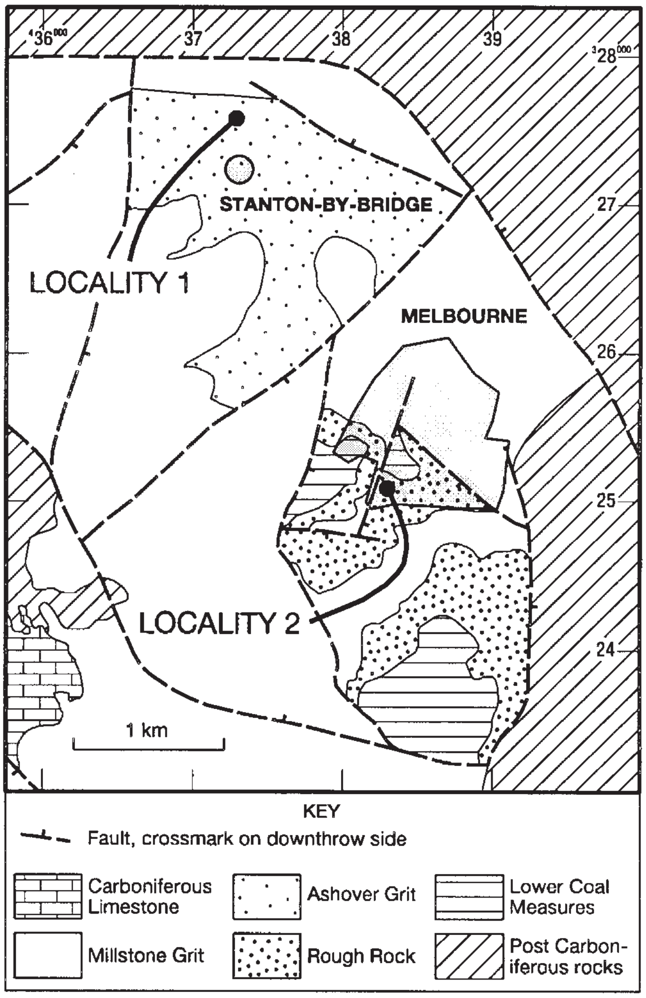
Wednesday 25th July 2001

The purpose of this excursion was to examine exposures of the inlier of Namurian strata, at Melbourne in South Derbyshire. This inlier has received very little attention from past workers. It was briefly described by Fox-Strangways (1905, 1907), who identified three subdivisions; an upper series of fine-grained, thin bedded sandstones; a middle series of massive, coarse, yellow, brown and red grits; a lower series of coarse conglomeratic beds. He noted that tracing the beds any distance was difficult and made no attempt to correlate the grits with those in North Derbyshire, nor did he give any indication of age. Mitchell and Stubblefield (1948) noted that the Dawsons (Carver's) Rocks inlier was probably the Rough Rock, citing evidence from a brick pit at Worthington in support. Here, marine Namurian beds were proved with a fauna suggesting a horizon a little below the Rough Rock. Kellaway and Horton (1963) noted a Marsdenian fauna from boreholes near the Staunton Harrold Reservoir and the Subcrenatum Marine Band, defining the base of the overlying Langsettian (Lower Coal Measures), was mapped at outcrop just to the south of Melbourne. This identified the presence of the Rough Rock. Ford (1968) noted Arnsbergian shales in the Ashby Borehole, sited just west of the Namurian inlier. Monteleone (1973) reported an E1 (Pendleian) age for the beds at Diminsdale, based on palynology, but gave no details of the assemblage. Fulton and Williams (1988) suggested the inlier was of Kinderscoutian to Yeadonian age.

Recent mapping by the British Geological Survey and an appraisal of cored boreholes in the area has provided new evidence for the Namurian stratigraphy (Ambrose, 1997, in prep; Ambrose and Carney, 1997; Carney et al., 2001a, b). The boreholes have proved several marine bands and identified the Rough Rock, Chatsworth and Ashover Grits. These grits have in turn, been mapped out at the surface. They have been worked for building stone in several places and this excursion visited two of these quarries, one in the Ashover Grit and one in the Rough Rock

The Millstone Grit sandstones have traditionally been regarded as deltaic in origin; the Ashover Grit was deposited by a major braided river complex, probably flowing across a delta top. Sediment, rich in feldspar grains and derived from a northerly source, was deflected to the NNW along the Widmerpool Gulf by a landmass which lay to the south. This landmass, variably referred to as 'St George's Land', 'Midland Barrier', 'Wales-Brabant Island/Barrier', 'Midland Landmass/Massif', is also thought to have supplied sediment in the early Namurian. Heavy mineral studies show two sources of sediment in the Millstone Grit of south Derbyshire. In the Melbourne Borehole, the lowest grits and the Chatsworth Grit were all derived from a southerly source, while the Ashover Grit and Rough Rock were derived form a northerly source. The same pattern was seen in the Worthington Borehole but with some suggestion of mixed sources in the Ashover Grit (Hallsworth, 1998). Palaeocurrent measurements taken from some sandstones show currents mainly to the north and northwest, with some to the west and northeast.

Locality 1 was at a quarry in the Ashover Grit at Stanton by Bridge. This quarry provided the stone used to build the bridge across the River Trent, here, linking it with Swarkstone on the north side of the river. The Ashover Grit crops out extensively around Stanton by Bridge where it is a single sandstone which is at least 33 m thick. To the east and southeast, the Ashover Grit splits into more than one sandstone bed. Its correlation with the Ashover Grit of the Melbourne Borehole is based on the presence of common, coarse, angular, pink K-feldspar grains; the sandstones above this level at



Outline map of the geology of the Melbourne area, showing the two localities visited.

outcrop and in the borehole are all devoid of pink feldspar.

The grit is well exposed in two quarries at Stanton by Bridge and has been worked in several others (which are now overgrown). It exposes about 8 m of buff to grey, fine- to very coarse-grained, poorly sorted, cross-bedded sandstone, which is commonly pebbly. The pebbles comprise rounded quartz and angular to subangular pink feldspars. Alternating coarser and finer foreset laminae with rapid upward fining are seen in some beds. Individual sets vary from 0.3 to 1.2 m thick and many have erosive bases with pebbly lags. Palaeocurrent data collected from here and a nearby quarry showed dominant trends to the north, northwest, and west with minor variations to the southwest, south, northeast and east.

Locality 2 was a quarry on the south side of Melbourne. The quarry, which provided much of the building stone used in the town, exposes about 15 m of the Rough Rock, which forms the uppermost bed of the Millstone Grit. Recognition of this sandstone as the Rough Rock is based on evidence from earlier mapping carried out in 1963, prior to the construction of the Staunton Harrold reservoir. The Subcrenatum Marine Band was identified at outcrop (Kellaway and Horton, 1963) overlying the sandstone and marking the base of the overlying Lower Coal Measures (Langsettian).

The main face exposes a uniform sequence of buff, with some red or orange-brown staining, fine- to medium-, locally coarse-grained sandstones. The sandstones are almost exclusively planar cross-bedded with sets generally 0.5-1.0 m thick. Locally there are thinner sets and in parts of the quarry, there are at least three thick sets 2.0, 3.55 and 4.0 m thick. No parallel-lamination is exposed. Some parts of the quarry expose large-scale trough cross-bedding, seen only in the lower beds. These bedforms are not persistent on any one level and pass laterally into planar cross-bedding. The sets are up to 1 m thick and 3-4 m wide. The recognition of trough cross-bedding may be a function of accessibility as the upper beds are not readily visible or are absent.

In some of the sets, clearly defined coarser (coarse- to very coarse-grained) and finer laminae are present, indicating grainflow and grainfall processes respectively. Bottom sets are well developed in many of the sets and bases may be planar or gently undulating; some have a basal pebbly lag, consisting of angular to well rounded granules and small pebbles up to 20 mm in diameter, of vein quartz and pink feldspar. The bottom sets of some units are also coarser. The upper of the two thick sets shows clearly defined rapid fining upward cycles 1-4 cm thick. In the uppermost beds, climbing ripple lamination is locally developed. Palaeocurrent measurements taken from planar forsets and trough axes show flow directions varying from WSW to NE.

The only other palaeocurrent data from the Rough Rock in this area has been published by Fulton and Williams (1988), from the outcrop at Carver's Rocks, to the west of the present area. They show a distinct bimodal distribution to the west and northwest. Bristow (1993) considered the Rough Rock to have been deposited by a braided river on a delta top.

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EXCURSION

The Yorkshire Coast

Leader: Andy Howard (BGS)

Weekend 22nd-23rd September 2001

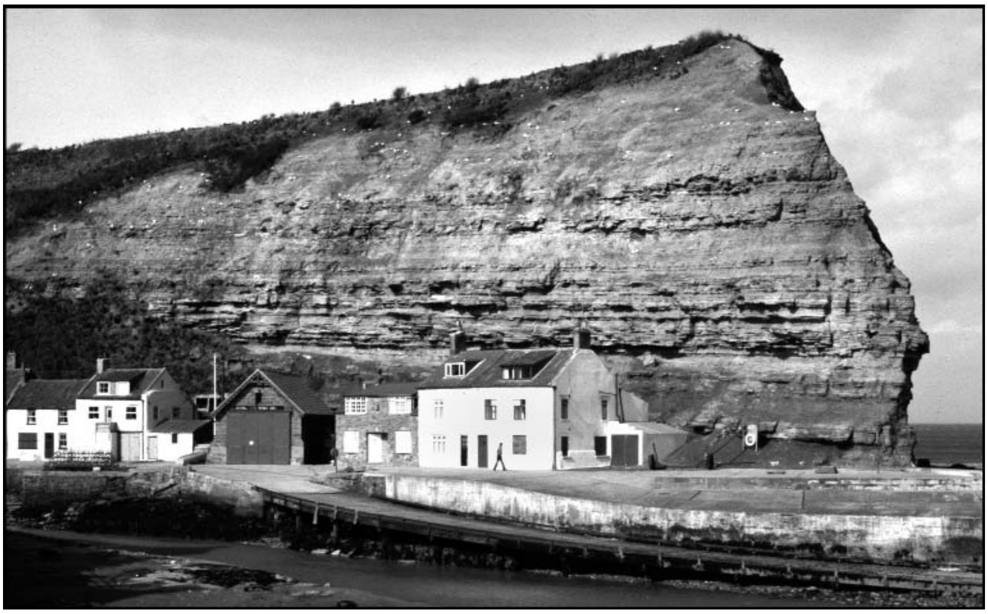
This weekend trip had been organised at short notice to supplement the Society's field excursion programme in 2001, which had been severely curtailed due to countryside access restrictions arising from the Foot and Mouth Disease epidemic. The aim of the trip was to demonstrate the wide variety of Jurassic sedimentary rocks exposed on the Yorkshire Coast and their associated depositional environments, including shallow marine storm deposits, shallow water carbonates, ironstones and fluvial sandstones. Of particular interest was the profound influence of sea level change on the deposition of the sequence, and the trip provided numerous opportunities to compare and contrast the sedimentary facies and fossils in adjacent marine and non-marine formations.

Cleveland coast

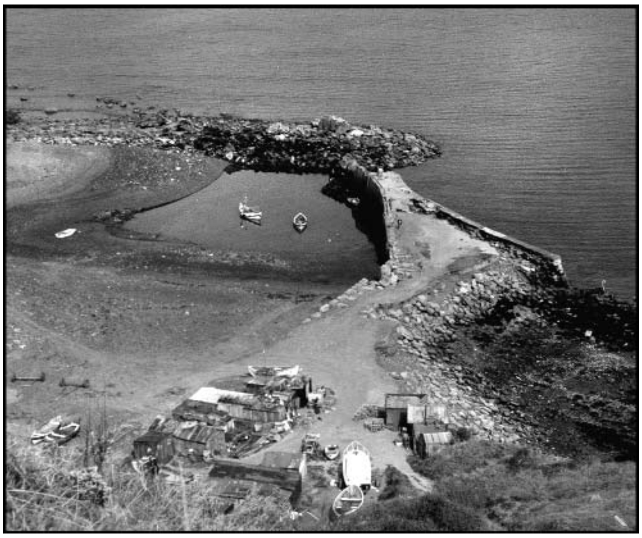
The Saturday was blessed with warm and sunny weather. Twelve EMGS members met in the car park at Staithes, and walked down to the harbour to view the shallow marine sandstones of the Staithes Formation. These are of Lower Jurassic age, and consist of thin, well-laminated sandstone beds interbedded with bioturbated, argillaceous siltstones. The sandstone beds contain abundant evidence of rapid deposition by storms, including hummocky cross-stratification, wave ripples and sharp erosional bases with shell lags. The interbedded siltstones are thoroughly bioturbated by a diverse assemblage of trace fossils, reflecting lower deposition rates during fair weather conditions.

Engineering works on the breakwaters at Staithes harbour had temporarily created a tidal pool that could not be crossed until an hour and a half before low tide. This delay was taken up by an early lunch, leaving the entire afternoon to traverse the excellent exposures of the Cleveland Ironstone and Whitby Mudstone formations on the foreshore between Staithes and Port Mulgrave. The Cleveland Ironstone includes several beds or seams of sideritic ironstone containing ooids (formerly known as 'ooliths') composed of the mineral berthierine, an iron-rich clay mineral. Each ironstone bed contains a diverse and often highly fragmented fauna of marine bivalves and also abundant trace fossils, including the distinctive U-shaped burrow Rhizocorallium. Each ironstone bed was formed during an extended episode of non-deposition and chemical alteration of the sea bed sediments associated with a period of sea level rise. Each bed lies above an upward coarsening sequence of several metres of mudstone, siltstone and fine sandstone, reflecting periods of gradual sediment accumulation and basin infill between the sea level rises.

At Old Nab to the south east of Staithes, former underground pillar and stall workings in the Cleveland Ironstone Formation have been exhumed by marine erosion. After examining these workings, the party moved on to the Whitby Mudstone Formation exposed near Port Mulgrave. Here, a large landslip in 1993 had brought down huge amounts of fresh 'Upper Lias' mudstone and ironstone nodules from the upper cliff, providing a fertile hunting ground for ammonite collectors. Members took the opportunity to gather some fossils, and were able to compare their finds with those of the many dedicated fossil collectors still scouring the landslip material. After searching the Whitby Mudstones for jet, a mineral formed from the compressed and altered remains of fossil wood, the party entered the small harbour at Port



The Staithes Formation above the village harbour.



The view down to Port Mulgrave.

Mulgrave. This was built in the 19th century to ship iron ore from mines at Grinkle, about 2 km inland. The ore was transported to the port through an inclined tunnel, the portal of which is still visible next to the harbour breakwater.

The party ascended the cliffs at Port Mulgrave, noting the landslips associated with a spring line at the base of the Middle Jurassic sandstones that formed the upper part of the cliff. They then followed the pleasant cliff top path back to the Staithes car park.

Cayton Bay

In marked contrast to the previous day, Sunday dawned dull, cold and equinoctal; seven members attended for the day. Cayton Bay, southeast of Scarborough, is essentially a buried valley floored by Middle Jurassic rocks, and plugged by glacial till of Late Devensian age. Marine erosion has cut into the softer glacial till plug to form the central part of the Bay, with the stronger Jurassic bedrock forming the headlands, or 'nabs', at each end. The till is extensively slipped with several excellent examples of classic, amphitheatre-shaped rotational landslides, and the beach is strewn with several World War II pillboxes that were originally built at the top of the cliffs.

The day commenced with an examination of the late Middle Jurassic sandstones of the Osgodby Formation, which form the lower part of High Red Cliff at the southern end of Cayton Bay. These sandstones contain a diverse fossil assemblage of marine molluscs and trace fossils similar to the Staithes Formation. But, unlike that formation, the entire rock is thoroughly bioturbated with only traces of original sedimentary lamination remaining, suggesting that storms were of lesser importance as an agent of deposition. The Osgodby Formation contains almost spherical calcareous nodules over 1 m in diameter, each containing beautifully preserved trace fossils. Lying immediately below the Osgodby Formation, the Cornbrash Formation consists of a thin, bioturbated, ferruginous limestone with berthierine ooids and abundant marine fossils including the distinctive, oyster-like bivalve *Lopha marshii*. The Cornbrash, which unconformably overlies the non-marine mudstones of the Ravenscar Group, strongly resembles the ironstone seams of the Cleveland Ironstone Formation. Like each of them, it marks a very long episode of non-deposition associated with a major rise in sea level.

After an extended lunch to wait for the outgoing tide, the party negotiated the boulder field at the southern end of Cayton Bay to view the Middle Jurassic rocks of the Ravenscar Group exposed at Yons Nab. The Yons Nab Fault separates these strata from the younger rocks of High Red Cliff. The Ravenscar Group is mainly composed of marginal marine, deltaic and fluvial sediments but includes thinner units of marine strata. Again, periodic sea level change had a major influence on deposition of the sequence. The lowest strata seen at Yons Nab were the marine, oolitic limestones of the Millepore Bed, a direct equivalent of the Lincolnshire Limestone of Lincolnshire and Humberside. Unfortunately, the high state of the tide made these rocks difficult to examine. The overlying Gristhorpe Member, however, was very well exposed. This unit consists of marginal marine mudstones, siltstones and sandstones and contains abundant evidence of smaller scale oscillations in sea level. Beds containing rootlets and plant fossils, including the famous Gristhorpe Plant Bed, strongly indicate emergence and soil formation, whereas other beds with marine trace fossils indicate submergence and at least quasi-marine conditions.

The excursion concluded with an examination of the Scarborough Formation, another marine unit that overlies the Gristhorpe Member. The Scarborough Formation is composed of well-laminated sandstones interbedded with bioturbated mudstones and siltstones containing a marine bivalve and trace fossil assemblage. It strongly resembles the Staithes Formation and was probably also deposited in a shallow marine setting influenced by major storms. These beds are overlain by a fluvial channel sandstone with a sharply erosional base that cuts down several metres into the underlying marine beds, indicating that deposition of the formation was terminated by a substantial fall in sea level. The channel sandstone displays an excellent example of 'epsilon' cross-bedding, which is formed by lateral migration of meanders within a sinuous fluvial channel. On retracing their steps back to Cayton Bay at the end of the trip, members were able to follow this channel at a higher level in the cliff, and determine both the extent of its lateral migration and the degree of downcutting into the underlying Scarborough Formation.

EXCURSION

Fountains Abbey / Brimham Rocks

Leader: Neil Aitkenhead

Sunday 30th September 2001

Fountains Abbey

Having travelled to North Yorkshire by coach, the party disembarked at the Fountains Abbey Visitors Centre where the leader outlined the day's programme. The abbey was built by the Cistercian Order between c.1130 and 1526 and made wealthy by its extensive sheep-rearing lands extending right across the Pennines. The carefully preserved ruins and surrounding land are owned by the National Trust and maintained by English Heritage, and are now a World Heritage Site.

The abbey lies in the incised meandering valley of the River Skell, part of which was landscaped in the 18th Century with lakes and follies as well as 'artfully contrived views'. However, it was the scattered rock exposures in the valley that were to be our main objectives and required a walk of about 2.5 km to the first exposure.

Generally the river has eroded down to 30-40 m below the adjacent terrain to expose bedrock in cliffs formed by the meander scars. However, the present flow seems too weak to erode such a deep valley. It seems likely that most of this erosion was by glacial meltwaters, perhaps initially sub-glacially and then pro-glacially. This occurred mainly during the melting of the Pennine ice-sheet towards the end of the last (Devensian) glaciation some 14 000 years ago. However, since this area was near the margins of both this ice-sheet and that of the Vale of York, meltwater erosion may have taken place over an extended time interval.

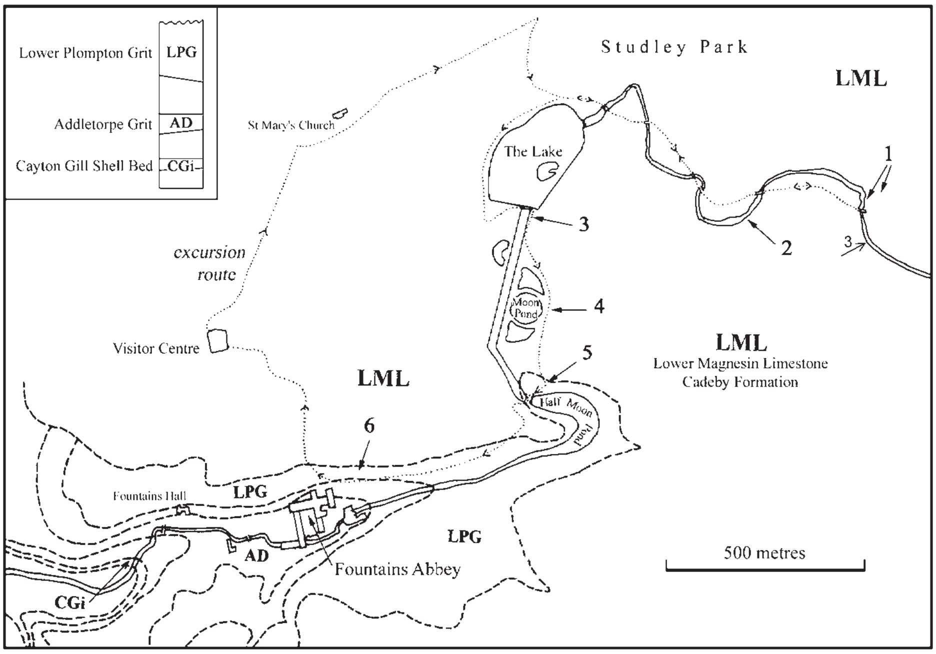
High relief moraines to the south of Fountains Abbey (e.g. How Hill with a relief of about 30 m at SE 276670) are thought to be marginal to the Vale of York ice-sheet, and the extensive cover of glacial till on the ground adjacent to the Skell valley was probably deposited by that ice.

Around Fountains Abbey, rocks of the Cadeby Formation (Lower Magnesian Limestone) of Late Permian age rest unconformably on rocks of the Upper Carboniferous Millstone Grit Group. Most of this area lies in a lower sub-division of the formation characterized by deeper water facies in contrast to "patchily-developed littoral or sub-littoral dolomites" with abundant bivalves (notably *Bakevellia*) in places (Smith, 1974). This deeper-water facies generally comprises "slightly fetid, thinly bedded to flaggy calcitic fine-grained dolomites and dolomitic limestones with knobbly bedding planes that are commonly coated with black stylolitic residues". Carbonate-lined cavities are abundant. Mottling similar to that in Durham is widespread, and much of the rock has a tendency to autobrecciation and a chunky fracture.

Our walk took us down into part of the Skell valley known as The Valley of the Seven Bridges, where seven meanders are each crossed by little hump-backed bridges. Locality 1 was next to the farthest downstream of these bridges.

Locality 1

Rubbly thin-bedded dolomitic limestones with fairly constant bed thickness occur at river level. There was some discussion about the origin of the rubbly bedding, which is sometimes attributed to burrowing or bioturbation. However, there seemed to be no evidence of the former presence of burrowing organisms such as bivalves and it was pointed out that similar rubbly beds in Durham were thought by Smith and Francis (1967) to be the result of pressure solution.



Geological map of the Fountains Abbey area, showing the route followed and localities visited. All the ground outside the Skell valley is covered with several metres of glacial till. The stratigraphic column shows only members of the Kinderscoutian within the Namurian Millstone Grit Group (based on BGS maps).

A precipitous face of apparently massive thick-bedded dolomitic limestone is present with its base about 10 m above river level showing marked contrast with the underlying thin-bedded facies. Access was not attempted due to its steepness but it was noted that the base was sharp, undulating and possibly disconformable, with a suggestion of cross bedding just above the base. A sample obtained from just above the base on a previous visit appeared under the hand lens to be a partially dolomitised grainstone in which a relict oolitic texture could just be discerned.

Walking upstream to Locality 2, it was noted that glacial till had slumped down almost to river level on the north bank and there were numerous erratics of Carboniferous sandstone on the bed of the river.

Locality 2

A meander scar extends for over 100 m, exposing some 12 m of a similar facies to the lower beds at Locality 1, at a slightly lower stratigraphic level. Bed thicknesses range from 5 to 20 cm, varying only slightly along the strike. At one point a spring seeping from the rock face has produced a large protuberance of moss-covered tufa.

Locality 3

After walking round The Lake, we arrived at a small exposure by the path below the Octagon Tower. This comprises blocky grey fine-grained dolomitic limestone (calcisiltite), and loose blocks contained tiny, white, coiled foraminifera.

Locality 4

The geological map (BGS, 1987) indicates that at some point along the path we were following, we would cross the unconformity where the Cadeby Formation rests on the Carboniferous Lower Plompton Grit. However, fragments of dolomitic limestone in the bank behind the folly known as the 'Temple of Piety', indicated that we were still on the outcrop of the Cadeby Formation.

Locality 5

A rubbly bank next to the junction of paths heading east and west of Half Moon Pond was found to have small exposures of medium- to coarse-grained sandstone. These are Millstone Grit just below the basal Permain unconformity, the actual plane of which was not exposed. However, its line can be fairly easily traced as it descends into the valley at this point.

It was pointed out that this unconformity is of great geological significance. It represents a time when some 2000 m of late Namurian and Westphalian strata may have been removed during an interval of folding, faulting, uplift and erosion lasting perhaps 30 million years. This Variscan orogeny resulted from the final collision of the continents of Gondwana and Laurasia to form the supercontinent of Pangea. From late Carboniferous to early Permian times, the region moved northwards from the equatorial forest belt to the tropical desert belt. Then, rifting in what is now the North Sea, possibly combined with a rise in sea level caused by melting of the southern polar ice-caps, created the Zechstein Sea. The carbonate rocks of the Cadeby Formation were then deposited on the western margin of that sea.

Locality 6

The Lower Plompton Grit is one of several distinct sandstone units of Kinderscoutian (R1) age in north and west Yorkshire that amalgamate southwards to form the extensive outcrop of the Kinderscout Grit. Generally, "it is medium- to very coarse-grained, locally pebbly, cross-bedded, feldspathic sandstone" (Cooper & Burgess, 1993). It was deposited in the great river system that formed an extensive delta prograding intermittantly southwards across the Pennine Basin in Namurian and early Westphalian times.

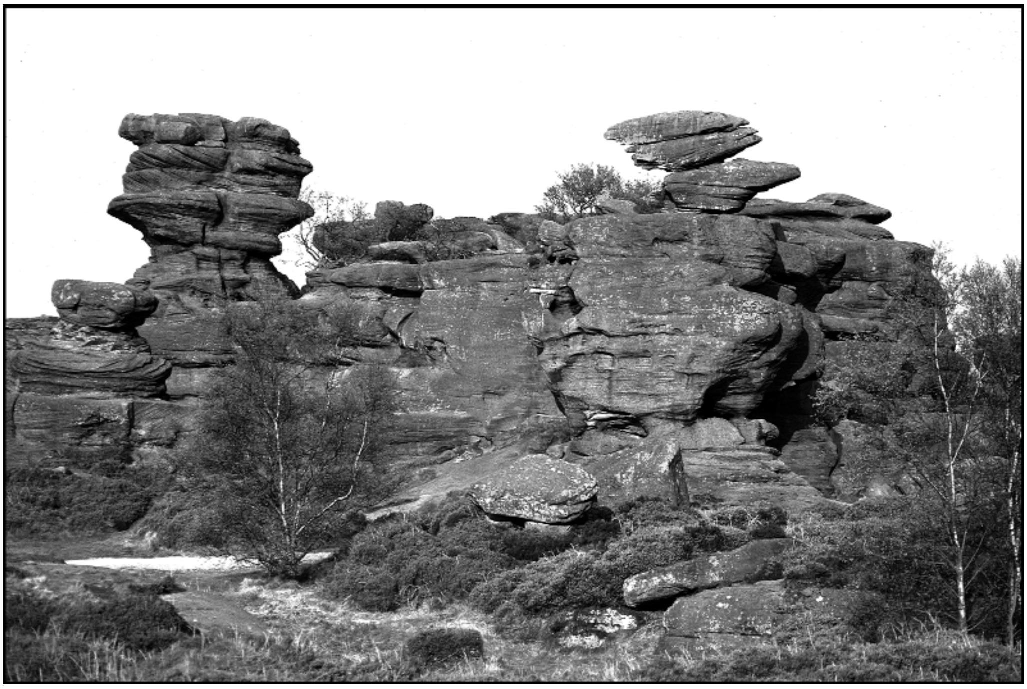
The Grit is well exposed in a quarried cliff that extends discontinuously for about 400 m beside the footpath immediately north of Fountains Abbey. The advantage of siting the abbey so near to this excellent source of building stone becomes obvious to the visitor. The sandstone in the cliff is medium- to coarse-grained and well weathered to emphasize the cross-bedding and reveal large ferruginous concretions in places. The attractive colours of the stone – pale to yellow brown with a pinkish tinge in places – probably indicates its proximity to the overlying plane of unconformity.

Before boarding the coach for Brimham Rocks, some members enjoyed their packed lunches among the abbey ruins, noting the rare examples of crinoidal Nidderdale Marble (Blacker & Mitchell, 1998) in some of the buildings.

Brimham Rocks

Owned and managed by the National Trust, Brimham Rocks lie on a broad hilltop reaching a height of 301 m on the north side of Nidderdale. This extraordinary landscape of sandstone tors is formed by the deep weathering of the Lower Brimham Grit - which is probably the lateral equivalent of the Lower Plompton Grit at Fountains Abbey, 7.5km away to the north-east. Wilson and Thompson (1965) note that in the Kirkby Malzeard area immediately to the north, the Lower Brimham Grit ranges up to about 30 m thick. The medium- to coarse-grained sandstone at Brimham displays a variety of cross-bedding sets. These can be interpreted as having formed as shifting sand bars, sandbanks and dunes migrating downstream on the bed of a powerful river that deposited huge spreads of sand in delta distributaries extending south to what is now the Peak District. Tree ferns fell from the eroding banks of this river and became buried in the sand. We saw the remains of one of these in the form of a sub-horizontal tube, 3.5 m long and 0.5 m in diameter in the side of a tor.

A few of the tors are surmounted by blocks of sandstone that have been tilted to a near vertical



The tors of Brimham Rocks.

position with respect to their bedding structures. In discussion, two explanations were put forward, the first being that the blocks had been let down by ice as it melted during a waning phase of the last glaciation. The second explanation was that at some point in the erosion process, the uppermost part of the tor had become undermined and unstable, and the perched block had simply tilted or toppled into its present position. No concensus was reached!

The main discussion, however, was about how the tors had formed in the first place. In general, it is commonly believed that tors remain after the intervening rock has been removed following softening by chemical weathering particularly along and adjacent to strong joint planes. Such planes are clearly present at Brimham and may have been widened by incipient cambering in this elevated hilltop position, especially near the flanking western and northern edges of the escarpment. About 20% of the sandstone consists of feldspar, a mineral prone to chemical weathering especially in the warm climate that prevailed during Neogene times when the area was probably uplifted to its present position.

Although it is generally accepted that almost the whole region was ice-covered during the last glacial maximum, there is little evidence of ice erosion at Brimham. The ice here may have only formed a thin, semi-static cover with the main local ice stream flowing down Nidderdale. Once melting and retreat had started, the Brimham escarpments would have been amongst the first areas to be uncovered, exposing them to the full force of katabatic winds descending from the main Pennine Ice Cap to the north-west. These winds, armed with ice crystals and (increasingly as melting progressed) with sand and rock particles, would have been the main agent for the erosion and removal of the softened rock and the abrasive etching of the tors. Disaggregation of the sandstone would have been greatly enhanced by the effects of repeated freezing and thawing. Other planes of weakness in the sandstone, such as bedding planes and poorly cemented beds, would have been more susceptible to erosion - giving rise to the strange shapes and features, including scattered small potholes, that add to the attractiveness of the tors.

Although the day had started rather cloudy and damp, it became clear and dry by the afternoon, and the party felt that their long journey from Nottingham had been well worth the effort.

Acknowledgements

I am most grateful to Dr Anthony Cooper of the B.G.S. for his help in my preparations for this excursion. The text was improved following helpful comments from Tony Benfield and Dr Albert Wilson.

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EXCURSION

Nottingham Sandstone Caves

Leader: Tony Waltham

Wednesdays 14th and 21st February 2001

This excursion was repeated, as each had to be limited to 25 people, but it was still over-subscribed, and it may be repeated again next winter. Its popularity may have been due to the opportunity to see the caves in the company of the author of the Society's very successful publication Sandstone Caves of Nottingham (£4.50 from the Secretary); or maybe that the trip was free.

There are hundreds of man-made caves cut in to the Nottingham Castle Sandstone under the city centre. One large group lies behind the old sandstone cliff spanned by the Broad Marsh Centre, and part of these forms the Caves of Nottingham, open to visitors during opening hours of the shopping centre. A number of caves are seen along the underground trail, including the old tannery site, and exhibits have been arranged to illustrate how the caves were used in times past, and then as air-raid shelters in 1939-1945.

The visit was arranged for Wednesday evenings, when members of the Nottingham Archaeological and Historical Society (NHAS) meet to excavate caves that have been filled with rubble and debris during successive stages of site. During the walk through the tourist section of the caves, Tony explained their history, and pointed out the engineering structures created when building the shopping centre to avoid damaging those caves of historical importance. It was particularly interesting to see a tiny part of the original Drury Hill surviving on the rock above caves that had been cut out beneath the old street.

We then headed into the western caves where NHAS archaeologists were working to clear caves that were used as stables in the 1800s, in order to find more about their earlier history. From these, we emerged into the night through a newly opened hole in the cliff, in a triangle of land that is now otherwise inaccessible between various modern buildings. We then went back into the cliff into the three caves under the garden of Willoughby House (by kind permission of the owner). These were the suitably magnificent wine cellars of Lord Willoughby, and it is suspected that they were also used as social drinking rooms. Further west along the cliff, the one remaining segment of the Black's Head caves was visited. Sadly, most of the caves here are now full of concrete, including a malt kiln and a tannery found and then filled during emergency engineering work. Tony also told how he was not quite tall enough to acquire some modest wealth during exploration of the cave. Intrigued? Buy the book or put you name down for the next trip.

Alan Filmer

CORRIGENDA

Despite careful checking a few errors crept into Graham Lott's masterly treatise on building stones in the last issue of the Mercian Geologist, and he gratefully accepts the following corrections, which were kindly supplied by Neil Aitkenhead.

Page 101, Table 2 - Quarries at *Ashford in the Water* and *Hognaston* are in limestones of the Brigantian Stage, not the Arundian Stage.

Page 103, Table 3 - Quarries at *Coxbench* and *Horsley* are in the Rough Rock not in the Crawshaw Sandstone.

Page 103, Table 3 and text paragraph 3 - Quarries at *Whatstandwell* are in the Ashover Grit not in the Kinderscout Grit.

Page 104, Figure 3 caption - The columns are of Crawshaw Sandstone, not of Rough Rock.

Page 104 - The last sentence in the final paragraph starting "The same sandstone from the Coxbench or Horsley quarries ….." should be transferred to the end of the 4th paragraph on page 103.

Page 110, Plate 1D caption - The stone is from the Widmerpool Formation, not Woodale Limestone.

Page 121 - Add to the list of references:-

Frost, D. V. & Smart, J. G. O., 1979. The geology of the country north of Derby. *Memoir Geological Survey G. B.*, sheet 125.

NOTES TO CONTRIBUTORS AND AUTHORS

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

Submissions. All material should be prepared and submitted in a format as close as possible to that of the *Mercian Geologist* since 1992. Please submit two copies of the full text and diagrams of scientific papers; only single copies are required of photographs and of the texts of shorter items. All texts should be machine-written on A4 paper, single-sided, double-spaced and with ample margins. The text should be followed by a complete list of the captions of all the diagrams, maps and photographs, numbered in a single sequence. It is helpful if text is also sent by e-mail, and is safer when cut and pasted into a message; please avoid attached files in the first instance. Electronic files should have plain text with no formatting. Illustrations and tables are required in hard copy only.

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

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

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

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

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

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

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

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

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Contents