MERCIAN

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Front cover: Chatsworth House, in Derbyshire, seen beyond its bridge across the River Derwent. See the report on page 27. Photo: Tony Waltham.

Back cover: A few of the ornamental stones, building stones and minerals from Chatsworth House, taken from the report on pages 27-42.

Contents

MERCIAN NEWS

Cave pearls

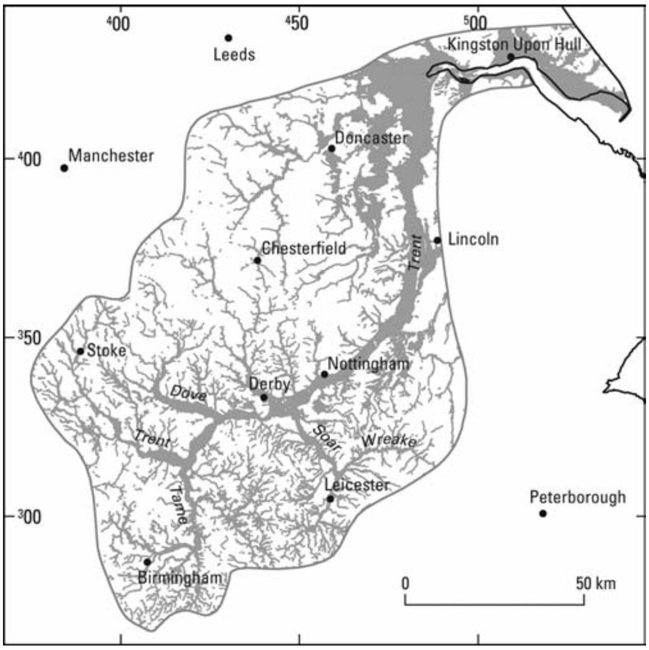
Many members of the Society have commented on Paul Deakin's splendid photograph of cave pearls that appeared with little further information on the front cover of the supplement with the *Mercian*'s last issue. Cave pearls are concretions of calcite, with an internal structure of concentric bands around a central grain. They form in shallow pools of lime-saturated cave water, and are close to spherical because they are rotated during their growth, due to regular disturbance of the pool water by drips from above. They are often found in pools beneath tall dripping shafts. These in the Golconda Mine lie in a pool within a flowstone cascade in a section of natural passage about 10 m tall. The larger pearls are 10-15 mm across, which is a good size for cave pearls. When they become too large to be rotated by the dripping water, they tend to lose their shape and become cemented to the floor, and this has now happened to the Golconda pearls - since their photograph was taken in the early 1980s.

Notes for authors

Guidance notes for authors are no longer printed in the *Mercian*. They may be retrieved from the Society's website at www.emgs.org.uk or are available on paper by request from the Secretary.

Erratum

Members and readers may have noticed that the Trent basin was singularly devoid of alluvial deposits in the map that was Figure 1 in John Carney's paper in the last Mercian (v16, n4, p231). This was due to a gremlin in the digital file, for which the Editor apologises. A more informative version of the map, defining the floodplains by the extent of alluvium and floodplain terrace deposits, is reproduced here.



Churchill Fellowship

Congratulations to Ian Thomas, immediate past president of the Society and Director of the National Stone Centre, who has been awarded a highly coveted Churchill travelling Fellowship to study traditional building craft training in the context of sustainability and modern building regulations. In the main, he will be focussing upon the use of stone. He plans to begin his seven-week tour later this year in Norway, travelling south through Sweden to the Danish island of Bornholm, then back into Sweden and across to Finland. The second leg of his journey will take him from Austria through Germany to Belgium.

Sandstone Caves of Nottingham

The Society's best-selling book on Nottingham's caves, started life as a paper in the *Mercian*, when it was penned by the current editor. It is now in its third edition (and on its seventh print run), as a book aimed at a wider readership. The new edition, published late in 2007, is in full colour, with 52 of the author's photographs, and also 23 maps or plans. It is fully up to date, including information on recent discoveries. The caves' geology, varied histories and current uses are all explained, along with their conservation issues. The book is essential reading for anyone with an interest is the history of Nottingham or with responsibilities for the city's conservation and development.

GEOBROWSER

Global climate change - a puzzle solved

The controversies over global climate change have generally revolved around two important aspects: a) is the Earth really warming up? and b) if so, what is causing it? Those in denial about the first question have so far been able to cite the fact that temperature readings taken from weather balloons and satellites have, according to most analysts, shown little if any signs of progressive warming when compared to surface measurements. If these weather balloon temperatures are truly representative of the situation, then most models that predicted global warming are wrong. This paradox has now been resolved by measuring changes in winds, which are tied to fluctuations in temperatures and would be a more accurate gauge of true atmospheric warming than the thermometers (*Nature Geoscience, May 2008*). Measurements on thermal winds, based on the motion of weather balloons at different altitudes in the atmosphere, show that temperatures at heights of 10 km in the Tropics have risen by about 0.65ºC per decade since 1970. This is probably the fastest rate of warming anywhere in the Earth's atmosphere, and is in line with other predictions of global warming models.

Problems with methane

The possibility that (geologically) sudden releases of methane, a powerful greenhouse gas, could help to ‘tip’ the Earth’s climate towards unbridled warming has been mooted for some years (e.g. *Geobrowser 2004, and talk by John Rees in November, 2005*). Such an event would be devastating, but its onset is difficult to predict; possibly for that reason, many non-geologists prefer to largely ignore it, and instead base their models on smoothly-curving extrapolations of recent global temperature increases. It is therefore up to geologists specialising in palaeoclimate changes to point out the danger. They can do this by going back into ‘deep time’, reversing Hutton’s principle of uniformitarianism by suggesting that the past may be the key to what is happening in the present.

In very deep-time….

With increasingly sophisticated methods of isotopic and geochemical analysis, we can now go back a long way and suggest that an abrupt release of methane may have occurred in latest Precambrian times, about 635 million years ago (*Nature, May 29, 2008*). This could have contributed to the chain of events that ended what was possibly the last "snowball" ice age, the Marinoan glaciation (see also *Geobrowser, 2005*). The mechanism involved is suggested to be the abundant release of methane from clathrates - masses of methane that form and stabilize within lattices of water molecules frozen in sea floor sediments beneath ice sheets under specific temperatures and pressures. When the Precambrian ice sheets became unstable and collapsed, they released pressure on the clathrates, which began to degas. The finding could explain many things, including the abruptness of the glacial termination, changes in ancient ocean-chemistry, and unusual chemical deposits in the oceans that occurred during the snowball Earth ice age. The researchers warn that we are currently witnessing an unprecedented rate of warming, with little or no knowledge of potential instabilities that lurk in the climate system and how they can influence life on Earth. But much the same experiment had already been conducted 635 million years ago, the outcome is preserved in the geologic record and this shows the planet’s potential to undergo an abrupt and catastrophic change from a very cold, seemingly stable climatic state to a very warm and stable climate, with no pause in between.

And the terrestrial dimension?

Methane out-gassing from terrestrial sources is another of the mechanisms suggested to advance the process of climate change towards the ‘tipping point’. We only need to go back to between 11,000 and 12,000 years ago, to the end of the last glaciation, to establish the potency of this phenomenon. American and Russian scientists have found that from 8000 to 12,000 years ago, the vast area covered by northern hemisphere peatlands increased dramatically, and methane levels -resulting from the decomposition of organic material and its release upon thawing - rose to 750 parts per billion by volume, a level they would not be reached again until the Industrial Revolution. Temperatures over Greenland likewise jumped an additional 7ºF, reflecting a period of warming, which in turn thawed more ice, particularly in North America, and freed up more land for bog formation. Today, with global warming proceeding apace, methane is once again being rapidly released from the northern tundra and in the near future will boost the present level of atmospheric carbon, possibly by several billion tonnes (*New Scientist, August 2005*).

Further evidence corroborating the importance of terrestrial out-gassing has come from studies of core samples from the Greenland Ice Sheet Project II. These ice cores, from the last 40,000 years of Earth history, show a rapid increase in methane, and while some researchers believe that clathrates were responsible, others believe that the methane was generated in wetlands. (*Science Daily, February 2006*). By studying the ratio of the heavier isotope of hydrogen, deuterium, to the normal hydrogen it was found that a contribution from clathrates could be ruled out, leaving only two realistic candidates - changes in wetland systematics and/or increased natural gas emissions during the glacial period. The former of these explanations is thought to be the most likely, since it is compatible with models predicting that, as climates warmed, and the area occupied by wetlands expanded, methane emissions increase.

The study of terrestrial carbon out-gassing is relatively new, but is now being applied to much earlier geological records, as recent analysis of British Tertiary peat bog material has shown. These fossil wetland deposits, belonging to the 55 million years old Cobham Lignite, were intersected during the construction of the Channel Tunnel. Their geochemical composition (*Science Daily, September 2007*) shows that carbon isotope values of hopanoids - compounds made by bacteria - suddenly decrease in a manner that can only be explained by switching to a diet of methane. This indicates that methane emissions must have increased, suggesting that 55 million years ago there was a massive release of carbon into the atmosphere that coincided with, and probably enhanced, global warming. In *Geobrowser* (2003), this event was attributed to a combination of out-gassing by volcanism and methane hydrates, but the new study suggests that there was a knock-on effect, causing environmental changes in wetlands. It is perhaps the earliest example of how terrestrial ecosystems millions of years ago were affected by rapid warming-induced changes in climate, and is therefore a further salutary lesson on how they could respond to warming in the future.

Good news for Nottinghamshire coal

Amid much fanfare it was revealed in April this year that UK Coal is considering re-opening Haworth colliery, in the village of Bircotes, 15 km south of Doncaster. This mine was mothballed 20 months previously, with 'geological problems' being cited as the cause, but even care and maintenance is expensive and last year it was marked for closure. All that changed with the doubling of world coal prices in the past year. The planned opening will not happen until seismic surveys and boreholes are completed, the company cautioned, but this could lead to an investment decision to re-open the mine. The last new mine to open was at Asfordby in Leicestershire 20 years ago, when the coal industry was still nationalised - and that pit was already being closed down (*Merciant, 1998*) by the time UK Coal bought the English coalfields in the 1994 privatisation. It is also reported that record coal prices have already encouraged UK Coal to invest £55m at Thoresby in Nottinghamshire and Kellingley in Yorkshire, extending the lives of those deep mines by a decade.

The company remains Britain's biggest producer of coal, despite falling output, but it supplies just 15% of the coal burned in Britain - while Russia, South Africa, Colombia and Indonesia account for most of the rest (*UK Government: figures for steam coal imports in 2006*). The concern for the security of supply is obviously very significant for government and consumers. One problem to further investment is that the three big customers - the electricity generators - signed fixed-price contracts with UK Coal, and are still buying cheaply. The company's average price last year was little more than half the market level and there are still 13M tonnes - 18 months' output - to supply under those contracts (*various reports, including the Daily Telegraph*).

The Humber Stone - a misapprehension

Media reports (*Leicester Mercury and* BBC'*s East Midlands Today*) during April heralded the placement of an information board at the site of this large boulder, which is located near to the traffic island at the intersection of Thurmaston Lane and Sandhills Avenue (SK62410709), north Leicester. These reports correctly identified the stone as being a glacial erratic of Mountsorrel granodiorite, but fell into the trap of assuming that the stone was transported to its present site as a result of ice movement during the last glaciation, which ended only about 12,000 years ago. In fact, no ice reached here during this Last Ice Age - it stopped well short, in Derbyshire, Staffordshire and along the Norfolk coast. Instead, the erratic owed its journey to a much earlier and more widespread glaciation, which occurred about 420-440,000 years ago during the Anglian Stage of the Quaternary. Very good corroborating evidence for this is provided by the newly published BGS map of Leicester (Sheet 156, with Sheet Explanation). This shows that the Humber Stone lies squarely within an outcrop of Thrussington Till, a boulder clay deposited by an Anglian ice sheet that, originating as it did in the Pennines region, would have travelled across Mountsorrel, picking up the stone and dropping it in its present location about 10 km to the southeast.

The Humber Stone. The trench surrounding this stone was constructed about the year 1900 - perhaps an early example of geological conservation in the East Midlands.

Another first for Charnwood Forest?

In this issue of *Mercian*, as in many others, deserved prominence has been given to the internationally important Precambrian fossils found in Charnwood Forest. The story behind their first recognition, by the then-schoolboy Roger Mason in 1957, has been recounted many times (Mercian 2007, p.280 for example). It was an event of tremendous importance globally, because it constituted the first find of large fossils in rocks that were conclusively of Precambrian age – in other parts of the world it had always been assumed that 'old' but undated rocks with fossils must be of Cambrian or Ordovician age.

If we examine the literature prior to Roger's discovery, we find that disc-like impressions in Charnwood Forest were occasionally mentioned, but were dismissed as being of inorganic origin. Recently, however, a very early reference, and the first to assign an organic origin to the discs, has been unearthed by Frank Ince, who brought it to the attention of Mike Howe, Chief Curator at the BGS. In 1868, a lecture on Charnwood Forest by R. A. Eskrigge (reported as an article in Transactions of the Manchester Geological Society, 7(5), 51-57) carried additional comments by a 'Mr J Plant'.

Plant stated that in April 1848, he and a colleague had 'discovered' on the rocks ring-like impressions, 6 to 12 inches [15-30 cm] in diameter, and had communicated this find to Professor A C Ramsay. The latter's opinion, as relayed by Plant, was that these circles originated where 'large seaweeds had been rooted, and probably by the action of the seaweed bending round by the force of the water, scooping out the mud in concentric circles'. Today this remains a most prescient conclusion, remarkably comparable to certain more recent suggestions. Although parts of the interpretation can be questioned, there seems little doubt that both Ramsay and Plant were convinced that these were the impressions of large, rooted organisms (modern seaweeds comprise several groups of multicellular algae, but also organisms of the kingdom Protista). Plant went on to say that no impressions of this type have been found in the 'Cambrians of North Wales', and here he may have been taking a sideways swipe at those who thought that the Charnian rocks were younger than Precambrian in age.

Unfortunately, we do not know the date of Ramsay's pronouncement, and it was presumably communicated in a letter or verbally, rather than being immediately published, but it probably occurred very shortly after 1848 and so could pre-date the accounts by Salter (1856) of organic impressions in Precambrian strata of the Long Mynd. If so, the Manchester article may document the earliest recognition of fossils in England's oldest rocks. In the communication, 'J Plant', stated that he had conducted '....many years careful exploration (in Charnwood Forest) before I came to Manchester'. This biographical note makes it fairly certain that the discoverer was John Plant rather than his brother, James, who also contributed on the geology of Charnwood Forest around that time.

REPORT

The National Stone Centre

The National Stone Centre stands on a dramatic site in old limestone quarries, overlooking Wirksworth, in the southern Peak District. Half of the 20 ha is a Site of Special Scientific Interest on account of its unique assemblage of carbonate mud mounds and shark remains. The Centre aims to tell the story of stone in all its aspects, including geology, geomorphology and geodiversity, also its historical use and applications in art and the man-made landscape. It is an independent charity managed by representatives of industry, government and academia, but is self-sustaining and draws no regular revenue from government or industry, relying on grant aid only for larger capital work. Main activities are sustained by income from commissioned work, much of this based on support from the Aggregates Levy Sustainability Fund.

Most of the geo-trails around the site have been recently improved, where a new series of interpretive panels cover earth science, history and ecology. New trail guides describe the site itself and nine, off-site, circular walks in areas between Stanton Moor and Whatstandwell. These recount the quarrying and mining history as well as their geology, and were supported by Countryside Agency, Heritage Lottery and Aggregates Levy funding. Work has also resumed on the "Geosteps", forming a small amphitheatre for use in outdoor presentations, with each step in stratigraphical sequence, upwards from Precambrian greywackes of Radnorshire at the base. The highest layers are still being sourced, but each step will be topped by local Hoptonwood limestone for seating. Longcliffe Quarries Ltd are supporting this work.

In the Centre's educational programme, volunteer leaders assist school visits with fossil casting and with demonstrations of rocks, minerals and soils, as well as walking the trails over the site or to overlook the nearby Dene Quarry which still produces aggregate. The Centre offers training courses related to stone; some are organised directly, while others are collaborations, including those in lime mortar and rendering, masonry, dry stone walling and stone carving.

The Centre generates income to sustain its other activities, by providing data on uses and sources of stone; it has created viewpoint panels for 20 quarries and geological sites across the country, and locally for Darlton, Dene, Crich and Ballidon quarries. It has also conducted a review of the Derbyshire and Peak District RIGS, and has worked on historical research of Mendip quarries. With the BGS, it has completed an investigation into the demand, supply and planning issues of aggregates to support major development in Milton Keynes and the South Midlands, and it is involved in the preparation of regional strategic policy documents for aggregate quarrying in the East Midlands and in Wales.

Ian Thomas

THE RECORD

We welcome any members who have joined the Society within 2007. Regrettably, the level of membership of the Society seems to be falling slightly at the moment.

Indoor Meetings

The subjects discussed during this year's indoor meetings have been as diverse as ever. They began with a very successful members' evening that was held after the AGM in March. Under the chairmanship of Gerry Slavin, Vanessa Banks spoke on Derbyshire springs as a water supply, Alan Dawn on reptiles from the Oxford Clay, Alan Filmer on Big Bend National Park in Texas, Tony Morris on a geological visit to Hungary and Gerry Shaw on the geology of Orkney.

Also in March, as part of the Geological Society's Bicentennial Local Heroes initiative 'Engineering Geology through the Centuries', was the annual joint meeting with the Yorkshire Geological Society at the BGS at Keyworth.

April's lecture had a medical theme when Gerry Slavin related Geology to Disease

The winter programme began in October with 'The History of Scafell Caldera: a dramatisation' by Professor Peter Kokelaar.

In November Keith Ambrose gave us 'Geodiversity and Education in Leicestershire and Rutland'.

In December Dr Richard Hamblin took us away for 'Ultimate Quaternary - the geology of Hawaii', followed by a well-supported Cheese & Wine evening.

In January Dr Howard Falcon-Lang spoke on 'Sex, lies and fossil plants', which revealed the life of Mary Stopes and her major contribution to Earth Science.

During this year's Foundation Lecture in February Professor Monica Grady had us 'Looking for Life on Mars'.

Once again we are grateful to Beris Cox for organizing such a varied programme of speakers, all the more so because this has been her final year as Indoor Meeting Secretary. Her place will be taken by Richard Hamblin who has a hard act to follow.

Field Meetings

A day trip to see the new exposures in an extension to Ketton Quarry, led by Alan Dawn, was the first of the season's field meetings in May. Evening visits were made to the Hemlock Stone led by Gerry Shaw in June, and to the Manifold Valley led by Colin Bagshaw and Ian Sutton in July. Also in July was a visit led by Keith Ambrose to Cloud and Breedon Quarries.

In early September a weekend in East Anglia was led by Richard Hamblin. Later in the month saw a visit to Stanage Edge with Fred Broadhurst.

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

The details of this summer's visits will be advertised in forthcoming circulars and on the website.

Council

Council met formally on six occasions during the year. Thanks are due to Mrs Sue Miles for producing the Circular that keeps members up to date with the Society's activities and provides information about other relevant events and organisations. New members continue to find out about us via the website, and now half the membership takes the circular via e-mail.

This year has seen the publication of the new colour edition of the ever-popular Sandstone Caves of Nottingham, and also a reprint of the successful East Midlands Field Guide. Gerry Shaw's leaflet 'Rock Around the Campus' highlighting the geology to be seen at Nottingham University has been well received, and the Society is looking to producing similar ones for other local sites - suggestions and/or help would be welcome.

Thank you to members who are passing on older editions of the Mercian Geologist that are no longer required; this has been very helpful.

Rock Boxes are now available for donation to Primary Schools, and we would like members to spread the word to any contacts they may have. We thank those members who have passed on specimens for this project, and ask that members continue to bear the project in mind when they visit appropriate localities.

The Society continues its interest in Geodiversity issues. Representatives of the Society this year visited Crich Quarry to discuss with the company geologist and site manager proposals to extend the quarry and how to preserve some of the old workings. A watching brief is kept at Dirtlow Rake and the Society is hoping to contribute to the East Midlands RIGS project.

The web site continues to bring us new members and geological enquiries, and informs the public about the Society's work. We are grateful for the work Rob Townsend puts into maintaining and developing it.

In conclusion I would like to thank all those not specifically named in my report whose hard work enables the Society to flourish.

Janet Slatter
Secretary

MEMBERS' EVENING 2008

The second Members' Evening was held on 8th March 2008, when four presentations were made. The instructions to the presenters were simple: *show us your interests and infect us with your enthusiasm*. It is hoped that other members, whether amateur or professional, will continue the success of the Members' Evenings in future years.

The Thulean Basalt Province

Alan Dawn

In the late Cretaceous, North America and Greenland were attached to Eurasia as part of Laurasia which had separated from Gondwanaland in the break up of Pangaea. Then, at about 63 Ma, in the early Tertiary, the North Atlantic began to form with rifting between North America, Greenland and Western Europe accompanied by voluminous volcanism. The area which is now the Inner Hebrides (Skye, Mull, Rhum, Eigg and Muck) together with the Ardnamurchan Peninsula were buried under massive flows of flood basalts. The rifting developed across mantle plumes (or hotspots), one of which lies beneath Iceland today. The previous track of this plume is traced by the Iceland - Faroes Ridge, with the basalts younging closer to Iceland, leaving the Faroes an inactive site. Above its hotspot, Iceland has been created by continuous volcanism since early Miocene times, c16 Ma. The island nation lies on the mid-ocean North Atlantic Ridge, and this is the only part of the currently active ridge exposed on land.

Water, ice and volcano interactions

There are various interactions between volcanoes and the ice fields. The largest ice field is Vatnajokul, in the southeast of Iceland, under which is an active volcano. When it erupts, huge volumes of meltwater burst from beneath the ice (forming the floods known as *jokulhlaups*) with massive damage to roads and infrastructure on the sandur outwash plains. Huge quantities of rock debris are transported by the floods and extend the coastline seawards.

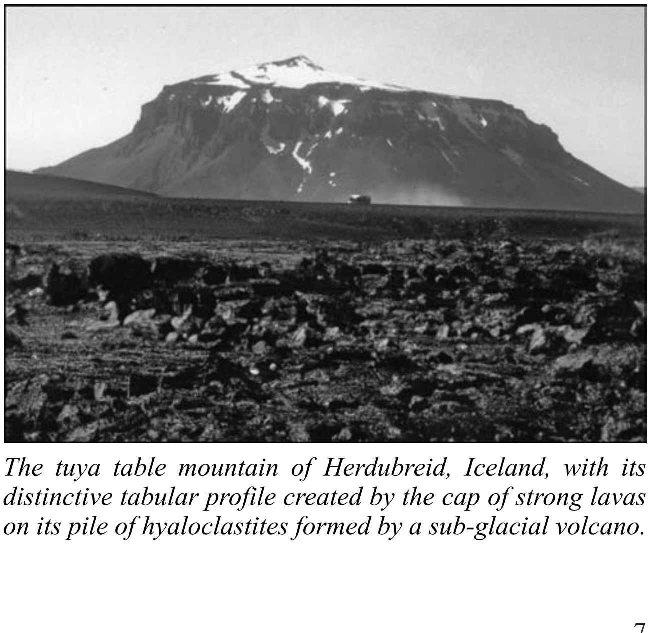
Another feature of eruptions beneath ice is the development of tuyas or table mountains. These form in three stages:

- when a volcanic eruption occurs through a vent covered by very thick ice, magma melts the ice to produce a water-filled cavity, and under high pressure pillow lavas are deposited;
- as the volcano grows, the ice/water pressure decreases and further eruptions are phreatomagmatic, with shattered hyaloclastic tephra (mainly fragments of basalt glass) overlying the pillow lavas;
- with further growth the vents may rise above water level, and subaerial effusive flows then build on the piles of subjacent hyaloclastites, thereby creating the distinctive "table top" appearance of the tuya.

The grand terraced waterfall of Gulfoss cascading over ledges of flood basalt, in southeastern Iceland.

Much of Iceland's scenery is dominated by successive, near-horizontal, basaltic lava flows that produce a characteristic trap or staircase morphology with the development of many spectacular waterfalls.

Because of the increased heat flow associated with the mid-ocean ridge, hot springs abound, and at Geysir the eruption of a hot water spout has given its name to other such features worldwide. Wilhem Bunsen, of burner fame, correctly attributed the phenomenon to meteoric water that penetrates to depths where it is heated geothermally, but then ascribed the eruptions to bubbles of high-pressure steam accelerating in their rise towards the surface. In fact, the key process is "flashing" whereby superheated water converts instantly to steam when pressure declines due to water being pushed out of the underground conduit.



The tuya table mountain of Herdubreid, Iceland, with its distinctive tabular profile created by the cap of strong lavas on its pile of hyaloclastites formed by a sub-glacial volcano.

The zeolite minerals

Iceland's basaltic lavas are commonly amygdaloidal, and the cavities are filled with minerals that include calcite, quartz and feldspars and widespread zeolites. These are tectosilicates, with three dimensional frameworks of SiO_4 and AlO_4 tetrahedra, that are characterised by an open crystal structure with channels and cavities that give space for water molecules. On heating, the loosely bound water is given off without structural collapse - hence the name from the Greek for 'boiling stone'. Zeolites are white, colourless or in pale colours, and many occur as handsome fibrous, acicular, tabular or cubic crystals.

[*This presentation was accompanied by a demonstration of zeolites collected from Scotland and Iceland*].

Zeolites from Jeigerhorn, Iceland.

Rise of the Roddons

Dinah Smith

The Fenland of Lincolnshire and Cambridgeshire is the largest area (4000 km^2) of Holocene deposits in Britain. These are up to 15 m thick and have a complex palaeo-environmental history. Their stratigraphy comprises a succession of interbedded clays (marginal marine salt-marsh environments) and peats (freshwater reed beds), representing greater and lesser amounts of marine influence over the time period from 6000 to 2000 BP.

Microfossils in a washed sample of roddon soil.

The salt marsh clays contain spectacular networks of silt/sand-filled tidal creeks known locally as roddons. These can be seen in many fields in the Fens as very slight ridges with paler-coloured soil, and are best seen after the land had been ploughed.

The roddons host a range of microfossils – especially foraminifera, ostracods and the spines and stereome fragments of echinoids. The latter provide firm evidence for the marine origin of the sediments.

By working out the mechanism of the infill that formed these roddons, by analysis of their sediments and microfauna, a greater understanding of the transgressive and regressive history of the Fenland may be determined. Work has been concentrated on the Thorney area of Cambridgeshire with visits to roddons at Whittlesey in Cambridgeshire and Methwold in Norfolk, and environments have been compared with the modern tidal system at Stiffkey on the north Norfolk coast.

Cross-section of a roddon in a ditch beside the new Thorney bypass (at TF316045), showing the paler soil in the clean-cut, U-shaped channel, beneath the gentle ridge of the roddon.

Water Wheels and Geology at Matlock

Lynn Willies

A major feature of the geology of the Matlock Gorge is a series of east-west anticlines and synclines, plunging to the east at the Carboniferous limestone margin with the overlying Edale Shales (Ford, 2002). The River Derwent cuts the gorge through limestone and associated volcanics, in a sinuous course of about 5 km between Matlock and Cromford, The complex river course is derived partly from superimposition from the overlying shale on to the limestone (with the various folds leading to its sinuous course); it then cut down into the limestone, rather than shifting eastwards in the softer shales, where its course was fixed by projecting limestone reef-knolls. Finally there was a uniclinal shift of the course above hard basaltic lavas and in soft volcanic tuffs at the latter's top surfaces.

The area is one of Missippian-type lead/zinc, fluorite/baryte mineralization with associated minerals, especially calcite, in both fissure veins and stratiform pipe deposits (Ford, 2001). Power sites for mine pumping to exploit the mineralisation are found on the River Derwent, and include from north to south, Dimple Mine 300 m north of Matlock centre, Ladygate at the west end of Pic Tor or Church Cliffs, two sites at Artists Corner, two under High Tor, one near Hodgkinson's Hotel Corner, Matlock Bath and the Hagg Mine at the southern end of the Lovers' Walks, Matlock Bath. This list of water wheel locations is not exhaustive and at least another couple of sites are possible. Contemporary evidence of the sites and their function lies in old paintings of this very scenic area.

Dimple Mine is on the major Seven Rakes Vein, with a wheel installed alongside the river in the 1760s; a steam engine was installed about 1808 and another a half-century later. One recent result of the documentary information was a forecast of cavernous sub-river workings above the lava and tuff where the vein cuts through. These were drilled for and found above 20 m depth, and reinforced concrete was laid to protect the new section of railway line above. Little remains to be seen today except for hummocks and cinders at the steam engine site next to the river and the outcrop of the vein in the quarry cliff behind the Sainsbury's recycling site. The top of the vesicular lava and the overlying tuff can be seen near the new River Bridge, but is likely to vegetate fairly soon.

Ladygate has a vein of the same name cutting the river and passing through Pic Tor, which is notable for its adjacent reef knoll and very cherty limestone. A water-colour picture of about 1789, of the timber scaffold bridge which carried the pumping rods over the river, is in the Cornwall Record Office. A steam engine followed, suggesting mining to considerable depth, but little came of it. The deep cleft of the vein is obvious today in the cliff and there are remains of the pumping shaft at its base. The water wheel was over the river, apparently fed by an extended leat from the Dimple site.

Ringing Rake ranges north from Artists Corner, and is a southward extension of the parallel veins that make up Seven Rakes; it continues south, being then known over the river as Raddle Rake, forming the huge fissure behind the main face of High Tor. There is a substantial side of the wheel pit south of the corner on the High Tor side of the river, which dates from about 1800. The other side of the wheel pit was in the river, and the wheel could be hauled up when there were heavy floods. A painting shows a section of the rods which ran a short distance upstream and then crossed the river to work a shaft on Ringing Rake, probably near the present public toilets in the car park. It is fairly certain that the wheel and pumps enabled the workings to go under the river for the first time. It is possible to enter this mine and see the fault, volcanics including hyaloclastites, and a range of other features of geological interest.

Raddle Rake is the continuation of Ringing Rake east of the river and up to High Tor face; a sough entry can be seen a few metres above the south side of the river bank, isolated by river-lowering operations in the 1790s and 1970s. The wheel site was across the river on the west or road side, almost opposite the Ringing Rake site, and again presumably operated by rods over the river and up the hillside to a pumping shaft. It was abandoned by 1789 when a little sketch of it was drawn by Turner.

High Tor Mine, worked about 1820, had a huge wheel, 8 m across and of about 80 HP capacity. The weir and leat are shown on Ordnance Survey large-scale plans, but were destroyed in a flood-relief scheme about 1970. However the wheel site and tail race still exist under the paint works that succeeded the mine by about 1850 and still operate. Rods took the power 300 m along a passage under the Tor following the Great Rake, and there are still holes visible that retained support beams for the pumping rods. The lack of appreciation of the depth the old miners worked below river – probably well over 30 m – was part of the reason for the failure of the Riber Mine in the 1950s.

Stone-lined pit that held a water wheel, dating from around 1800, on the High Tor bank of the River Derwent.

South of High Tor, midway between the above site and Matlock Bath Station, was another small weir, from about 1780, shown on a water colour, while there is also a further picture, possibly by de Loutherberg, that appears to have rods looking rather like a post and rail fence going up to what became the site of the 1950s Riber Mine. The picture location is unknown.

By North Parade, at its western end and near the Jubilee footbridge in Matlock Bath, there was a weir across the river probably in the mid-18th century, again seen in paintings. This was near a sough that went under the Heights of Abraham and the Coalpit and Great rakes, though it is more likely that it fed a leat to a wheel working veins on the east side of the river just around the corner.

Hagg Mine was portrayed by de Loutherberg about 1780. His romanticised picture may be seen in Buxton Museum and shows a rather-too-rustic bridge carrying rods and chains running on pulleys across the river. The mine is still enterable, but it is in very soft slippery tuffs. The river-level sough drained almost a kilometre to just beyond the White Lion at Starkholmes, but it is doubtful whether the lower pumping level ever reached that far. A little sketch made by Eric Geisler, a Swedish traveller in about 1773, shows the wheel and rods; the wheel was undershot, on the west side of the river.

In conclusion, historically the veins have been tested well east of the river and the associated geology has been investigated to reasonable depths. Overall, the evidence is that economic mineralisation is limited to the east, and the presence of volcanics makes mining difficulties because of the associated clays. Appreciation of this might have prevented heavy financial losses at Riber Mine in the 1950s. Knowledge of the cavernous substructure beneath Dimple Mine, still had economic usefulness in railway development. One does not actually need to go out and get tired and dirty to study geology – there is much evidence of economic geology available in archives and galleries. In addition try searching for Matlock Bath pictures on the internet and especially the British Library and Picture the Past collections.

Thanks to Roger Flindall who has supplied much data from his extensive researches, and who also searched parts of the area with me.

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Ardnamurchan Macro to Micro

Rob Gill

Correct identification of rocks by their mineralogy and texture is one of the cornerstones of geology, and the desire to be able to achieve this, prompted by a visit to Montserrat and the collection of some rocks from there, was responsible for the creation of Geosec Slides, a small business producing thin sections on microscope slides. Setting up the business involved a move from Lincolnshire (and the East Midlands Geological Society) to Ardnamurchan in Argyll.

Geosec is now located at Achnaha, in the middle of one of the Tertiary volcanoes on the west coast of Scotland. The area is remote, and the scenery is spectacular, with the ring formation that is known worldwide and remains the subject of active geological debate over its formation. One of the main reasons for being in this area is the range of different rock types available nearby for study. The feeling of being within a volcanic structure is more obvious here than in most of the other centres in the Scottish volcanic province; the topography of many others has been modified by ice, to produce a landscape that is more post-glacial than volcanic.

It is not too difficult for anyone with an interest to make thin sections for their own study. Modern cements are easier to use than the traditional Canada balsam; clear epoxy resin, sold for glass and china repair, is fine for cementing the sample to the slide, and UV-setting superglue can be used for fixing the coverslip. Grinding is done on a glass plate with 220- and 400-grade silicon carbide grit, and slicing is with a diamond saw, either a lapidary model or even one of a tile-cutter type. Many rocks, of only moderate attractiveness in hand sample, become objects of beauty when viewed in polarised light; spectacular birefringence colours are displayed, and the structure and mineralogy are revealed, leading to easier correct identification.

Ardnamurchan's Tertiary ring complex, seen from the west.

Pleistocene and Flandrian Natural Rock Salt Subsidence at Arclid Green, Sandbach, Cheshire

Peter Worsley

Abstract. This applied geological case study concerns the Quaternary geomorphological evolution of a small part of the lowland Cheshire characterised by 'equifinal subsidence landforms' resulting from the processes of rock salt dissolution and post Last Glacial Maximum glacial ice meltout. The context relates to environmental issues arising from the quarrying of Chelford Formation industrial 'silica sands'. Problems related to natural and human induced rock salt dissolution are reviewed. The respective roles of Triassic bedrock halites, collapsed strata, periglacial alluvial sands and multiple glaciation in determining the local stratigraphy and allied landforms are discussed. The morphology and fill of a post glacial subsidence area is examined. It is concluded that natural rock salt dissolution is the principal process influencing the superficial deposits and geomorphology of the study area and that this process has been active over hundreds of thousand years. The deposition and survival of thick silica sands and the glacigenic sediments beneath is probably due to halite dissolution.

In eastern Cheshire, a significant part of the lowland geomorphology is characterised by an excellent example of what, in 'General Systems Theory' jargon, would be termed 'equifinal behaviour' (Chorley, 1964), also known as polygenesis. Such behaviour in a geomorphological context envisages that different initial earth surface processes have resulted in similar morphological outcomes. Hence, equifinal landforms do not necessarily betray their primary causal origins, and geological observers should be vigilant when attempting to establish their genesis. Specifically, the Cheshire terrain is peppered by numerous hollows and troughs, including some which have yet to be fully integrated into the surface drainage network. Dependent upon the degree to which they have been infilled since their formation, this distinctive relief forms part of the classic Cheshire landscape of lakes (meres) and bogs (mires/mosses).

The key to identifying the significance of this particular group of landforms are two quite independent subsidence processes. These are :- (a) the decay of detached masses of buried glacial ice creating kettle holes in association with the deglaciation event which followed the LGM (Last Glacial Maximum) at c.20 ka BP, and (b) the dissolution, by circulating ground water, of saliferous beds within the Triassic bedrock succession. This latter, more-deep-seated, process induces collapse of the cover sediments and has been omnipresent process since preglacial times. However, in lowland Cheshire, a region of recent (Devensian) glaciation with a more than 90% blanket of superficial (drift) sediments, it is often far from easy to discriminate between depressions resulting from one or the other kind of subsidence, especially in the absence of exposures or any sub-surface data. Paradoxically, the field delineation of areas thought to be underlain by saliferous strata is frequently dependent upon accurate identification of landforms resulting from salt dissolution processes per se.

A further complicating factor is human induced salt subsidence exacerbated by historic shallow mining for salt and wild brine pumping, for example, Ward, (1887), Calvert (1915), Cooper (2002), Sherlock (1922), Wallwork (1956, 1960), Waltham (1989), and Waltham *et al* (2005). Following the near universal enforced abandonment of these extraction techniques in the 1970s, active subsidence arising directly from brine pumping is now much reduced. Anomalously the New Cheshire Salt Works at Wincham near Northwich was until recently able to continue wild brine pumping largely because of the extreme difficulty of attributing subsidence (and liability) to a specific site in an area of complex hydrogeology. Dormant future problems relating to old mines are not eradicated. An example of this relates to the central business district of Northwich. After initial spectacular collapses (Fig. 1), for over a century the hazard posed by catastrophic salt subsidence had been countered by constructing low rise buildings on adjustable frames (Waltham, 1989). Nevertheless, the conurbation core area remained in quasi-equilibrium as it was underlain by shallow C19th pillar and stall worked mines filled with saturated brine - a veritable ticking time bomb, as the pillars were degrading and the brine could drain at any future date. Understandably, this situation had discouraged redevelopment despite commercial pressures to do so. Under a government land stabilisation programme, a £28 million scheme that involved replacement of the brine with a grout consisting of mainly pulverised fuel ash was implemented between 2004 and 2007. This approach could only be justified where land values are high.

This contribution documents the issues relating to the recognition of subsidence landforms at Arclid Green (SJ 786612) just over 2 km east of the centre of Sandbach (Fig. 2). An investigation of the subsidence geomorphology contributed to the successful establishment and operation of a major silica sand

Figure 1. *Collapsed buildings in Northwich when wild brine pumping was at its zenith a hundred years ago.*

quarry, producing sands for foundry moulding and for making fibre glass insulation. As the new quarry expanded, it exposed pre-LGM sand sequences deformed by salt subsidence, features hitherto unique in Cheshire. Furthermore the distinctive stratigraphy provides constraint on the age of this process.

Bedrock geology

Within the tectonically controlled Cheshire Basin rift system, is preserved a fill over 4.5 km of Permo-Triassic red bed sediments and locally Jurassic marine strata (Plant *et al.,* 1999). Below the aerially restricted Penarth Group, the uppermost part of this sequence constitutes the argillaceous red-bed Mercia Mudstone Group (formerly named the Keuper Marl) and this is now classified into seven formations (Wilson, 1993). The group is interpreted as the product of sedimentation in a playa and tidal flat environment, and includes major halite formations and anhydrite and gypsum-rich horizons. The regional key to unravelling the pattern of concealed subsurface crops of the Mercia Mudstone came with the boring in 1959-60 of a deep cored borehole at Wilkesley (SJ 629414). Some 16 km

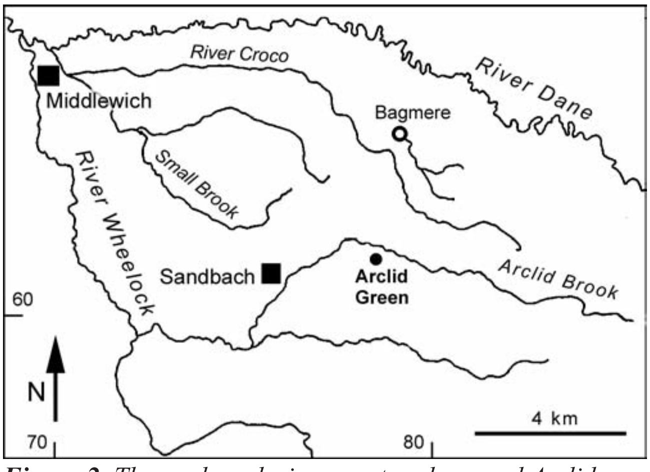

Figure 2. *The modern drainage network around Arclid.*

SSW of Crewe, this was located on a Lias outlier occupying the basin centre. Previously it was assumed that there was just a single major rock salt bed in Cheshire, but the Wilkesley cores revealed that two separate substantial saliferous units occur within the Mercia Mudstone. The estimated proven reserves of rock salt doubled following this discovery and are now thought to be some 117 km^3. Later, following the proposals of Warrington *et al.* (1980), these horizons became known as the Northwich (Lower Keuper Saliferous Beds) and Wilkesley Halite Formations (Upper Saliferous Beds). The highest three formations of the group, were named the Wych Mudstone, Wilkesley Halite and the Brooks Mill Mudstone by Wilson (1993), and are relevant to the Arclid area.

Brines and subsidence geomorphology

Although industrially-induced subsidence has tended to dominate attention, there remains the fundamental geological process of saliferous beds interacting with a zone of ground water circulation on a geological timescale. Indeed globally, mobile groundwater interacts with rock salt, has undoubtedly been active through at least the Phanerozoic and continues at the present time. The saline ground waters so produced, ultimately feed natural brine springs which are normally located at the level of the contemporary river floodplain. In the eastern Cheshire Plain, natural rock salt dissolution has probably contributed to overall land surface lowering from before the Quaternary and of course this activity continues today. The earliest known written record of natural subsidence is attributed to John Leland, the pioneer Tudor antiquary, who in 1533 reported on 'a sinking as having occurred near Combemere [SJ 590446, 5 km NW of Wilkesley], and the formation of a pit containing salt water'- quoted by Calvert (1915). During the period of extensive industrial brine abstraction, the natural cycle of brine creation was masked, but this century it has largely reverted to its former relatively low rate. An analysis by Earp and Taylor (1986), in the Chester and Winsford Geological Survey memoir, presents an excellent overview of the topic along with a discussion of the problems which confront the field geologist.

The first comprehensive insight into the relationships between a rock salt bed outcrop and allied subsidence was given by Taylor *et al.* (1963) in the Geological Survey Memoir describing the Stockport and Knutsford region and Evans (1970). They emphasised that in the humid British climate, rock salt cannot crop out in the normal way because of its very extreme solubility. By weight, the solubility of rock salt is 35.5%, making it 7500 times more soluble than limestone. Hence, the rock salt beds necessarily lie at depth, with their upper terminations characterised by undulating surfaces, occasionally with entrenched channels (Fig. 4). In an equilibrium state, this surface corresponds to a front determined by the lower limit of groundwater circulation; above a thin zone of saturated

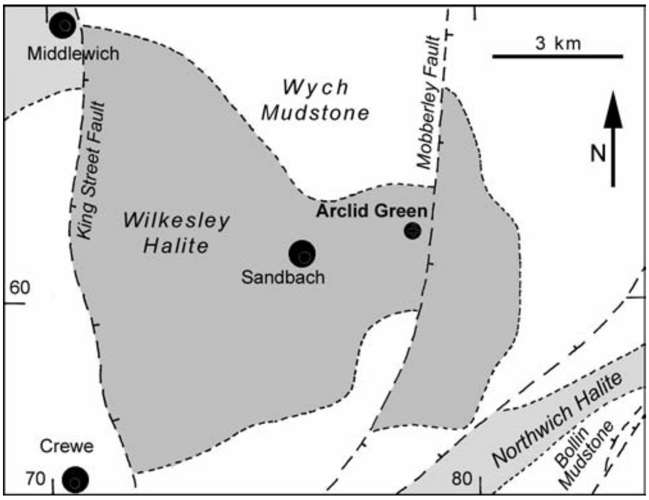

Figure 3*. Bedrock geology of the region around Arclid (after British Geological Survey).*

brine, the rock salt has been taken into solution. The front, the upper surface of the rock salt, is referred to as the 'wet rockhead' and this is overlain by a zone, which can vary between 65 and 160 m thick, of a dissolution breccia of mudstone. This comprises a residual unit of broken and collapsed material that typically is brecciated and permeable. It is derived from non-soluble sediments that originally overlay or were components of the halite formations. Some brine filled cavities are present, especially towards the base of the breccia. Technically the collapsed unit should be regarded as a superficial deposit as the material is no longer *in situ*.

Usually the rock salt bed and confining mudstones have a dip, and this factor has an important bearing on the aerial extent of active subsidence processes. The relationship is best illustrated by a sketch cross section (Fig. 4), which demonstrates that where a younger *in situ* impermeable mudstone formation is present, the uppermost rock salt is beyond the reach of circulating ground water. This is designated a 'dry rockhead', though it is not true rockhead as it is not overlain by unconsolidated surficial sediments. Thus the dry rockhead of the Wilkesley Halite corresponds to the base of the undisturbed Brooks Mill Mudstone.

Industrial pumping of the saline ground water within the collapsed zone, has lead to the development of a local 'brine run', effectively a concentrated flow of brine along the top of the wet rockhead, and this converges upon the abstraction point. In turn, this artificially enforced brine flow leads to fresh water entering the system from the surface to replace the pre-existing brine. Inevitably, the introduction of fresh water triggers the aggressive dissolution of the wet rock salt head and attendant enlargement of the 'brine run'. Following progressive reduction in the strength of the bridging roof material, collapse ensues, and subsequently this extends upwards through the breccia to cause linear subsidence at the land surface. These 'brine runs' commonly follow the strike of the halite and can be traced from the brine abstraction point outwards for at least 8 km. It is likely that some tributary runs develop without any surface expression, but these invariably have their upstream ends where surface water is able to enter the system. They result in areas of enhanced dissolution expressed at the surface by a circular collapsing landform or doline subsidence.

The Arclid area geology

The regional relief and drainage is shown in Figure 2. Around Arclid the general altitude is around 75 m OD. Arclid Brook rises below the ridge forming Congleton Edge and flows WNW for 7 km to Arclid, where it turns SW through Sandbach for a further 4 km, to join the River Wheelock, which in turn joins the River Dane at Middlewich about 9 km NW of the study area.

The Arclid vicinity was re-mapped by Wyndham Evans of the British Geological Survey in 1957 during the revision of the Macclesfield One-inch sheet 110 (Evans *et al.,* 1968). The bedrock was assigned to the basal Wilkesley Halite ('Upper Keuper Saliferous Bed'), and this formation, with a conjectural thickness of around 100 m, was inferred to form part of a westward plunging shallow syncline. Beneath is the Wych Mudstone Formation. The sequence was thought to form a block some 8 km wide sited between the roughly north-south trending King Street and Mobberley faults, both of which are major antithetic faults downthrowing to the east, contra to the major extensional growth faults. With a cumulative normal throw of over 4000 m, these faults of the Wem, Bridgemere and Red Rock Systems define the eastern limits to the Cheshire asymmetrical half graben. Evans invoked the presence of saliferous beds immediately beneath the superficial sediments seeing these reflected in the geomorphology. Taxmere, a small lake

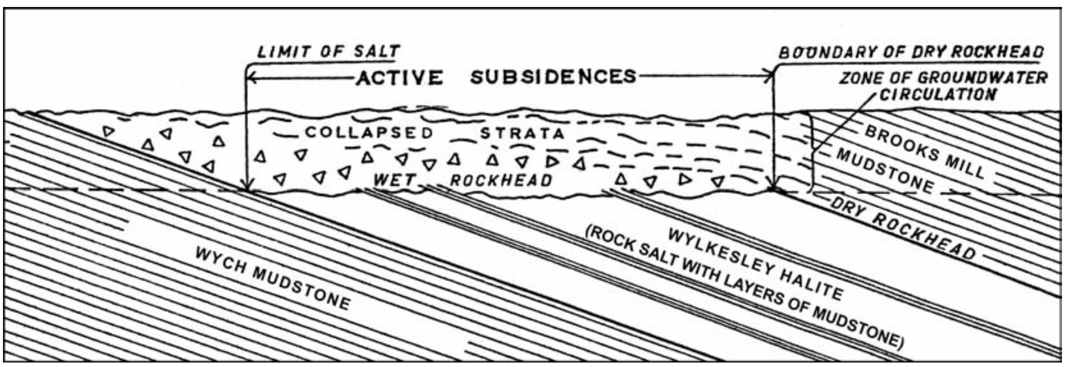

Figure 4*. Diagrammatic representation of the relationships of a dipping salt bed to the salt sub-crop with zones described as dry and wet rockhead (after Taylor et al., 1963).*

occupying a hollow just beyond the old Arclid quarry limits was interpreted as a likely crater-type (non linear) salt subsidence.

The immediate area is underlain by unusually thick Quaternary sediments, with a formal lithostratigraphy following Worsley (1999). The cap unit, the glacigenic Stockport Formation, consists of thin patchy sands over an extensive till sheet with fluvioglacial sand lenses, giving a maximum thickness of some 12 m. The shallow valley of the Arclid Brook cuts through the glacigenic cover sequences where it forms the southern boundary of the old quarry. On its floodplain several boreholes were sunk by Sandbach Urban District Council c1940 around SJ779621. These revealed over 20 m of a sand dominated sequence significantly forming a **fresh** water aquifer. This potable water was abstracted for use by the local community (from 1946 the local Water Board) until the boreholes were abandoned in 1963, after which Bathgate Silica Sands commenced quarrying on the adjacent land. The initial quarry exposures (above the water table) showed that beneath a thin till, up to several metres of sands rich in comminuted coal and northerly derived gravel erratic clasts, lay unconformably on sands which were deficient in the 'glacial' clast lithologies and clearly not sourced by glacier meltwaters. These lower sands were assigned to the Chelford Sands Formation (Worsley, 1966), later called Chelford Formation, and this includes the Congleton Sands (Middle Sands) (Evans *et al.,* 1968). A decade later, as the quarry expanded, there was a change from dry to wet sand extraction in order to work the full thickness of the sands below the ground water table. This was achieved by suction dredging from a pontoon floating on an ever extending lagoon. Careful washing of the raw sand was necessary since the deeper (unseen) sands included the Arclid Member, a sequence consisting of beds of organic deposits, including fragmentary sub-fossil wood and peat clasts, both of Quaternary aspect.

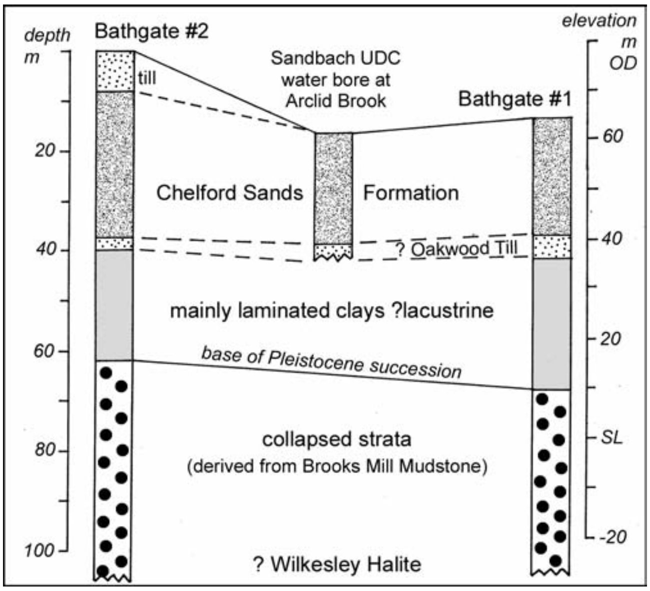

***Figure 5**. Logs of the Bathgate A and B boreholes.*

Subsequently, several radiocarbon age estimate assays on the sub-fossil organics were undertaken. These were discussed by Worsley (1980), who concluded that they had an age beyond the limits of that dating technique. Also, from a depth of at least 27 m, the pump picked-up a mammoth tooth with organic mud embedded in the cavities and from the latter a pollen spectra was extracted. This was identified and interpreted by Michael Keith-Lucas as being of probable Last Interglacial (Ipswichian) character, (Worsley, 1992). It may be part of the Arclid Member.

The predicted presence by the Geological Survey of the Wilkesley Halite beneath the Arclid quarry led to concerns by Cheshire County Council over possible problems arising from the reactivation of rock salt dissolution by escaping lagoon water. Since both planning permission for expansion of the site and a switch from dry to wet working were dependent upon these fears being allayed, two specially commissioned deep boreholes were sunk for the quarry company in 1971 some 400 m apart. These yielded an unexpected insight into the deeper Quaternary geology.

Bathgate No 1 (107 m deep) was located on the floodplain of the Arclid Brook immediately W of Near Arclid Bridge close to the A534 road (SJ783619). It penetrated 48 m of superficial sediments, and terminated at a depth of 59 m in collapsed debris derived from the Triassic bedrock. Unfortunately, coring only commenced at a depth of 24.3 m, i.e. within a basal till unit. Above that depth, the log is based on the examination of samples in the bentonite drilling fluid collected at 1.5 m intervals. In contrast Bathgate No 2, located 500 m NNW of Arclid church (SJ774620), was close to the lagoon within the active quarry. When this borehole was sunk the overburden had yet to be stripped, and hence it first had to penetrate the Stockport Formation. In all 62.2 m of Quaternary deposits were proved and below the unconformity, 62 m of collapsed mudstone breccia were proven before drilling was terminated. In Plant *et al.* (1999), reference is made to the source of a sample of Wilkesley Halite used in their Cheshire Basin study as being from an Arclid Bridge No 2 borehole. Its location is identical to that of Bathgate No 2, and it is known that the British Geological Survey examined the cores. Also the writer saw several halite cores at the quarry. This suggests that the top of the Wilkesley Halite was proven. Logs of these boreholes are shown in Figure 5.

Bathgate No 1 is closest to the centre of the Arclid Green study site, lying 800 m to the NW. Hence its findings are the most relevant here. Silica sands of the Chelford Formation are 24.4 m thick, and surprisingly are underlain by a further 23.7 m of unlithified sediments (Fig. 4). This lower succession comprised – (i) 3.7 m of till (? Oakwood Formation), (ii) 3.4 m laminated clays with silty/sandy partings, (iii) 11.3 m silty sands, and finally (iv) 5.4 m of laminated clay, sand and clay above the unconformity marking the top of the collapsed Triassic mudstones. Prior to drilling, the confirmed presence of glacigenic sediments below the Chelford Formation in Cheshire had been somewhat enigmatic, as in the Burland borehole succession (Worsley, 1970; Bonny *et al.,* 1986), but the new borehole revealed unambiguous evidence for an earlier glaciation in eastern Cheshire, although its precise age was indeterminate. A similar till was later seen at outcrop in the Oakwood quarry at Chelford (Worsley *et al.,* 1983). The presence of the unsuspected glacigenic sequence adds to the minimum total thickness of strata above the Wilkesley Halite. This, along with the collapsed mudstone breccia, gives a combined thickness of some 80 m.

Subsidence at Arclid Green

With the approaching exhaustion of the old Arclid Quarry, a Chelford Formation silica sand resource beneath Arclid Green and Hall Farms some 1 km south east was proposed for development in order to supply fluidised sand by pipeline to the existing processing plant. The terrain at this new prospect possessed a much greater relief than the original Arclid Quarry site, and, being adjacent to the buildings of two working farms, there were sensitive environmental issues to be addressed. To minimise the impact, the proposed quarry design capitalised on the presence of a surface depression with a floor some 15 m below the average surface level in the vicinity. This had a plan form like a golf club head, consisting of an oval hollow and associated elongate trough occupying the eastern and southern parts of the site (Fig. 6). The depression afforded the possibility of both screening the overburden storage area from the adjacent land, and

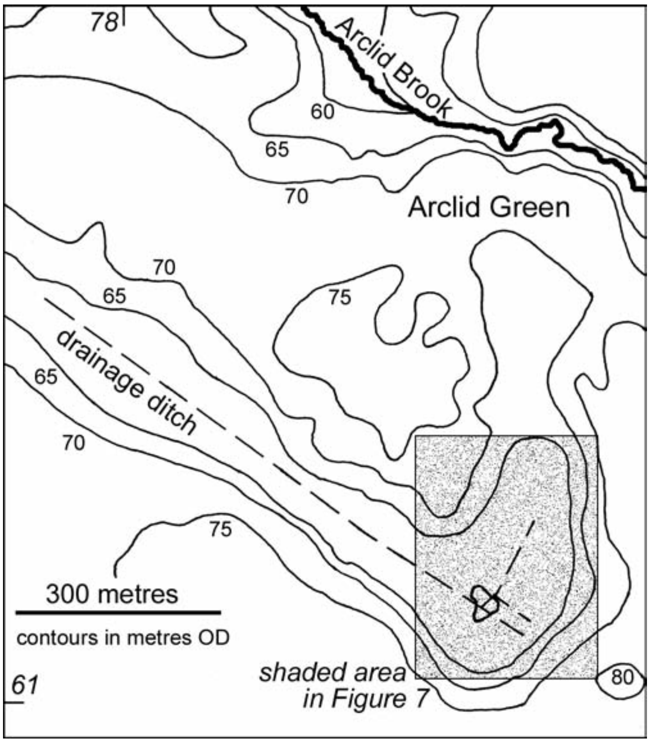

***Figure 6**. The Arclid Green study area with contours at 5 m intervals prior to sand quarrying activity. The peat margin on the valley floor extended to the 63 m contour*

later after restoration, reclaiming what had before been poorly drained areas for agricultural use.

A field investigation by the writer focussed on the nature and origin of the depressed area with special reference to any infill deposits. In view of the regional geology, particular attention was paid to possible indicators of salt dissolution subsidence and the extent of any low strength materials, e.g. peat, that might have accumulated, as it was proposed to infill the depressed area with quarry overburden derived from the stripped Stockport Formation capping.

The area formed part of the Arclid Brook catchment, but had no direct surface drainage connection with the brook. An artificial ditch system was present and this drained very sluggishly into an enclosed boggy area at the NW end. The 1:25,000 OS sheet SJ76, from 1960, revealed a closed 200-foot contour defining the lowest part of the depression at this location. The later (1979) 1:10,000 map SJ76SE, with metric contours at 5 m intervals, by chance fails to pick up the area of internal drainage. Another topographic low defined by a closed 61 m contour corresponded to the centre depressed feature. Thus, any excess water had to drain laterally through the subsurface sands as part of the local ground water flow. Active subsidence hollows are commonly marked by subsidence steps, simulating normal faults, and typically are some 1 m high. None was observed on the slopes at Arclid Green and this suggested that the area was currently stable.

Hand augering established that the floor of the area with internal drainage was underlain by peat. The 3-D geometry of the peat body was determined by augering along two levelled transects, NE-SW and SE-NW along the depression's main axes, supplemented by several other borings. Both Holman and Hiller hand-operated borers were used and these proved a maximum peat thickness of just under 16 m (mapped by 2 m isopachytes in Figure 7). It was estimated that there was some 300,000 m^3 of peat in the main hollow. In addition, two cased shell-and-auger holes were sunk and reasonably continuous cores were obtained.

The morphology of the hollow did not confirm or deny salt subsidence as the cause of the depression and its possible origin as a kettle hole feature could not initially be eliminated. Clearly the internal nature of the drainage was consistent with subsidence process having been active at the site in the past. Examination of the peat stratigraphy, in cores taken from within the main hollow, showed a very abrupt change in sediment character at the base and the presence of woody material low in the succession. In the absence of a classic tripartite late glacial succession of organic-rich/sterile/organic-rich sediments, the probability was that the peat was Flandrian in age. Over a decade later, when the peat fill of the linear trough was excavated during quarrying, the base of the peat was seen to encase Alder tree stumps in position of life, and this strongly suggested that a woodland had abruptly become flooded, again consistent with a post-glacial

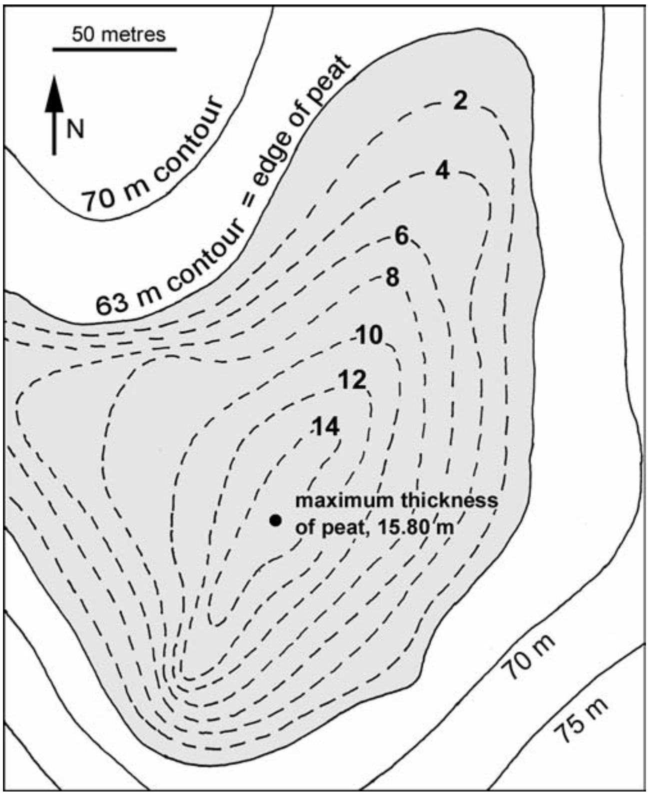

***Figure** 7. Limits of the main peat body within the Arclid depression. The 63 m contour approximated to the margin, but the peat surface formed a low dish with a surface low of 60.9 m OD. Peat isopachytes are drawn at 2 m intervals. Note the site of maximum peat depth of almost 16 m.*

age. After the hollow itself had been infilled by quarry overburden, exposures were subsequently created by quarrying through the marginal parts of the main hollow peat infill. Again the transition from the sands beneath to the peat above was fairly abrupt consistent with subsidence having commenced in the Flandrian rather than at the start of the Late Glacial. Furthermore, it could be seen that the original hollow form was not restricted to the glacigenic succession, since the basal Stockport Formation unconformity lay at a significantly higher level than the deeper parts of the peat infill. Finally, excellent exposures were created during dry extraction of the main sand body, revealed that the Chelford Formation (with included organic beds) and the till beneath were cambered at 22º directly towards the axis of the linear valley trough (Fig. 8). The till surface formed the working floor of the quarry. Together, these factors support the contention that the depression is a subsidence landform due to rock salt dissolution, rather than ice meltout. Otherwise it would have to be rather implausibly argued that a detached mass of glacier ice had somehow been intruded into the Chelford Sands prior to meltout and kettle hole formation.

Role of glacial processes

Progressive subsidence has occurred over significant timescales and given the presence of halite at depth, it is likely that this process has some role in the enhanced accumulation of the Chelford Formation sands at the locality. However, the rate of dissolution will also have been influenced by the changing climatic environmental conditions. For instance, under the influence of meltwater drainage during glaciation it may have accelerated, while in contrast, if permafrost was present it was probably retarded if not static. The sub-superficial (drift) surface in the Cheshire Lowlands is complicated by a network of deeply incised channels, many of which appear to have undulating thalwegs and must have functioned as subglacial meltwater drainage systems (Howell, 1973; Howell & Jenkins, 1977). It should be noted that there is no way of determining whether these channels operated synchronously as an integrated system. At least parts of them may be inherited from earlier glaciations. Their incision is likely to have been rapid, and it cannot be assumed that glacial meltwaters did not directly erode the halite in places. Within these channels, thick variable sequences of porous sediment subsequently aggraded to later form conduits exploited by ground water flow. These circulating ground waters were probably saline, and flows were possibly increased when sea level was low during the cold stages.

A steep sided channel with a valley fill 102 m thick at Ettiley Heath (5 km WNW of Arclid) has been ascribed by Evans *et al.* (1968) to a 'glacial period of low sea level' by sub-glacial meltwater erosion (i.e. a tunnel valley). A drawn section following the base of the channel long profile has an average level of -50 m OD, and appears to be almost coincident with the wet rockhead above the Wilkesley Halite. This suggests that the expected cover of collapsed strata must have been largely eroded prior to aggradation. It was thought that this channel was traceable southwards (Rees & Wilson, 1998, with a rockhead map). It is stated that the buried channel base is at c52 m OD east

***Figure 8**. Working face in the new quarry showing the stratification in the Chelford Sand Formation dipping south towards the axis of the linear subsidence zone at 22º. Superficially this deformation looks like distal Gilbert-type deltaic cross bedding. The unconformity with the Stockport Formation lies at the stripped surface at the top of the face.*

of Crewe but has an undulating long profile. They also document pre-Late Devensian organic deposits within a complex sequence including several tills proved in boreholes at Stowford on the north side of the A5020 bridge over the Alsager-Crewe railway line (SJ735533), 4 km west of the M6, and demonstrate that at least part of the valley existed long before the Devensian. There is a possibility that the low rockhead surface below Arclid might link into this feature.

An additional factor is the role of the fluvial erosional system which presumably was initiated immediately after deglaciation. The outer part of the Arclid Brook catchment lies beyond the area with the halite sub-crop and the stream network as a whole appears unmodified as it extends across the halite zone. Progressive natural salt dissolution may have influenced the rate of down cutting but there is little evidence to suggest any major change of the stream pattern. The Arclid Green 'valley' may well have originated as a 'normal' tributary to the Arclid Brook, but later, progressive, linear subsidence, perhaps with crater subsidences, led to it being modified into its present form where the surface flow in the upper part of the tributary is reversed and the lower part is effectively abandoned. At Bagmere the local drainage shows an area of inward flow unconnected at the surface to the regional river network (Fig. 2).

Less than 5 km to the west, the area between Sandbach and Elworth has subsided as a result of extensive wild brine pumping that extended over several centuries (Fig. 9). Though extraction has ceased for the last 30 years, the question of whether any of the linear subsidences associated with brine runs extending into the Arclid area (Fig. 10) were accentuated in the historical period remains unresolved because of a lack of clear evidence.

Palaeoecological investigations in Cheshire

That natural salt subsidence has been responsible for enclosed hollows formed in antiquity has been considered by some ecologists who have investigated the nature and origin of some of the Cheshire meres and peat mosses. A particularly good example is Wybunbury Moss at SJ697503 (Poore & Walker, 1958; Green & Pearson, 1977), where the adjacent parish church became so unstable that it had to be demolished apart from a buttressed tower. The subsidence feature at Wybunbury is dimensionally similar to that at Arclid Green but differs in that it has a central surface mire floating on a pond occupying a steep-sided basin some 15 m deep. In contrast, Birks (1965), favoured a kettle hole origin for Bagmere (SJ793643) where the fill exceeds 13 m, 'because of the relatively steep sides and the nature of the [sand and silt] minerogenic sediments'. Yet now appears that Bagmere, like Wybunbury Moss, is underlain by the Wilkesley Halite, increasing the probability that both are geomorphological expressions of subsidence that is related to dissolution of rock salt.

Figure 9. *Houses in Sandbach affected by salt subsidence related to brine pumping from the wet rockhead on the Wilkesley Halite beneath 20 m of Quaternary sediments.*

Subsidence at Upton Warren

Coincidentally, an earlier example of an important Quaternary fluvial succession having been affected by salt subsidence has been documented at the classic Upton Warren Interstadial type locality in Worcestershire (Coope *et al.,* 1961). This interstadial is conventionally regarded as being of mid Devensian age. In 1955, sagging of organic beds (Upton Warren Bed) by some 3 m was evident in the basal part of a gravel sequence c10 m thick beneath a low terrace of the River Salwarpe, a tributary of the River Severn. The deformation was attributed to salt subsidence, since a then-active saltworks lay within 1 km of the quarry at Stoke Prior. Mining of rock salt commenced in 1828, but soon the workings became flooded by an underground brine stream. Salt extraction then switched to wild brine pumping and continued until 1972. Judging by relationships on the levelled drawn section in their Figure 1, this subsidence may be at least in part syndepositional, and hence due to natural dissolution. Coope *et al.* also drew attention to a 'large subsidence with a lake' close to the Salwarpe near 'the Moors', although Poole and Williams (1980) later cast doubt on this interpretation of the lake, since a nearby

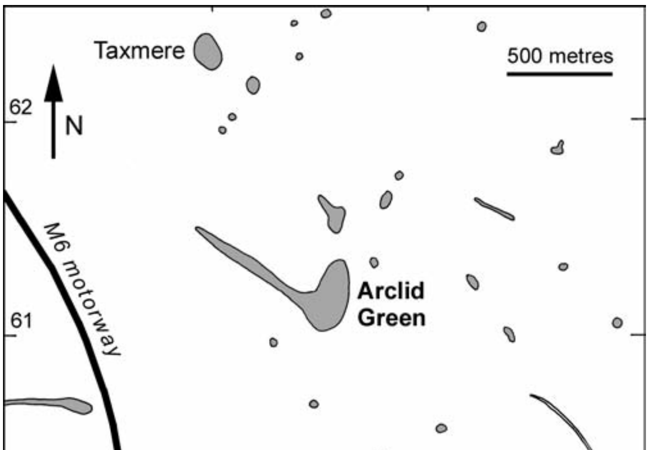

Figure 10. *Probable salt subsidence features in the Arclid area (in part from a British Geological Survey data base).*

borehole failed to prove any rock salt beds. What is certain is that Upton Warren lies beyond the LGM ice limit and hence the direct influence of Devensian glaciation. It spans a much shorter time period and as such the setting is not directly comparable to Arclid.

Conclusions

We may conclude the Arclid area surface morphology is consistent with the Triassic Wilkesley Halite forming the bedrock of the area. The depressed landform at Arclid Green appears to be primarily a product of natural Flandrian subsidence linked to dissolution at the wet rockhead at the top of the halite. Removal of the rock salt at this horizon must have removed support from the overlying mudstones that brecciated and collapsed. This appears to have been transmitted through the Pleistocene glacigenic Late Devensian Stockport Formation, the Chelford Formation and earlier glacigenic sediments. More generally, since the thick silica sands of the Chelford Formation appear to be preferentially preserved around Arclid, this suggests that dissolutional subsidence has been operative episodically at least through part of the middle Pleistocene and the Upper Pleistocene. It is considered that buried Late Devensian ice meltout, which could have produced a kettle hole, is unlikely to have directly influenced the present day geomorphology.

Acknowledgements

A long term interest in the geomorphology of rock salt dissolution was stimulated by my participation in a Meres and Mires conference organised by the Nature Conservancy in 1965 (Oswald & Herbert 1966). Without the full co-operation and financial assistance of Bathgate Silica Sands and particularly the help of the late Chairman and Managing Director T.E. Curley, Director Roderick Walker and late Director and Quarry manager Cyril Davies, this study would not have been possible. Enthusiastic field assistance was given by Jackie Bath, Clair Blatchford, Susan Creak, and Jane Hart. I thank Tony Cooper, Ian Fenwick and Tony Waltham for helpful reviews and Tony Cooper, the late Wyndham Evans and Jack Taylor; David Thompson and Albert Wilson for sharing their evolving understanding of the English Permo-Triassic over many years.

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The Big Hole of Starkholmes

John Jones

Abstract: A major ground collapse at Starkholmes, near Matlock, was caused by inappropriate site development over old mine workings.

East of the River Derwent, and almost above Matlock Bath railway station, the village of Starkholmes stands on a steep hillside of shale overlying Carboniferous Limestone that is penetrated by the Riber Mine.

Riber Mine

In 1950, when the price of lead was at a high, the Johannesburg Consolidated Investment Company came to Derbyshire in the general belief that major new ore deposits could be found where the "old man" (the miners of yesteryear) could not go due to the shortcomings of their equipment and the knowledge they had at their disposal in the 18th and 19th centuries. Matlock Bath was the chosen target site, and inclined exploration boreholes were drilled to intersect the rakes and veins lying on both sides of the River Derwent. All the drilling into veins to the west failed to find ore, as the "old man" had been there first.

But drilling in the east was more promising, where many veins are associated with the Great Rake along its length. Three inclined boreholes were drilled towards the south to intersect a rake length of 200 m, and all three were successful (Fig. 1). A major vein was encountered, at one place with 1.2 m of galena within a thicker calcite vein. The other two boreholes found sphalerite, also with galena values, and again in a calcite vein 2 m wide. The drilling programme seemed to indicate reserves of 60,000 tonnes of ore with a combined lead and zinc content of 8%, all lying below the level of the Derwent. This more than justified the cost of opening a new mine (Varvill, 1959; Greenough, 1967; Ford, 2002).

Underground work began early in 1952, and Riber Mine was born. An inclined drift, 3 m wide and 2.5 m high, was driven from below Starkholmes village, northeastwards towards Riber for a distance of 275 m. Starting at 149 m OD, this descended on a gradient of 1 in 3.5, to reach a level of 67 m on the vein (Fig. 2). It was then found that the 1.2 m rib of galena intersected by the drilling was only a pillar left by the "old man". If the borehole had deflected by a fraction of a degree either side, the Riber Mine would never have been developed. However, the Johannesburg Company carried on working the mine until April 1956, when Derbyshire Stone took over and worked the mine until closure in 1959.

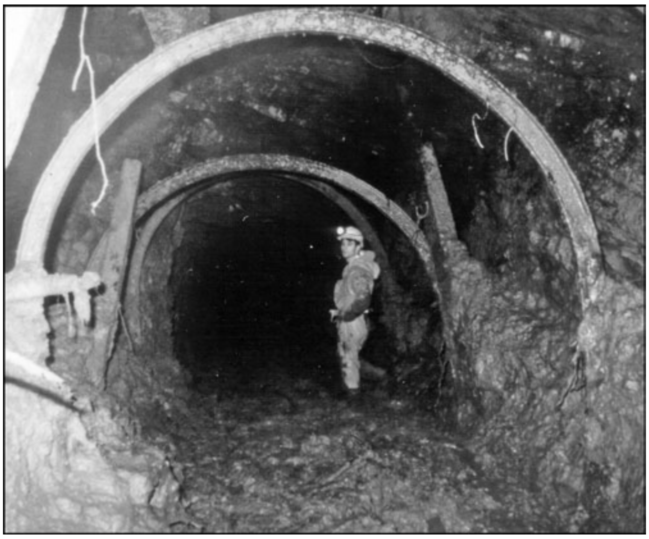

Figure 2. The Riber Mine inclined drift, with steel arch roof supports at critical points (photo: Paul Barsby).

In 1987 the land around the drift portal was sold to a building company for housing development, and one plot immediately above the inclined drift was given away free of charge as an extension to an existing

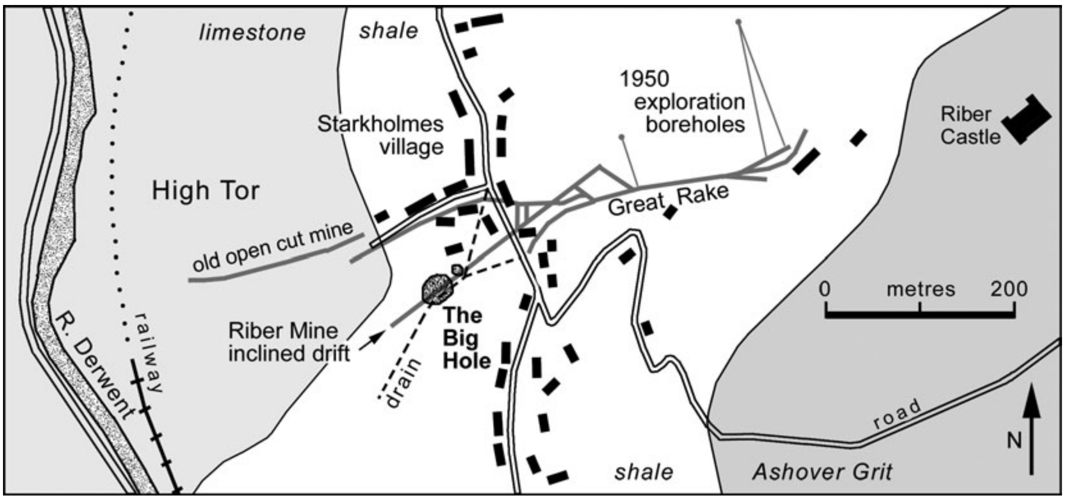

***Figure 1.** Main features of the mines and geology around the Big Hole at Starkholmes.*

Figure 3. The Big Hole on October 23rd.

garden. Early in 1989, the new owner dumped quarry waste on to his garden extension, without planning permission and without knowledge of what lay below the ground. Later that year, and having been granted retrospective planning permission, he landscaped the site using 6000 tonnes of landfill. However, he had unknowingly crushed a clay drainpipe that extended beneath his plot, and crossed above the inclined drift. This culvert took stormwater from the road through the village, down towards the River Derwent.

Ground collapse

Some three years later, in 1992, it began raining in August, and continued almost unabated through September and into October. During the night of October 16, a hole appeared in the beautifully manicured lawn (Fig. 3). It was not very big, just an inverted conical shape about 10 m in diameter. But the rain kept falling, and by October 23 the new sinkhole had grown to 20 m diameter and 15 m deep. An open hole lay at the bottom, where the roof of the drift had collapsed under the additional load of the landfill when weakened by water from the now-inoperative culvert. The sides of the sinkhole continued to flare out by repeated slumping, as huge volumes of landfill fast disappeared down into the mine. By November 10, the Big Hole had extended to an area 30 m by 20 m, and it was full of water (Fig. 4).

Figure 4. The Big Hole when it had filled with water on November 10th (photo: Paul Barsby).

Figure 5. The Big Hole on November 11th, with the broken electric cable visible after the water had drained out.

During the evening of November 11, the water all disappeared. At the same time, the lights went out in Starkholmes and Matlock Bath. It appears that the water had been held back by a temporary blockage within the inclined drift. When this had failed, the water rushed down in a giant whirlpool. And this had scoured the unstable sides of the sinkhole, with yet more slumping of the newly saturated landfill. The whole process carried away and broke an 11,000 volt electricity cable. However, the water had not travelled far down the incline. It was stopped by another choke, where tonnes of mud and debris were caught within the drift only a short distance down from the open sinkhole, but out of sight.

At 11 o'clock the following morning, a site meeting was called with representatives from Severn Trent Water, East Midlands Electricity, the local council, the county council, Tarmac (who had become the last owners of the mine by their takeover of Derbyshire Stone) and the Wirksworth Mines Research Group. All were gathered round the rim of the Big Hole, staring at the severed 11,000 volt cable that was hanging down its side (Fig. 5). All was peaceful, and it had even stopped raining.

Figure 6. The second hole, on the collapsed mine shaft

Suddenly, from behind and in the direction of the house, there was an enormous roar, and a fountain of water, soil and stones erupted 15 m high into the air. Muddy water and debris rained down on to the assembled party, and everyone ran for his life. A second hole had appeared in the sloping lawn. This one was only about 4 m across (Fig. 6), but it was a full 30 m deep. It lay northeast of the Big Hole, and was only a few metres from the landowner's house.

The water in the incline had penetrated and liquefied the mud that had been holding it, so that it could again pour down the inclined drift. This new debris flow of mud and water had then collided w four massive steel ring arches that were lining the drift.

Figure 8. Setting off down the drift, from the foot of the Big Hole, to find the cause of the second ground collapse.

These had been placed by the drift miners where they had intersected a shaft left behind by the earlier lead miners; just a metre in diameter, this shaft had since lain hidden above the ring arches. The same steel arches stopped the progress of the saturated debris flow and water down the drift; but this now had a partial escape route up the old shaft. The pressure of water, air and debris arriving at the blockage in the drift, blew upwards the loose fill within the old shaft.

It then blew out the top of the shaft that had been hidden under the lawn beside the house. What was a metre-square shaft down below expanded to a hole some 4 m across in the lawn. At first this new hole, and the shaft, were full of water, but this soon drained down, as mud, debris and water found their way onwards down the inclined drift.

Figure 7. Multiple land slips progressively enlarge the Big Hole, until its rim approaches the driveway off to the left; the second collapsed hole is visible beyond the main hole and beside the large tree.

Figure 9. The first stage of the new shaft on top of the new access chamber into the drift (photo: Paul Barsby).

A week later, the house owner's insurance company advised him to move all his furniture out if the hole came any closer - advice that was neither helpful nor innovative. But a temporary equilibrium appears to have been reached in the Big Hole, in its underlying drift and in the adjacent old shaft.

So work began on January 15, 1993, to build a concrete access chamber that enclosed the collapsed section of drift. This used 46 cubic metres of concrete, and was topped by an access shaft built upwards with concrete rings (Fig. 9). The shaft reached 12 m high as it was enclosed within the estimated 250 cubic metres of earth poured in to completely fill the crater. The project was completed on February 26 (Fig. 11), when the new access shaft was topped off with a steel lid. The second, smaller, sinkhole and its old mine shaft had also been backfilled.

The bad news was that the entire cost was carried by the house owner; the current mine owners could not be held responsible, as the collapse was essentially self-inflicted. A major ground failure had become almost inevitable when the landfill was dumped on the site and impeded sound drainage by collapsing the active culvert.

Figure 10. Beginnings of the new shaft and the new drains within the Big Hole before backfilling (photo: Paul Barsby).

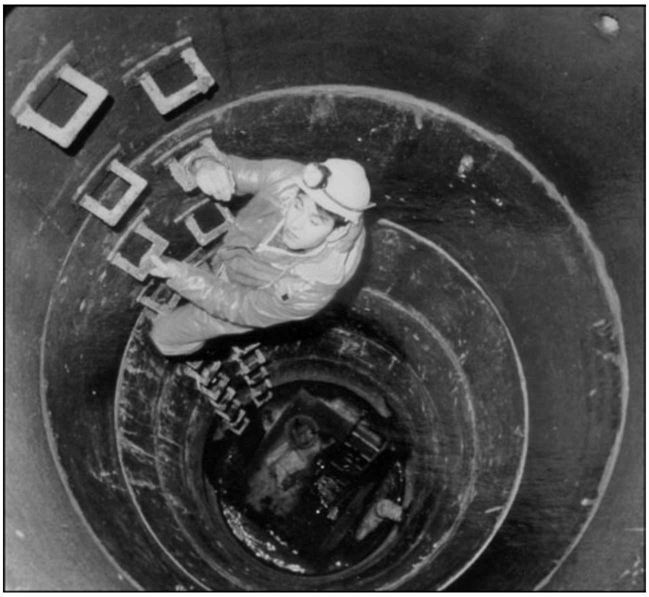

Figure 11. Climbing the new shaft (photo: Paul Barsby).

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Thanks to members of the Wirksworth Mines Research Group in 1992-3, especially Paul Barsby, Ray Legge, David Barsby, Roy Paulson and Albert Warsop. Not forgetting the house owner, for getting us involved.

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The old Allotment Shaft, lay almost directly above the Riber Mine, just east of the village road; it had originally reached down to the Coalpit Rake, a branch of the Great Rake, at a level above that of the Riber Mine's much later inclined drift. This shaft had also collapsed, in 1984, when the shaft fill had run in, leaving a surface crater 15 m across. The ground failed after the shaft had long been used as a toilet in the middle of the village allotments; fortunately, the allotments' 'facilities block' was unoccupied when the collapse occurred in the middle of the night.

Formation of St. John's Hill, Gruczno, Poland

Michael J. Czajkowski

Abstract: The lower Vistula valley has provided an important trading route between the Baltic and the interior of Europe since the Neolithic. In antiquity east-west crossing places were few but at Gruczno, where the river was fordable, religious sites were established on hills on opposite sides of the bank. At Gruczno, this developed into a fort on top of St. John's Hill, and then the surrounding settlement seen today grew around it. There has been much discussion about the extent of anthropogenic modification of the hill at Gruczno due to its unusual shape. Investigations have shown that the hill is a natural feature largely formed by fluvial processes, including river capture, with limited anthropogenic intervention.

The Vistulan (Weichselian) ice sheet reached as far south as central Poland. Upon its retreat, a layer of sandy till, 50-100 m thick, covered the area north of the Berlin - Warsaw spillway. Into this, the lower part of the River Vistula has cut a channel, 10-20 m deep and of varying width (3-7 km), forming the present day flood plain, north to the Baltic Sea (Niewiarowski, 1990); the till now forms low plateaus on each side of this wide valley. Adjacent to Gruczno (Fig. 1) the river was fordable and allowed development of an important intersection between an east-west overland trade route and the River Vistula, which formed part of the amber trade route south from the Baltic. Here hill forts were constructed on two hills on the opposite banks. At Gruczno, the hill of St. John developed as a settlement site, down the hill and around the hill fort, and this eventually formed a Christian parish (Cholewscy, 2005). Although the archaeology of the hill was investigated in the early 20th century, the records were destroyed in the war and post-war investigations have concentrated on the hill fort. The unusual shape of St. John's Hill has been a source of discussion as to its formation and the extent of its anthropogenic modification.

St John's Hill

The hill forms a rounded elongated body trending NNE–SSW, decreasing in height from about 75 m a.s.l. at its SSW end down to below 50 m at its NNE end. The northern half has a rounded profile, while its southern end widens with steep slopes on the south-

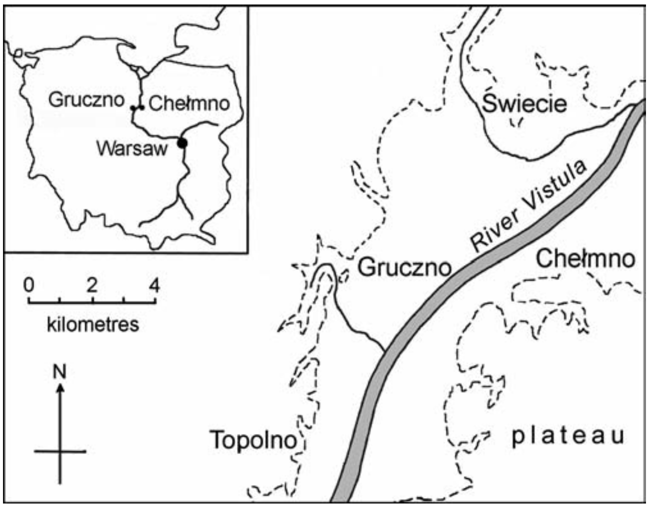

Figure 1. Location of Gruczno in the lower Vistula valley.

Figure 2. St. John's Hill, its hill fort and the village of Gruczno seen from the WNW. Dworcowa Street curves left of the hill and into the main village, while Młynska Street passes in front of the hill and into the wooded glen. The New Quarry had not been dug when this picture was taken. (From Cholewscy, 2005)

west end. The flat top contains a semi-circular structure, enclosing a dished area that was the site of a wooden hill fort, in use until the 12th century (Fig. 2). The steeper slopes are obscured with trees, but there is a strong break of slope between the steeper fort side and the hill slope discernable on Figure 2.

Modern drainage is by a small stream, with tributaries shortened by post-glacial permeability, from the west of Gruczno, with elongation of the drainage basin parallel to the Vistula valley. The main stream flows east-south-east, before turning south around the western side of St. John's Hill, and then southeast across the alluvial fan and into a regulated course across the flood plain to the Vistula (Fig. 7c).

Geological Sections

The Old Quarry to the north of Dworcowa Street (Fig. 3 and Fig 7c) has cliffs exposing sandy till that is typical of the area; it has some evidence of stratification with a series of sandy horizons about 3 m from the base. The top part appears to show poorly sorted sand and gravel lenses, with some evidence of possibly cryoturbated deposits near the top.

The New Quarry at the NW corner of St. John's Hill, at the corner of Dworcowa and Młynska Streets (Fig. 3) is not accessible, due to an uncooperative owner, and is now obscured by buildings. The visible part of the N-S section (Fig. 4), comprises weakly stratified, sandy material. The left (north) part is capped with about a metre of a darker material above a distinct iron horizon. This may represent an anthropogenic deposit since it is thicker and abuts against the thinner soil horizons that are more common in the area. There is an in-filled channel feature, to the right, which may be natural, cutting into material that may have been contorted by natural processes. The return of the quarry face at its southern end, along a roughly W-E line shows near-horizontal stratification of sandy seams in the lower part of the till; these are truncated by the slope of the hill, but the west end is overlain by a thin wedge of slope debris marked by an iron-stained horizon.

On Dworcowa Street, near the New Quarry entrance, sand from excavated fence-post holes contained fragmented root casts (sample GT/PL.3).

A small exposure on the WSW corner of St. John's Hill (Fig. 3), sampled in 1996 (GT/PL.5), showed mid-grey-yellow, bedded sands with pale orange-brown horizons that were gently inclined.

Spring sapping with resulting cliff collapse was seen at Topolno, about 5 km south of Gruczno (Fig. 5). Groundwater flowing through the sandy till bluffs has undermined the cliff, resulting in collapse and cliff retreat. Within the till, sandy horizons, dipping gently to the south (seen as dark lines in Figure 5) probably assisted southerly sub-surface flow due to their higher permeability. Similar horizons are exposed within the till in the Old and New Quarries.

The Sands and their Interpretation

Statistical analysis of grain size distribution can be used, with other evidence, to determine possible origins of sediments. In cumulative frequency diagrams the accumulation of grain sizes, "% coarser", is plotted against the actual grain size measured on probability paper. This format is used because this matches most sediment distribution (Briggs, 1977). The steeper the graph the better sorted the sediment, the extreme being wind blown particles, and the most poorly sorted are usually glacial tills.

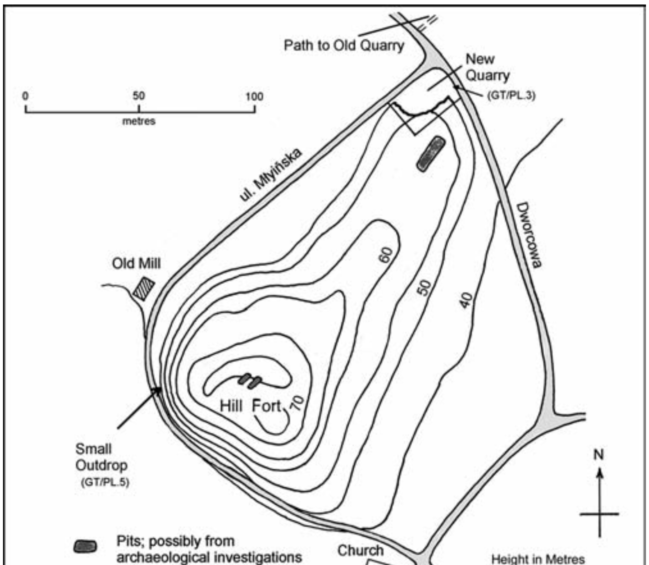

Figure 3. Sketch map of St. Johns Hill. Heights in metres.

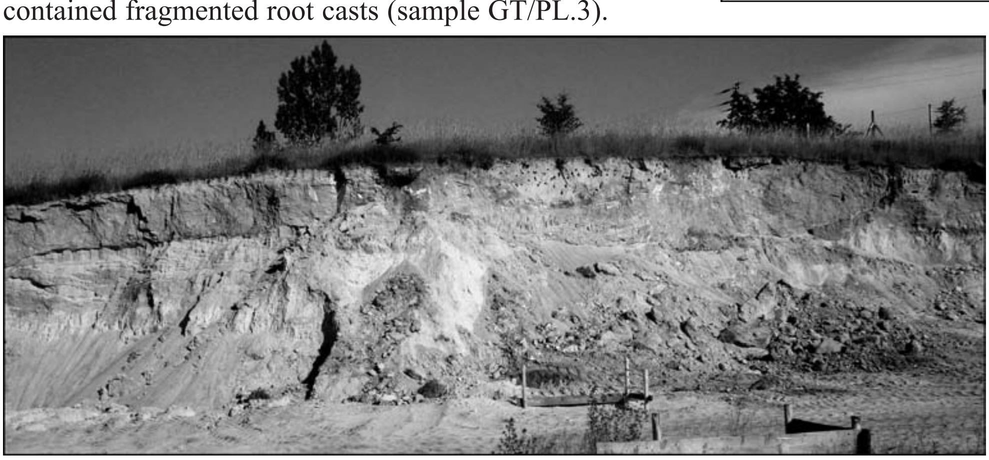

Figure 4. The new quarry N-S section cut into the NW corner of St. John's Hill; North is to the left. The upper dark layer to the left may be anthropogenic, and the channel infill lies to the right

***Figure 5**. Spring sapped bank collapse at Topolno, 1995*

There is some variation in the tills forming this part of the plateau (Fig. 6a). Aspects of this variation have been described elsewhere (Mojski, 1995). Sample GT/PL.1 contained pebbles of limestone which influence the multi-modal frequency distribution curve. Sample GT/PL.4 contained only a trace of limestone. Sample GT/PL.2 showed a slight bimodal frequency distribution, but is well sorted, and GT/PL.3 is similar (Fig. 6b). All the limestone in sample GT/PL.3 was authigenic, associated with the calcified root casts, and was removed prior to grain analysis.

The glaciofluvial nature of the till sample (GT/PL.4) (Fig. 6a), is seen elsewhere, at Topolno. Fluvial interbeds, possibly associated with sub-glacial streams, are distributed widely within the tills of this region. North of Gruczno, outwash terraces and a sandur are described by Drozdowski (1990) and Niewiarowski (1990) respectively.

The multi-modal distribution of GT/PL.2 probably reflects accumulation from variable flows, and its high carbonate content suggests a possible strong input of material from the bluffs to the west which are rich in limestone pebbles (GT/PL.1 in Table 1). The mono-modal distribution of GT/PL.3 suggests a non-variable fluvial deposit within the Dworcowa Valley gap, which later became vegetated.

	Location	*Date*	*Grain analysis*	*Limestone content*	*Origin*
1	Near top of plateau	June 1992	mainly sub-angular. some sub-rounded	pebbles, lmst forms ~60% grains 0.25-0.50mm	mainly glacial
2	Alluvial fan	June 1992	sub-rounded to sub-angular	~50% lmst, grains corroded	fluvial
3	New Quarry NW corner	June 2007	well polished sub-rounded	authigenic casts around rootlets	fluvial
4	Old Quarry	June 2007	sub-angular	trace	glacial or glaciofluvial
5	St. John's Hill SW corner	July 1996	sub-rounded some frosting	none	aeolian

***Table 1**. Sampled sediments, with locations, analyses and deposition modes; sample numbers are prefixed with GT/PL.*

Previous work by Niewiarowski (1990) suggested that the Vistula valley in this area had formed prior to the last glacial stage, possibly within the Older Dryas (Dimlington Glacial) and the Allerød (Windermere) Interstadial periods, though modified in the Younger Dryas (Loch Lomond Stadial). During the Allerød, large amounts of melt-water would have flowed off the bluff sides, and assisted by spring sapping from large amounts of sub-surface water from the sandy tills, supported by permafrost water tables, would have easily carved short channels, forming alluvial fans at their mouths. Many short channels exist to the north near Grudziądz (Drozdowski, 1990).

The village of Gruczno is located on alluvial fans that afforded a relatively dry settlement site. One fan, with Gruczno's church close to its apex, was fed by discharge through the Młyńska Channel, and the other lies below the Dworcowa Channel; each channel is now traced by a street of the same name.

The Dworcowa Channel

The lower gradient off St John's Hill towards the north, and the higher elevation of the Dworcowa gap compared to the Młyńska gap, suggest that the former was the original main channel, which was fed by outwash discharge and which cut much of the valley to the west. Palaeocurrent directions in the in-filled channel and other deposits in the New Quarry may confirm this. In which case, the low northerly gradient off St. John's Hill reflects the original valley profile, which has been destroyed by later spring sapping on the north side of the Dworcowa Channel valley (Fig. 7c). Reduced flow, may have resulted in vegetation developing on fluvial sand banks within the gap - the deposits seen near the New Quarry entrance. If dating of the Vistula formation is correct, this dry phase was probably the Younger Dryas. If the contorted deposits in the New Quarry are the result of cryoturbation, then this would confirm that the valley was already cut by the time of the Younger Dryas.

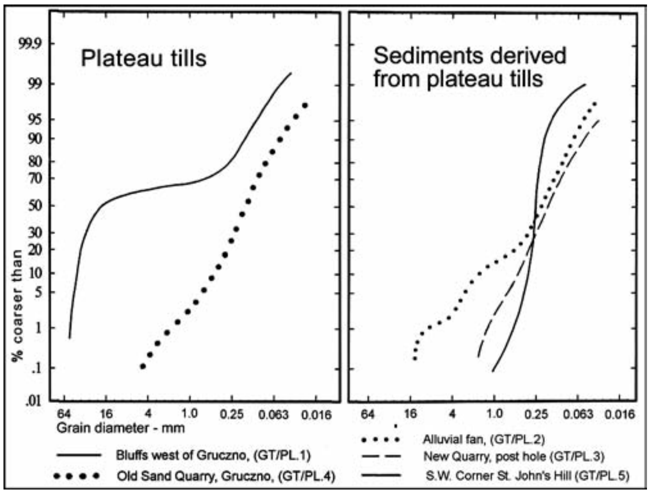

***Figure 6**. Cumulative frequencies of grain sizes within sampled sediments. The tills show variation in sorting, and are distinct from sediments reworked from the local till.*

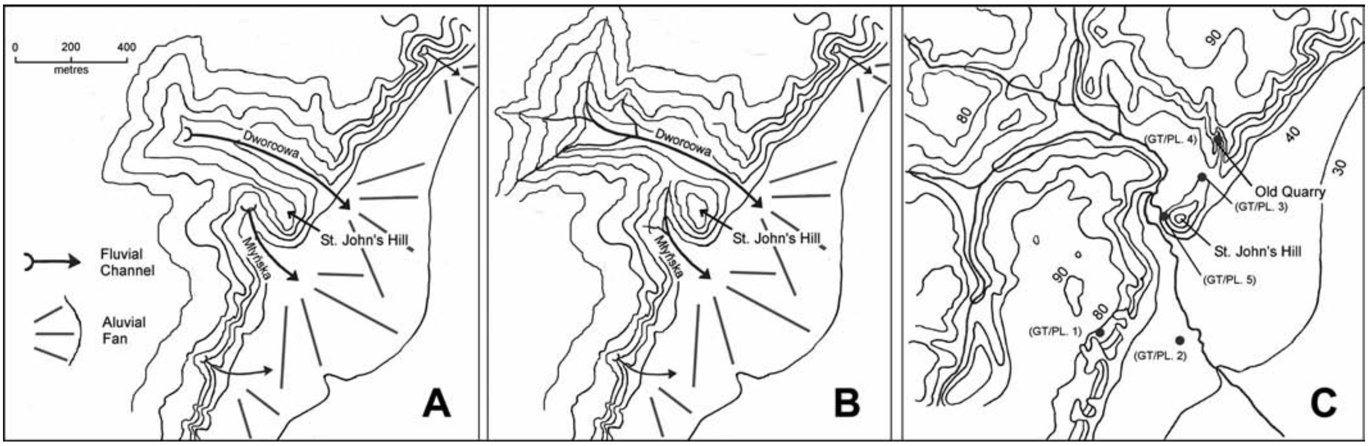

Figure 7. Evolution of St. John's Hill. ***A****: The hill forms a spur between the Dworcowa and Młynska channels.* ***B****: The Dworcowa channels develop a dendritic drainage system and the Młynska Channel starts to cut back into the neck of the spur.* ***C****: The waters of the Młynska channel capture the drainage that originally flowed through Dworcowa gap.*

The Młynska Channel

Although this outwash channel is much shorter than the Dworcowa system, it is no shorter than many other channels cut into the plateau edges south of Gruczno. The Młynska channel may have developed a tributary to the north and thereby started to separate St. John's Hill from the main bluffs (Fig. 7b). The Gruczno stream systems have developed marked tributaries parallel to the Vistula (Fig. 7c), which were probably initiated by sub-surface steams within fluvial sediments interbedded with the tills similar to those at Topolno (Fig. 5) and indicated by stratified sandy layers in the Old and New Quarries. Continued spring sapping and headward erosion eventually captured any flow in the Dworcowa channel. Increased flow after the Younger Dryas further modified the Młynska channel forming its present shape, leaving St John's Hill as a detached plateau remnant. The E-W section in the New Quarry shows no slumping of the strata, only erosion of stratified sands; this suggests that the valley is a fluvial feature that discharged onto the alluvial fan, and that St John's Hill is of natural origin.

Decreasing Holocene discharge has left the present small stream as an underfit in its valley. Spring sapping continues today, above several boggy areas at the base of the slope south-west of the church. Sandy horizons within the till, which would act as sub-surface conduits, were exposed at Topolno after its landslip Fig. 5). The north side of the Dworcowa gap (Fig. 7c) has also been cut back by former spring sapping, though excavation of the Old Quarry has interrupted the flow and the area is now relatively dry. It is likely that sub-surface flow within these horizons strongly influenced the development of the tributary streams shown in the west of Figure 7c. Evidence of present and former spring sapping can be seen in many locations along both sides of the Vistula river.

The aeolian sand in the SW corner of St. John's Hill (Fig. 3) may relate to dry conditions during the Younger Dryas, or earlier, suggesting that this part of the valley had formed by then. Aeolian dunes are recorded in the floor of the Vistula valley (Niewiarowski, 1990); St Laurent's Hill, Kaldus, on the east bank to Gruczno was modified by dunes prior to the late glacial, c.16,500 yrs BP (Chruścińska et al., 2004). Although the extent of the aeolian sands has not been assessed at St John's Hill, their presence suggests that the rounded southern end was not radically modified when the hill fort complex was built.

Conclusion

Although it is clear that the top of St. John's Hill was modified when the hill fort and settlement were constructed, the hill appears to be a largely a natural feature formed by fluvial processes and river capture. It is likely that the hill top was originally much more rounded and was then flattened to produce an area for settlement. The excess material was probably used to produce ramparts that may have reinforced the sharp edge to the southern part of the hill as well as supplying ramparts on the northern side. The thick dark soil at the top of the section in the New Quarry (Fig. 4) may well be the result of anthropogenic intervention when settlement spread down the hill.

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The Geology of Chatsworth House, Derbyshire

Ian Thomas and Mick Cooper

Figure 1. *Chatsworth House*

Chatsworth is one of Britain's great treasure houses, and it exemplifies perhaps more than any other, the use and display of local and exotic stones and minerals. Like many landed families, the Cavendishes were avid art connoisseurs; more unusually, several members were equally keen mineral collectors. Lady Georgiana Spencer, the 6th Duke and the late 11th Duke (1920–2004) were the most prominent. In particular, the 6th Duke formed strong links with Faustino Corsi, a prominent Italian decorative stone specialist and with Czar Nicholas 1 of Russia; they exchanged not only ideas, but also many materials. These connections, coupled with the ability to source materials from the family's own estates, strongly influenced the probably unique blend of locally derived and exotic stone lithologies at Chatsworth.

> *The love of stone possesses you like a new sense…*
> 6th Duke on visiting Rome

Most of the building stone and many of the decorative stones at Chatsworth have come either from the estate itself or from Devonshire lands further afield. The main body of the house was built in various stages, all from the Ashover Grit (and not as some have suggested, from the Chatsworth Grit). The stone in the building as it now stands (initially from the late C17th) was sourced from Ball (or Bow) Cross, overlooking Bakewell, and from Whicksop Edge, now known as Bakewell Edge. Many other local quarries were later employed. An attractive, honey-coloured sandstone with liesegang rings (formed by iron mineral staining) makes up the grand North Gateway (Fig. 2); this and the stone for much of those parts of the house (mainly in the North Wing) remodelled in the 1820s, was quarried at Burntwood high above Beeley. A small amount of much later work drew upon Stancliffe Stone, from Darley Dale, outside the family lands.

The Tour of the House

Within the house, and just inside the main public entrance, the North Front Hall contains turned, cylindrical columns, each 1.2 m tall, of bioturbated black marble. These are conventionally black over most areas, but surprisingly grade into only a mid-grey in others; the grey surfaces are those more exposed to daylight, where it appears that the hydrocarbon colouring in the stone has broken down, and consequently the columns have faded. Indeed, the 6th Duke commented in 1844 that they were already losing their colour and were inferior to stone from the Ashford Rookery Quarry. It has been suggested that the stone may not be Ashford Marble, but could be Rosewood Marble (as used elsewhere in the house), but the latter normally has alternating grey and black veining rather than a graded change in colour.

The substantial balustrades to the stairs here are in pale cream-grey, Derbyshire fossil, crinoidal marble, likely to have been sourced from Once-a-Week Quarry at Sheldon, or possibly One Ash Grange Quarry at

Figure 2. *Liesegang rings in the sandstone blocks of the North Gateway.*

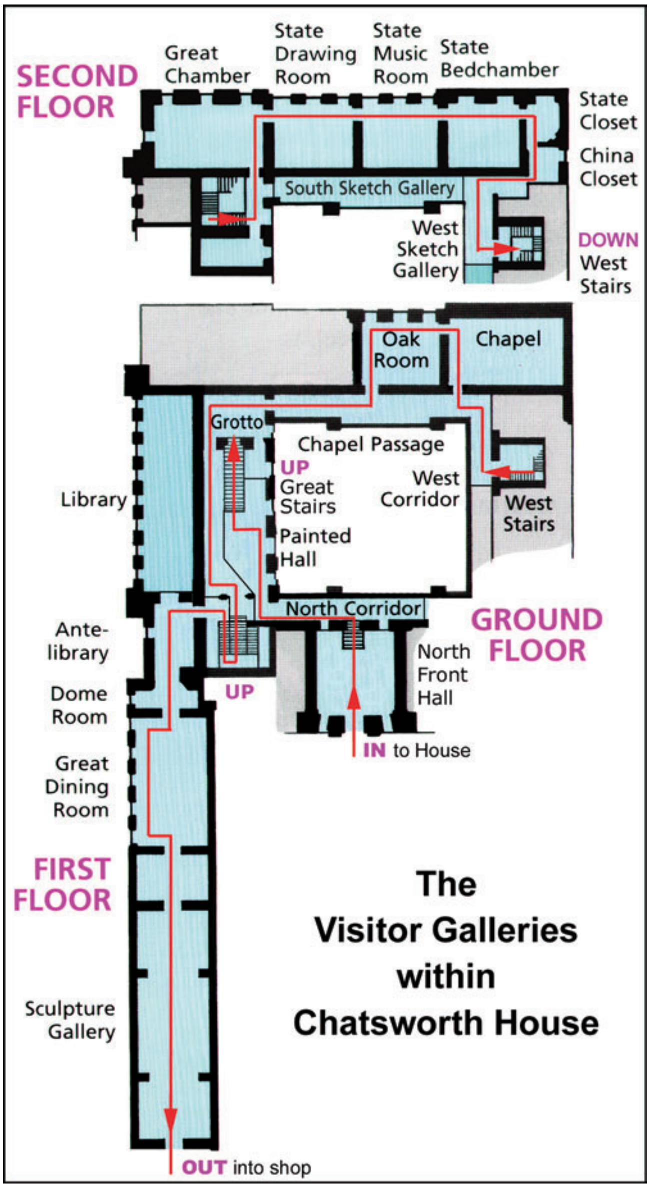

Figure 3. *The tour route around Chatsworth House.*

Monyash, but not from Ricklow Quarry, which was not on the Estate. This 'marble', is not a marble in the geological sense (ie a metamorphosed limestone), but is a hard limestone capable of taking a high polish (and therefore referred to as marble within the trade); it is the only one of a number of Derbyshire marbles still in production. These steps lead to the North Corridor, where the most noticeable feature is a floor of various marbles (Fig. 4) installed by Leonardi, 'a poor man who lives at the Forum in Rome'. The classical marbles within the star patterns include *diasporo tenero* (brick-coloured, so-called soft jasper from Sicily); the lighter material may be *giallo antico* from Tunisia, though the date of installation, in 1841, does not accord with that of the reopening of those ancient quarries in 1876. The white marble is from the Apuan Alps. Vases standing in this section include red Egyptian porphyry (porphyritic andesitic dacite) and local Ashford Black Marble.

In the Painted Hall, a number of tables and columns supporting classical busts are of various granites, probably Scottish in origin. The black and white chequered floor here and elsewhere in the house comprises local black marble and white Carrara from Italy and was apparently installed by White Watson.

One of the table tops, edged in red Swedish porphyry, is made of a polished anorthosite known as larvikite, similar to the distinctive Finnish variety, specrolite, from Ylämaa (which was only discovered in 1941). Some of the labradorite feldspar crystals within it are up to 100 mm across and show excellent iridescence resulting from the interference effect of alternating twins and exsolution lamellae within the crystals themselves. This table top originates from the 6th Duke's visit to Russia in 1830. He saw men working on a canal bridge foundation on Nevsky Prospect, in St. Petersburg, when he noticed blocks of larvikite that he speculated had been introduced as ships ballast. He brought them back to Chatsworth, had them made into the table top at the Ashford Marble Mill, and pointed out that it was harder than

Figure 4. *Marbles forming the floor of the North Corridor.*

Figure 5. A small part of the second-floor doorcase made of allabaster from Tutbury.

larvikite from elsewhere and displayed marked "irridencency". Although he says no more on the likely source, St. Isaac's Cathedral was being built at the time in St. Petersburg, and was sourcing "black granite" pillars from Peterlax (now Virolahti), part of the Rapakivi (or Wiborg) granite complex of southern Karelia. Though there appear to be no coastal outcrops of larvikite in this area, gabbroic anorthosite rafts similar to those at Ylämaa have been reported recently on the Russian side of the frontier. St. Isaac's was later also supplied with larvikite from Zhytomyr, Ukraine.

The Second Floor

A series of stairs rise to the second floor, where massive doorcases are of alabaster from Tutbury (Fig 5). The side rooms are normally used for temporary displays that sometimes include a small selection from the Chatsworth Mineral Collection. A nearby pillar, supporting a bust of Charles, Prince of Wales, reveals excellent cross sections of large masses of Carboniferous colonial corals (*Syringopora*), possibly from Millers Dale, and produced in the C19th. Window sills in the Great Chamber are classic, pale-

Figure 6. Crinoidal limestones forming a window sill in the Great Chamber.

grey, Derbyshire, crinoidal limestone (Fig. 6), probably from quarries at Calver, although a 'gray marble' from Haddon Fields referred to in C17th accounts, could equally have been the source. Those in the next room, the State Drawing Room, are of a different crinoidal limestone that has fewer and smaller crinoid fragments between patches of darker fine-grained limestone that may represent an auto-brecciated structure, also from one of these sources.

Near the far (west) end of the South Sketch Gallery, a spectacular C19th inlaid table was at the time of the Society visit only accessible by special arrangement, but is likely to be on a modified tour route in the near future (Fig. 7). Nearly all its materials

Figure 7. The beautiful C19th table that stands in the South Sketch Gallery.

Figure 8. Inlaid blocks within the C19th table, (from top left clockwise) baryte and galena, Syringopora coral, fluorite, brecciated limestone; each block is 10cm square.

are of local origin. Square segments, each about 10x10 cm (Fig. 8) include representatives of oakstone (Derbyshire banded baryte), a fine Carboniferous colonial coral (*Syringopora*, sometimes then known as madreporite), crinoidal limestone probably from Sheldon (this was known as encrinite), Duke's Red Marble (in samples both with and without white calcite banding), rosewood marble, cross sections of small galena-baryte-calcite veins, purple and green fluorites, vein breccias, 'cockleshell marble' (an iron-rich non-marine lamellibranch bed or mussel band, probably from immediately above the Cockleshell Coal, the upper leaf of the Tupton Coal, and likely to have been from one of the Duke's collieries in the Rother Valley), and a limestone that is probably dolomitic. All these are framed individually and the table is edged in Ashford Black Marble.

The Duke's Red Marble is an almost blood-red, heavily hematised, Carboniferous limestone, capable of taking a high polish (Fig. 9). Its precise source has been enigmatic, with Alport, Youlgreave and Newhaven all being cited. According to records in the Chatsworth archive, it was produced as a decorative material from small mines around Newhaven, near Hartington, mainly in the 1820s. Various accounts that suggest it came from Alport-by-Youlgreave appear to be based on the use of solidified iron-rich sediments derived from mine drainage channels in that area, which were used for inlay in decorative table tops.

Figure 9. A block of the Duke's Red Marble set into the C19th table, adjacent to a block of "cockleshell marble".

The Ground Floor

Returning to the ground floor, on one of the landings we inspected two scagliola plinths that form square corner columns boxing in services (scagliola is created by applying a mix of plaster and pigment as a covering to a wooden core, giving the appearance of a true marble). Just into the West Corridor, a very fine table is inlaid with a variety of marbles that are mainly of Italian origin. Next to it, a small and slightly bizarre table is decorated with three large stalactites that hang beneath it (Fig. 10); these may have been taken from Water Icicle Close Cavern near Monyash. Beside this, another column of Ashford Black Marble is noticeably faded on its window side.

The Chapel, built between 1688 and 1693, features four black marble columns, each 3 m tall and 350 mm in diameter, turned from monolithic pieces from Sheldon Moor near Bakewell. These, which contrast with a massive ornate altarpiece, are believed to have been carved on site by Samuel Watson, assisted by others from London. As the 1689 accounts testify, the alabaster for the altarpiece itself was from Gotham, Nottinghamshire, but the remainder was drawn from the family lands at Tutbury, Staffordshire. The latter was reputed to be from Castlehayes Mine adjacent to land largely destroyed by the Fauld munitions explosion. Records of the mine's history were also thought to have been lost in that event. Much of the alabaster in the House has been wrongly ascribed to Chellaston, near Derby; but, as far as is known, none of the material is from that source.

Figure 10. The table with stalactites, in the West Corridor.

Figure 11. A small part of a beautifully inlaid table in the Oak Room, with its leaves of green Florentine limestone.

The Oak Room exhibits large vases and tables, again of Ashford Black Marble; these are so uniformly black that they appear to be of ebony or factory-made in ceramic or plastic. The inlaid work is superb and includes lapis lazuli, Duke's Red and Florentine green (i.e. Alberese limestone from along the Arno Valley); the latter produces extremely realistic leaves (Fig. 11). These pieces were probably by Thomas Woodruff, and one or both are thought to have been included in the 1851 Great Exhibition. Back in the Chapel Passage, the statue from the Temple of Mut at Karnak, Egypt, is of a green metagabbro, widely known as verde antico.

The Grotto lies at the end of Chapel Passage, and contains a noisy water fountain with a black marble basin surmounted with swags of flowers in Roche Abbey stone (Permian Cadeby Formation from South Yorkshire) reputed to have been carved by Samuel Watson. Standing by a window, a columnar plinth 1.2 m tall was turned out of luxullianite (Fig. 12). This remarkable rock has almost perfectly regular large pink orthoclase phenocrysts set in a dense mosaic of black schorl (a variety of tourmaline) and derived from Luxulyan in West Cornwall. Nearby is an inlaid table surfaced in an oakstone veneer. Tucked beneath the Great Stairs is a large tazza (a large flat vase or basin, supported by a pedestal) of the classic *fior di pesco* (peach blossom) marble from Euboea, Greece. Along the route back through the Painted Hall, columns of various pink granites, probably of Scottish origins, support white marble busts.

***Figure 12.** The luxullianite column in the Grotto, with its feldspars in a matrix of black tourmaline.*

The First Floor

Up the Oak Stairs, the landing has a table with a top of stunning garnet amphibolite (Fig. 13), and also a large amethyst geode from southern Brazil (Fig. 14). The final section of the tour encompasses the suite of rooms in the long 1820s North Wing on the first floor.

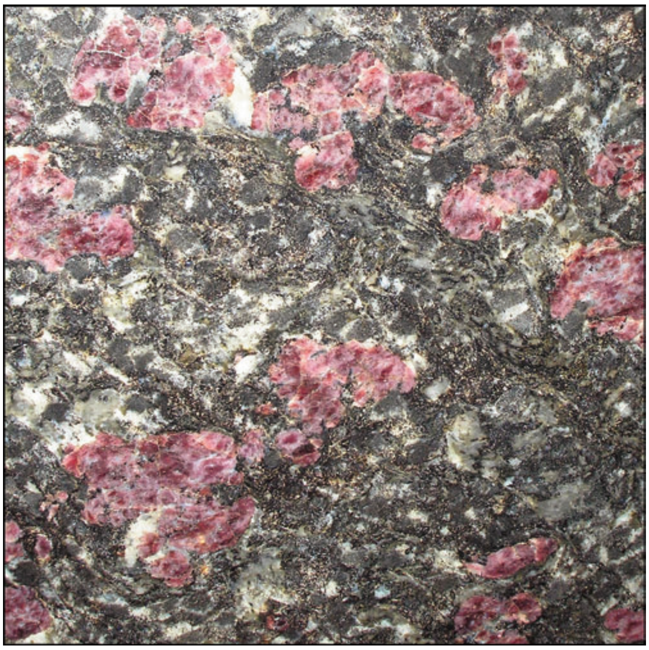

***Figure 13.** Red garnets in the amphibolite of the table on the Oak Stairs landing.*

Figure 14. *The amethyst geode from Brazil, standing at the top of the Oak Stairs.*

Figure 15. *One Rosewood Marble columns in the library.*

Figure 16. *The giant quartz crystal from the Simplon Pass, now in the ante-library.*

Standing in the private library, there is a unique set of columnar plinths, each 2 m tall, of Rosewood Marble, distingusihed by its wavy bedding and mined from Nettler Dale, near Ashford in the Water (Fig. 15). The ante-library contains an exhibit of Henry Cavendish's scientific instruments, including a full range of crystal forms modelled in wood, and also a quartz crystal a metre tall that came from the Simplon Pass in Switzerland (Fig. 16)

A number of exotic marbles feature in the Dome Room and Great Dining Room as linings, pillars, urns and doorcases. The former room includes two oversized vases in peach coloured *occhio di pavone* marble, a Late Cretaceous shelly limestone from Turkey. A pair of columns is of so called 'oriental alabaster', which is a banded calcite from hot springs or cave deposits and probably from an Italian source. A second pair of supporting columns is of *pavonazzetto* (brecciated marble). The grand columns on entering the Great Dining Room are of Porta Santa marble, quarried on Chios, Greece. Those of the exit are of Africano Breccia, and the source of this stone, widely used in classical times, had been lost or ascribed to a dozen possible localities, but has recently been confirmed as Teos (now Siğacik), Izmir in Turkey. Among the table tops in the Dining Room, the rich red ones are of Swedish porphyry that the 6th Duke commented as being finer (presumably in terms of the size of phenocrysts) than the material from

Figure 17. The spectacular tazza, 500 mm across, carved in Blue John fluorite and displayed in the Great Dining Room

Älvdalen (as in the Sculpture Gallery). The unusual grey top is of a phyllite (metamorphically between slate and schist), which the 6th Duke recorded as Siberian Jasper, a present from Czar Nicholas I.

A table on the left at the far end of the Great Dining Room supports three excellent items carved in Castleton Blue John fluorite. Two vases each 420 mm tall have low-heat lights inside them, which show they were turned from slabs of Blue John joined together (Fig. 18); the central tazza has a shallow bowl 500 mm across on a small stand and is the largest piece of Blue John carved by William Adam, for the princely sum of £120 in the mid-1800s (Fig. 17).

Beyond the Great Dining Room, the linking Vestibule displays two spectacular inlaid tables, each framed in Ashford Black Marble. One illustrates a variety of flowers in exotic stones that include numerous sectioned agate pebbles (Fig. 20). The other features a beautiful blue bird with wings of lapis lazuli, within a frame of Duke's Red Marble (Fig. 19),

The Sculpture Gallery itself is entered through a door surround comprising truly magnificent monolithic slabs of Derbyshire crinoidal limestone from Sheldon – among the largest examples ever shaped. Most other elements are of exceptional size – Carrara marble statues by Canova, Gibson, Thorvaldsen and others, resting on plinths or columns of a considerable range of igneous rocks – porphyries,

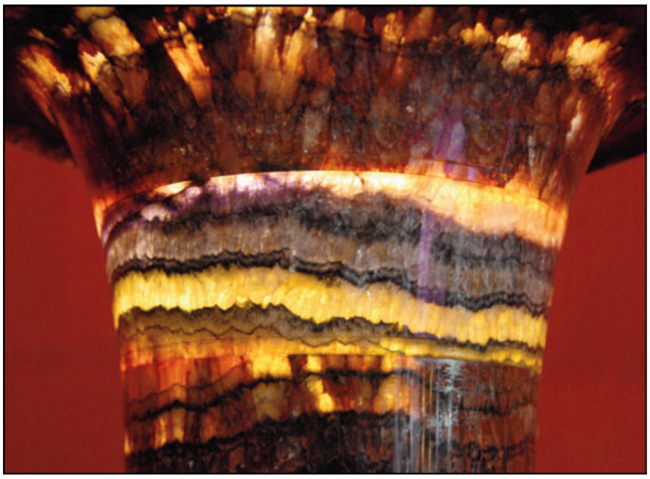

Figure 18. *One of the Blue John Vases with internal lighting, in the Great Dining Room.*

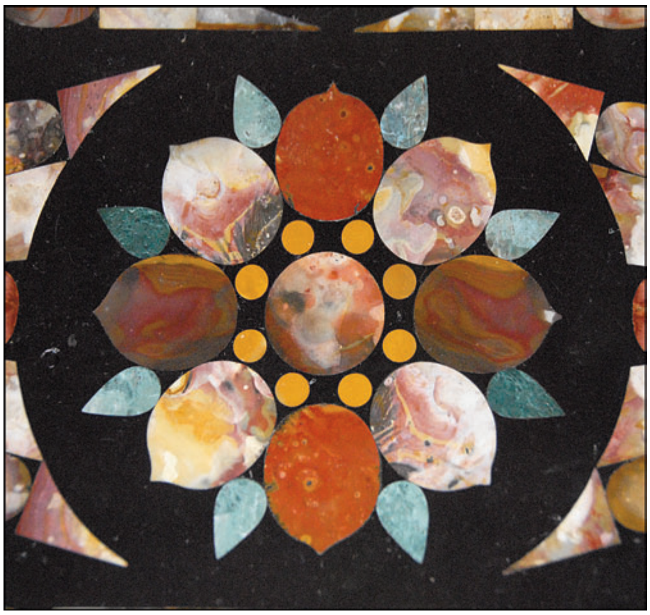

Figure 19. *Inlay of various agates in Ashford black marble, forming a table top in the Vestibule.*

Figure 20. *The beautiful inlay on a second table top in the Vestibule, featuring a bird of lapis lazuli.*

granites and serpentines as well as breccias. The red porphyry is almost certainly Swedish (and is not the classical Egyptian) from the operation at Älvdalen, in the north of Dalarna county, which at the time was the only quality source of porphyry in Europe and found its way into many of the royal houses of Europe and Russia; its texture appears to show magma mixing (Fig. 21). A stunning green table top of malachite from the central Urals, is 2 m x 1 m, but has only a veneer 2 mm thick of malachite in pieces each about 100 mm across and cut to fit together; along with a malachite framed clock (Fig. 22), both were presented to the 6th Duke by Czar Nicholas 1. Other exhibits include a fossil silicified tree trunk. The last marble but one on the left stands on a plinth with a base of crinoidal limestone with the slightly pink colour characteristic of stone extracted from the Monyash area.

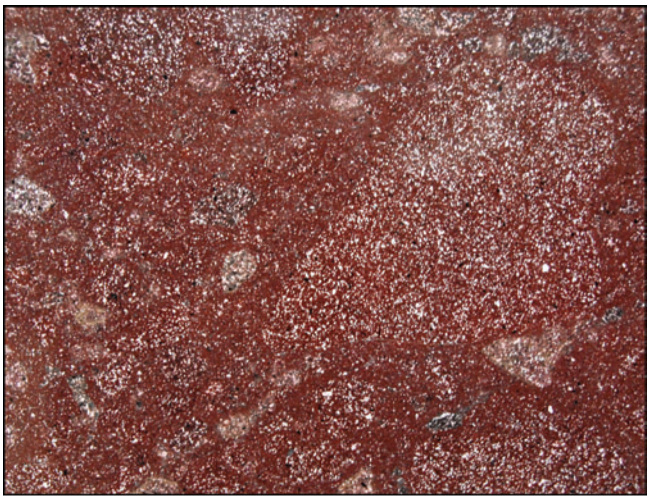

Figure 21. *Textural variation created by magma mixing in a red porphyry forming a plinth in the Sculpture Gallery.*

The floors in the Gallery are of a fine, grey-buff sandstone of unrecorded source, but the stone generally being employed at this period was coming from Beeley Moor. Elsewhere (and in most of the private quarters), Hopton Wood Stone, much in vogue in the C19th, is the main flooring stone. This was also used extensively for flooring and staircases in grand buildings through the British Isles.

After breakfast we all flocked to the North Passage where there were hundreds of stones in glass fronted cupboards. Petrified this and fossilized that. Blue John and Lapis Lazuli were the most exciting. Large flints, which looked as if they had been picked up by the side of the road, the least valuable. The minerals in the North Passage are good enough for a museum.

(from *The Pursuit of Love*, written in 1945, by Nancy Mitford, the Dowager Duchess' late sister)

Figure 22. *The malachite-faced clock from Russia on display in the Sculpture Gallery.*

The Mineral Collections

The minerals at Chatsworth House comprise three main collections, those of Georgiana, Duchess of Devonshire (1757-1806), those of her son the 6th Duke, and those of the late (11th) Duke. The significant material is in the first two of these mineral collections, which have been recently restored by members of the Russell Society, and their highlights are described below. The main collection is now housed in a Chatsworth store in two old mahogany drawer units purchased from the Hunterian Museum in Glasgow. Some is exhibited in Georgiana's original display cases in the stable-block conference centre, but there is very little on public display. Access is by request via the curatorial staff.

Perhaps surprisingly there is no great wealth of mineral material from the family's own mines, either at Ecton or elsewhere in England, as the collections were made independently by family members who gained enjoyment from the collecting. The family is Derbyshire based, and there is no direct connection with mines in Devon; their Devonshire name originates only from the fact that this was an available dukedom at the time of their elevation to the peerage.

These notes do not refer to the large display minerals that are scattered around the house; these were purchased separately, from Sotheby auctions and other sources, largely by the 11th Duke, and were specifically for display; they are briefly described within the notes above where they are encountered along the tour route around the House.

Georgiana, Duchess of Devonshire

The Devonshire Mineral Collection was begun by Georgiana Spencer, daughter of John Spencer (the 1st Earl Spencer) and Georgiana Poyntz of Althorp. Georgiana began collecting minerals in the closing years of the 18th century. At the time she was exiled in Europe, banished from her husband's house as a result of her absurd gambling debts and the discovery of her affair with the politician Charles Grey. While she was living in France, Georgiana began to study natural science, partly as a means of supporting and contributing to her children's education, and almost certainly as an escape from her sad state. Quite apart from any innate interest in the subject (she already professed a fascination with geology, the hottest science of the day), she may have been influenced not only by the considerable vogue for natural history collecting at the time, but also by the eminent mineralogists among her many acquaintances abroad. By the time of her return to England in 1793 her collection was quite substantial and she continued to add to it with gifts and purchases.

White Watson (1760-1835) was employed for nine weeks, April to June 1799, to catalogue her then substantial collections at Chiswick. On the same visit to London he also arranged the mineral collection of Lady Henrietta Bessborough (Georgiana's sister) in Cavendish Square. Five years later he performed the same task on Georgiana's specimens at Chatsworth.

From Watson's original handwritten *Catalogues* it is apparent that many of Georgiana's specimens, especially those from Derbyshire, were supplied by him, but it is obvious from certain *Catalogue* entries and omissions that several collections were already in existence when he began his work. Watson also instructed the Duchess in mineralogy, and an interesting hand-written *Catalogue of External Characters of Fossils* by *White Watson F.L.S. Bakewell, Derbyshire 1798* survives at Chatsworth (the term "fossils" in those days included minerals and archaeological material as well as true fossils). The book may also have been used to teach Georgiana's children mineralogy.

Watson listed Georgiana's minerals as ten separate collections, and his catalogues survive in two hardbound notebooks in the Devonshire archive at Chatsworth. Georgiana's original display cases also survive: a pair of matching bow-fronted glazed cabinets. Their construction (by one James Frost) appears to have been organized by White Watson in 1797 and 1798 at a cost of about £24 each, and he completed the arrangement of their contents in 1799. These cabinets have closely spaced, steeply sloping shelves each fitted with narrow horizontal strips of wood to support the specimens. The collection must have been very crowded in this limited space.

Figure 23. *A boulder of Blue John fluorite, 250 mm tall, with some cut and polished faces, from Castleton.*

Consequently, there would have been little space for display labels, and it was perhaps to facilitate reference to a separate *Catalogue* that many specimen number labels were attached to the display surface of the pieces. In 1998 Georgiana's cabinets were refurbished and placed in the Coffee Room of the new conference centre in the Chatsworth Stable Block. A selection of specimens from the Devonshire Collections is displayed within them, but does not reflect the original arrangement.

Many of Georgiana's specimens are rather dull and unattractive to the modern collector; typical of a systematic collection rather than a display of the exceptional, they were obviously acquired with more regard for their place within some mineralogical scheme than for their aesthetic qualities. This may seem unexpected in a society hostess whose early involvement with fashion and frivolity was so often satirized and censured, whose homes were filled with the marvels of art, whose husband was one of the richest men in the country, well able to afford the premium that rarity and beauty acquire. It supports the idea that she had a genuine interest in the systematics of the subject, though it may equally demonstrate a lack of sophistication.

'Hart', the 6th Duke

William, known as Hart from his courtesy title of the Marquess of Hartington, was born in Paris in 1790 -– a quite remarkable place for his mother to be in such troubled times, and an episode that stimulated an enormous amount of speculative gossip. Little more than two months after Hart came of age his father died, and he inherited title, estates, great houses, possessions and wealth almost beyond belief.

In London in 1816 Hart struck up a deep and lasting friendship with the Grand Duke Nicholas of Russia, destined to become the Czar of all Russia. When Nicholas left England to return home to his bride-to-be, he invited Hart along. Hart stayed for several weeks in St Petersburg and was much struck by the beauty of the city. He dined with the Emperor Alexander I and was feted by the Russian nobility. This fondness for Russia is later reflected in the Russian minerals he collected. The Duke was appointed as Britain's Ambassador Extraordinary to Russia on Nicholas's succession to the throne in 1826.

Hart employed the architect Jeffry Wyatt (later Sir Jeffry Wyatville), to build a formidable extension to Chatsworth to house his collections and accommodate his intentions for grand entertainments. Wyatt was wholly unimpressed with the window that the Duke had made from slabs of Blue John fluorite, as the Duke relates in his Handbook: *The Derbyshire spar in the window is made of beautiful specimens: it shows how fine a thing might be made of the material. The stones were intended for a cabinet of minerals, and from their shape could only be arranged in a formal and not graceful pattern; and much did Sir Jeffry condemn the whole thing, which he pronounced to be the exact resemblance of his grandmother's counterpane.* This window was moved by the 11th Duke from the Theatre to the West Sub-Corridor.

Figure 24. *Polished slabs of four different Derbyshire fluorites from the Faustino Corsi suite.*

Hart toured Italy in search of Italian art, especially marble sculpture to which he devoted a fortune and much effort. His fascination with Italian decorative stone led him to Faustino Corsi (1771-1845), an Italian lawyer with judicial responsibility for the Vatican police and an expert on the decorative stones of antiquity. In his *Catalogo ragionato...* of 1825, he notes that the Duke of Devonshire had "honoured his collection with a visit, and also enriched it with precious gifts". Corsi's collection of 1000 slabs was presented to the University of Oxford in 1827, and is now in the Oxford University Museum of Natural History. It contains 16 polished slabs of Derbyshire stones (Fig 24), including Duke's Red Marble, Ashford Black Marble, Rosewood Marble, various fossil limestones, and fluorites including Blue John. The Duke's Red is a beautiful hematitic limestone that was found in a limited deposit near Newhaven in Derbyshire in the 1820s. The Duke used it extensively in table tops and other lapidary work for Chatsworth, where the remaining world's supply of this unique stone lies piled in a basement corridor. One block of stone recently taken from this pile was carved by Angela Conner to make a pen tray (Fig. 25). This has bands of vein calcite between slices of very dark red, hematitic limestone; there is some mystery over its exact source, but it may be vein material that lay within a wider mass of the Duke's Red and was therefore extracted at the same time.

Hart died in his sleep in 1858. No catalogue of the collection from the Duke's time exists, though there are a few short lists of items acquired c.1817-1827. None of his specimens is systematically catalogued,

Figure 25. *The pen tray carved by Angela Conner out of banded red calcite that appears to be associated with the Duke's Red Marble.*

though many bear handwritten or printed labels of one sort or another. The earliest record of his collecting is that of Hart buying specimens from White Watson in 1809: Watson's cashbooks record a "Tablet of Ironstones and coals" purchased by the Marquis of Hartington for £6.0.0. Unfortunately this cannot be found today – perhaps it was a gift for another. We know too that he bought from Henry Heuland (1778-1856), the leading mineral dealer of the day, in 1820 and 1833, and attended a Heuland auction in May 1834. Lecturer and mineral dealer Prof. James Tennant (1808-1881) is known to have stayed at Chatsworth while working on the collection, though we do not know what he did and only one specimen can be attributed to him (it bears his label and must date from after 1840). The Duke had sufficient confidence in Tennant to entrust him with the "Duke's Emerald," to exhibit at his stand in the Great Exhibition at Crystal Palace in 1851, along with the Simplon Pass quartz crystal on display in the Chatsworth Sculpture Gallery.

Other than the Heuland specimens described below, Hart's most inspired purchases were from the sale of the collection of Sir Alexander Crichton (1763-1856). The polymathic Crichton was physician to Emperor Alexander of Russia from 1803 to 1814, and was well respected for his work on insanity. In 1818, Crichton's mineral collection was described by Joseph F. Wagner as the finest in Russia. Wagner tells us that the Duke of Devonshire gave Crichton specimens for his collection including an "extraordinarily beautiful" tourmaline with apatite, from the then-new occurrence at Bovey Tracey in Devon. A pocket book of the Duke's dating from shortly before 1817 lists "Minerals given me by Doctor Creighton [sic] in exchange for Cornish and Derbyshire ones." There are 18 specimens listed, many of which seem to be of good quality, but it has so far not been possible to reconcile them with extant specimens. Whether the two men first met in England or Russia we can't tell, but in his *Handbook to Chatsworth and Hardwick*, the Duke mentions the existence in the Devonshire Collection of "specimens I added, and some that Dr. Creighton assisted me in procuring at St. Petersburg, where I gave some Derbyshire and Cornwall ores in exchange."

Crichton retired from his post in Russia in 1819 and returned to London. His marvellous mineral

Figure 26. *A sample of the minerals in the 6th Duke's collection.*
From left to right, and top to bottom -

amethyst,
smoky quartz,
heulandite,
grossular garnet,
fluorite,
aquamarine,
sphalerite,
gold on quartz,
siberite,
prehnite

collection was auctioned in London by George Brettingham Sowerby 1 (1788-1854) in 2721 lots over a period of 16 days from 20 April 1827. The Duke attended the Crichton sale, choosing the lots himself on the 4th and 7th of May. To identify them, the entries in the sale Catalogue were carefully cut out and pasted onto the specimens.

The Mineral Collection Today

By the mid-19th century the Devonshire mineral collections seem to have been long neglected. As early as 1844 the Duke comments in his Handbook: "All these minerals [i.e. his mother's and his own] are in a disgraceful state of neglect and want of classification. Those collected by my Mother ought to be replaced in their former order, as they were in the days of White Watson of Bakewell, who in vain endeavoured to hammer mineralogy into our youthful heads."

The collection continued in a more or less neglected state until the 1990s when the Russell Society took on the challenge of restoration, including systematic cataloguing and historical research. According to Watson's *Commonplace Book*, the Chiswick Collection contained 1076 specimens in 1799, and the Chatsworth Collection about 1000 in 1804. The Russell Society's analysis shows that the Chiswick Collection accounts for 1076 entries in the catalogue of which 1036 were extant when Watson did his work. The Catalogues of the Chatsworth Collection have 1032 potential entries but only 858 specimens were described. Watson, therefore, found 1894 specimens from a potential total of 2137, and noted that the specimens at Chiswick also included "a large collection of lavas, etc. collected by Her Grace in Italy that were not catalogued or described." Of the Duke's collection, the Crichton list numbers 75 pieces, there are 10 pieces in the 1820 Heuland purchase, and some 50 pieces in other *Catalogues* that we assume to have been his. This gives a grand total of about 2250 known to have been in the collections at one time or another since 1799. There are many un-labelled, and so far un-reconciled, specimens remaining at Chatsworth.

Figure 27. *Mick Cooper working on the Chatsworth mineral collections in their new housing.*

Figure 28. *Calcite on fluorite from the Gregory Mine at Ashover.*

Minerals from Georgiana's collection featured in an exhibit at Chatsworth concerning her life and times, following the publication of Amanda Foreman's fine biography, but this has now been closed. Suites of specimens from her and her son's collection toured several American museums in 2003 as part of the travelling exhibition *The Devonshire Inheritance.*

Highlights of the Mineral Collections

The restoration of the collection by the Russell Society has retained the arrangement established in Watson's original catalogues (here lettered A-K) and has added several other "artificial" catalogues based upon groups of specimens brought together by shared label styles or other common associations.

Catalogue A

Catalogue of a Collection of Fossils, the Productions of Derbyshire, in Her Grace the Duchess of Devonshire's Cabinet at Chatsworth: Arranged According to the Order of the Respective Strata in which they are found; Accompanied with a Tablet Representing a Section of the strata in Derbyshire, with a Printed Explanation. By White Watson F.L.S. &c 1804.

This contains a superb series of about 30 excellent galena, fluorite and sphalerite specimens from the Gregory mine, Ashover, in Derbyshire, many of which seem to have come from the same find (Fig. 28). The best show cuboctahedral galena crystals to 5 cm or so on colourless fluorite cubes with later, smaller, purple fluorite crystals and a sprinkling of minute chalcopyrite and marcasite crystals. They are surprisingly free from damage, given the fragile nature of the minerals present, and represent some of the finest Derbyshire galena specimens known. The fluorite specimens comprise groups of colourless cubes to almost 5 cm, spangled with minute sulphide crystals or scatterings of larger, well-defined sphalerite crystals. Some of the specimens exhibit minute crystals of enargite. Another Derbyshire speciality in the collection is "Elastic Bitumen" from Castleton, including one huge lump of this intriguing mineraloid some 30 cm across. There are 30 specimens of chalcopyrite and other minerals from Ecton Hill in Staffordshire, including some malachite which is of rare occurrence there (Fig. 29).

Catalogue B

Catalogue of a Collection of Fossils Chiefly Volcanic and Pseudo volcanic from Dr. Townson. [White Watson, Chatsworth 1804].

Dr Robert Townson (1763-1827) was an important English traveller, naturalist and geologist, who was an expert on the petrology of volcanic rocks. He was the author of, among other works, of *The Philosophy of Mineralogy* (1789), which he dedicated to Georgiana (suggesting, incidentally, that her interest in the subject predated her lessons on her European exile). We still have 21 of Townson's 24 "pseudo-volcanic rocks," a third of which were baked clays and marls from a burning coalfield between Birmingham and Dudley in the English Midlands. Many of the remainder are basalts from various British and Welsh localities. The realization of the volcanic origin of basalt was a relatively new idea (by the Plutonists) at the time, and had been the subject of much contention with those (the Neptunists) that considered basalt of aqueous origin.

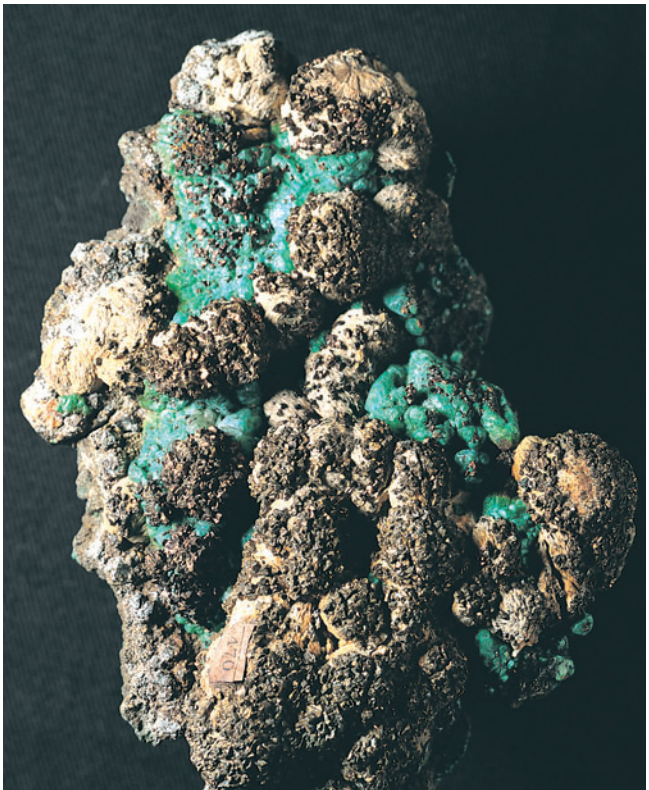

Figure 29. *Chalcopyrite and malachite overlying baryte in a specimen 130 mm long and from the mines in Ecton Hill.*

Figure 30. *Dendritic native copper displayed on a marble slab, in a framed display 152 mm tall.*

Catalogue C

Catalogue of a Systematic Collection of British Fossils [White Watson, Chatsworth 1804].

Notable inclusions here are specimens of galena, sphalerite, calcite and baryte from the Earl Ferrer's mine, now totally under water, at Staunton Harold in Leicestershire.

Catalogue D

Catalogue of a Collection of Fossils, The Productions of Cornwall [White Watson, Chatsworth 1804].

The majority of extant specimens from Georgiana's Cornish suite are cassiterite, copper and cuprite. Some of the latter were once good pieces, but have tarnished and darkened with the passage of time. The most interesting item in the Catalogue is No. D-254: *Arborescent Native Copper, Inlayed on an oval of White Statuary Marble, surrounded with black marble and a white frame by White Watson*. It is a rectangular slab of white marble upon which several flat pieces of arborescent copper have been glued, not inlayed (Fig. 30). This arrangement is surrounded by an oval mount of black marble and the whole is framed by a thin moulding of white marble; its front is glazed. There is no maker's mark or other inscription, and the item is unique among Watson's known work.

Catalogue E

Catalogue of a Collection of Fossils from Scotland, chiefly polished. [White Watson, Chatsworth 1804].

This small collection of Scottish minerals is mostly composed of cut and polished samples of the small but exquisite agate pebbles and nodules for which Scotland is world-famous. The best here are from Montrose. There are also a few small examples of the smoky quartz crystals known, from the locality, as cairngormite. Of an original 64 pieces, 58 survive.

Catalogues F and G

F: Catalogue of the Fossils in the Cabinet in the Closet adjoining Her Grace's Dressing Room; & G: Catalogue [sic].

There were 231 specimens in Catalogue F, of which 164 survive. Catalogue G had 371 specimens, of which 303 have been identified. It is probable that these are mostly specimens acquired by Georgiana during her European exile and may in part be those arranged for her by Henri Struve. These Catalogues contain similar mixes of species, the majority of which are European, including many Alpine rock crystal and smoky quartz crystals (most rather damaged), kyanite with staurolite ("Sappare with red Shorl in micaceous Shistus") typical of material from Pizzo Forno, Switzerland, and adularia. There is a lump of massive pyromorphite from Anglesey (a rarity for the locality), a drawerful of Elba hematites of middling quality (obviously a favourite species at the time), and a plethora of "Vesuvian Hyacinths in the Matrix," most of which is well-crystallized vesuvianite (also known as idocrase) from Vesuvius. There are two specimens of well crystallized gold, and an *Eaglestone*, which no self-respecting 18th century mineral collection should lack: these hollow rattling ironstone nodules were once supposed to be found in eagles' nests and were imbued with all manner of occult powers, from combating miscarriage to curing gout.

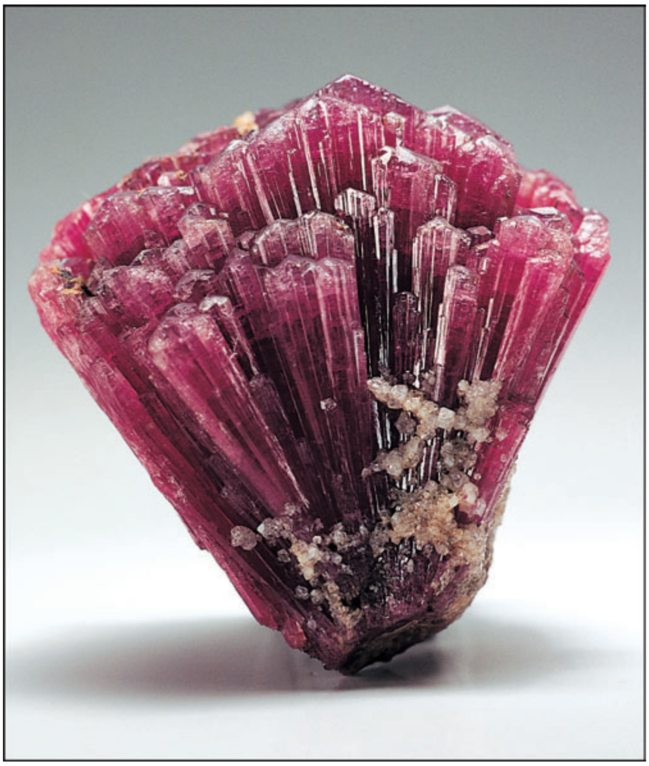

Figure 31. *Siberite, a variety of tourmaline, from the Urals.*

Other than the Watson tablet, the most elaborately described item in the whole collection is the first in Catalogue F: *A stone which fell from the Clouds*. The entry contains a detailed account of the occurrence by "Mr Santi, [Giorgio Santi (1746-1822)] the Professor of Natural History at Pisa," who may, or may not, have supplied the specimen: *On the 16th of June 1794, at Pienza near Radifocini [sic], a dark and dense Cloud was discovered at a great height above the horizon, coming from the South east, that is, in the direction of Mount Vesuvius, which may be about 200 horizontal miles distant – from their height the Cloud was heard to issue noises like the discharge of several batteries of Cannon: it then burst into flames, at which moment fell a Shower of Stones, for seven or eight miles round, while the Cloud gradually vanished – These stones are various, being composed of grayish Lava, exactly resembling what is found on Vesuvius, and Mr. Santi, who took infinite pains to investigate this Phenomenon, is perfectly convinced, that the Cloud rose from Vesuvius, which was at that moment disgorging fires*. However, it is undoubtedly part of the meteorite shower of San Giovanni d'Asso (or Lucignano d'Asso) near Siena, an extremely important event in the history of meteorite science. In 2002, a piece of "Pallas's Iron" was discovered in a Chatsworth attic. It had been purchased from the collection of Alexander Crichton in 1827. This is another of the world's most famous meteorites. The original 700 kg mass was discovered some 230 km from Krasnojarsk, Siberia, in 1749, and was excavated by Peter Simon Pallas (1741-1811) of the St. Petersburg Academy of Sciences in 1772.

Several other specimens are also associated with well known scientists: Specimen F-219 is a piece of "Porphyry" obtained "from the very top of the highest point of the Mount St. Gothard" by Lieutenant General Benjamin Thompson, Count Rumford (1753-1814). Specimens of "*Sydneia of Terra Australis*" and amazonite were donated by the chemist and mineral collector Charles Hatchett (1765–1847) who analyzed Sydneia in 1798. Liversidge (1882) describes the material as "of no importance" but says of Hatchett's paper that "it contains probably the first analyses of any mineral from this Colony [Australia]." Sydneia had first been brought to England by Sir Joseph Banks, and was examined by Josiah Wedgwood (1790) for its potential for porcelain manufacture. It is an impure clay (probably kaolin) derived from altered granite.

By contrast to the majority of Georgiana's specimens, which have little aesthetic interest, many of Hart's specimens are of considerable beauty. Of particular note is a superb example of the rare raspberry-red siberite, a variety of tourmaline from Shaitansk, near Mursinsk, in the eastern Urals (Fig. 31), and an associated group of very dark green prisms. These were lots 2087 and 2082 from the Sowerby sale of the Crichton Collection, and Joseph Wagner illustrated both pieces life-size in his 1818 catalogue of Crichton's collection. A sprinkling of pale ivory-white sparkling crystals on one side of the siberite spray appears to be the extremely rare rhodizite, a characteristic associate of siberite from Shaitansk, which is the co-type locality. Wagner considered Crichton's suite of siberite good reason alone to visit the collection, irrespective of its other merits.

Also identifiable from its label and its reproduction by Wagner is a large amazonite feldspar crystal described in the Sowerby Catalogue (lot number 2571) as "The Magnificent sousquadruple Crystal of Amazon Feldspar" and featured life-size by Wagner, who considered it one of the two finest crystals known.

Catalogue W: Heuland Specimens

The Silver Vault at Chatsworth is home to two of the most remarkable pieces in the collection - fine native silvers from Kongsberg, Norway. One is over 25 cm long and curls like a plume of metallic smoke, still lustrous, from a mass of crystallized white calcite (Fig. 32). The other is a thin, sail-like, triangular sheet of tarnished metal, 19 cm high, clasped at the base by a block of grey rock. They were sold by Henry Heuland, then the most famous and well-respected mineral dealer in Europe, with other pieces (including a Greenland tourmaline, a Saxony fluorite, a slab of rose quartz, and a German pyrargyrite) on the 6th April 1820, but how they came to Chatsworth remains a mystery. Hart also bought items from Henry Heuland's famous mineral auctions. On Wednesday 7th May 1834, lot number 512, "The most beautiful group known in this Country of the Amethyst from Rodna, in Transylvania; to be put up at £10", is probably the striking nest of milky, purple, bulbous amethyst crystals sprouting from pyrite-coated rock, which is still at Chatsworth.

Figure 32. *A twisted blade of native silver from the mines at Kongsberg in Norway.*

Figure 33. *The large crystal of vesuvianite from Italy.*

Another highlight of the sale was "The most valuable Crystal known of the Idocrase, from Ala, Piemont; cost 600 francs; to be put up at £24", for which the Duke parted with £30. It is probable that this is the remarkable, deep olive-green, striated, single crystal that was mounted in an oak block and labelled as diopside. When removed from this support it was discovered that the perfect lustrous flat termination of this fine crystal (useful in distinguishing idocrase, now known as vesuvianite, from diopside) had been used as its base. The few small orange grossular crystals on one side are characteristic of material from Ala in Piedmont, though the crystal itself, at 13.5 x 5 x 4 cm, is anything but typical (Fig. 33). Even if this is not the Heuland specimen, it is still one of the largest vesuvianites known from Ala. Also within this collection are two beautiful specimens of heulandite, an orange-red zeolite, in basalts from the Clyde Valley of Scotland, purchased in 1827 (Fig. 34).

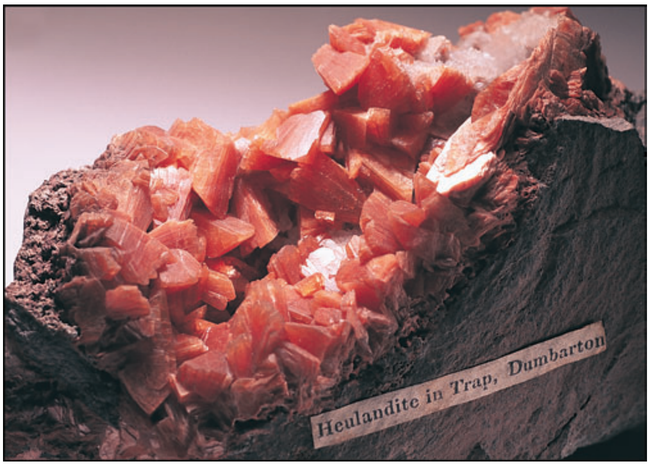

Figure 34. *Beautiful heulandite in Scottish basalt.*

"The Duke's Emerald"

This emerald is an incredible terminated crystal from the mines of Muzo, Santa Fé de Bogota, in Colombia, home of the world's finest emeralds. It is a superb, deep green crystal, perfectly transparent in places, though heavily flawed in others, 5 cm across the pinacoid, and weighing 1383.95 carats. It was for long renowned as the largest and finest uncut emerald in existence. It is said to have been given to the 6th Duke by Emperor Dom Pedro I of Brazil in 1831, though there is no original documentary evidence for this at Chatsworth. It is currently on display in the Natural History Museum, London, in their superb new exhibit "The Vault" at the far end of the main mineral gallery.

Acknowledgements

This paper originates from a visit to Chatsworth House by members of the Society on 17th September 2006. The Society group divided into two, and each toured both the decorative and buildings stones of the House (led by Ian Thomas, who wrote the first half of this text) and also the extensive mineral collections (led by Mick Cooper, who wrote the second half of the text).

The main rooms of the House are open for public access, and the above notes follow the normal visitor tour route (though parts of this may change in future years). The mineral collections are only accessible by special arrangement. The hospitality, assistance and advice of Stuart Band, Archivist in the Collections Department at Chatsworth House is gratefully acknowledged, as are the helpful observations made by Society members during the tour, and by Tapani Rämö and Trevor Ford.

Thanks are due to Tony Waltham for providing most of the photographs of the stones and minerals along the House tour route, to Wendell Wilson for supplying files of Mick Cooper's mineral photographs from the archives of The Mineralogical Record, and to Diane Naylor for supplying photographs from the Devonshire Collection (reproduced by permission of Chatsworth Settlement Trustees).

While this issue was in press with the Society, Mick Cooper died, suddenly and unexpectedly. He had been an extremely knowledgeable mineralogist who worked as curator at the Nottingham City Museum, and was a very active and highly respected member of the Russell Society. His abilities and his kindness will be missed by many.

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Two Notable Earthquakes in 2008

John Carney, John Aram and Tony Waltham

Abstract: Reports on this year's very modest earthquake in Market Rasen, Lincolnshire, and the much larger event in Sichuan, China.

The Market Rasen earthquake

by John Carney

On the 27th February 2008, at 00:56 GMT, an earthquake occurred in Lincolnshire, the trace of which was recorded on BGS seismograms (Fig. 1). It was felt throughout the East Midlands and across England and Wales, with the most distant reports coming from Aberdeen, Truro and Ireland (Fig. 2). Most people would have been asleep at that time and the reason for our apparent alertness may be that the 'felt' part of the event lasted for several seconds, beginning with an audible rumble that would have woken many up. The earthquake was widely reported in the British media, and several TV crews filmed on the same day at places such as Gainsborough, where damage occurred, and also at the British Geological Survey at Keyworth.

The details of the earthquake can be found on the BGS website, some of which is summarised here. Its epicentre (Lat. 53.404° N, Long. 0.331° W) was located approximately 4 km north of Market Rasen. The magnitude is estimated at 5.2 ML, making this the largest earthquake in Britain since a magnitude 5.4 ML earthquake struck North Wales in 1984. Earthquakes of this size occur in Britain roughly every 30 years, so this was a significant event locally. In global terms, however, it was only 'moderate' and one of around 590 earthquakes of this size happening somewhere in the world every year.

In terms of energy released, this event was approximately one million times smaller than the magnitude 9.2 earthquake that triggered the devastating tsunami in the Indian Ocean on 26 December 2004 (each unit of magnitude results in roughly 32 times the energy released - Table 1). Most of the world's earthquakes occur at the boundaries between the Earth's tectonic plates, which are continually moving at a few centimetres per year. This process results in the build up of tremendous stress, which is then released in the form of earthquakes. The British Isles sit in the middle of the Eurasian plate and although we are far from any plate boundary some of this stress is transmitted into the core of the plate, where it combines with stress from other geological processes such as uplift, to create so-called "intraplate" earthquakes.

The Market Rasen earthquake resulted from compression in a NW-SE direction, which culminated in the sudden release of stress on a strike-slip fault some 18.6 km below the surface. This depth is constrained by both nearby and distant instrumental

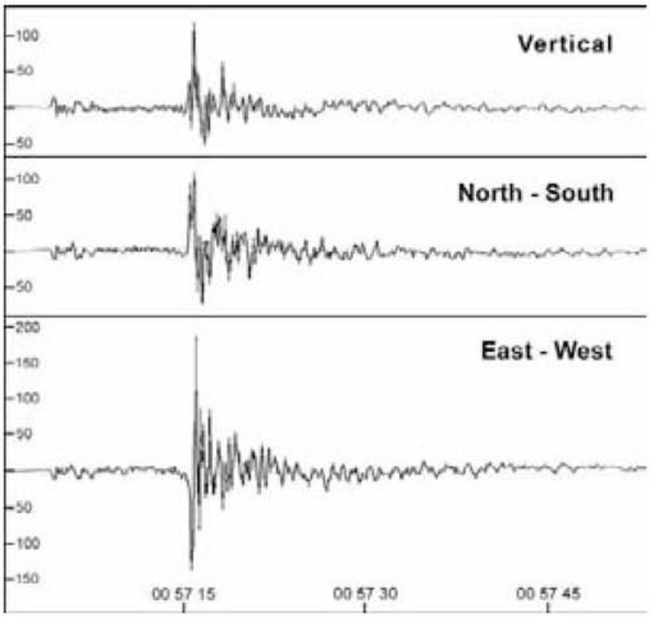

***Figure 1**. The February 2008 event recorded on the Charnwood Lodge siesmogram. The record shows ground displacement on the three directional components, with scales in microns, and times in hours, minutes and seconds (courtesy of BGS Seismology and Geomagnetism section).*

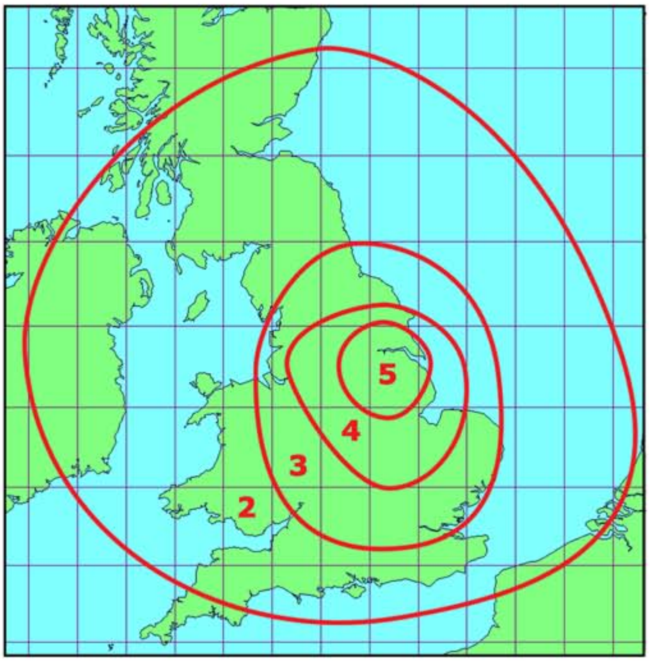

***Figure 2**. Map of the annular zones of earthquake intensity (on the modified Mercalli scale) around the epicentere just north of Market Rasen (after BGS data).*

Relative energy	Richter Magnitude	Example	Max Intensity	Damage at epicentre	Area of influence
	1 - 3	–	I - IV	Social disturbance, no damage	small
1	4	2008 Market Rasen M4.8	VI	Slight	small (Major earthquake for Britain)
30	5	1979 San Francisco M5.7	VII	Little damage to reinforced concrete	(Minor earthquake for California)
				Severe damage to adobe houses	Intensity VI slight damage to 10 km away
1000	6	2003 Bam (Iran) M6.6	IX	Severe damage to many buildings	Intensity VII damage to 10 km away
30,000	7	2005 Kashmir Pakistan M7.6	X	Major damage to most buildings	Intensity VII damage to 50 km away
1 M	8	1906 San Francisco M7.8	XII	Near-total destruction	Intensity VII damage to 200 km away
30 M	9	2004 Aceh (Sumatra) M9.1	XII	Total destruction (and tsunami)	Intensity X severe damage to 20 km away

recordings of the earthquake, including observations from Canada and Alaska. The Earth's crust under Britain has many such faults, but it would be unusual for an earthquake epicentre to plot directly along a surface fault-line. This is because faults are dipping planes and thus any epicentre, when it is projected vertically upwards, will be displaced to one side of the surface trace of the causative fault. This being so, we can find a structure that may have caused the Market Rasen earthquake. In the vicinity of Market Rasen, very few faults of any significance have been mapped in the Jurassic and Cretaceous rocks that crop out. However, this is misleading, because at greater depths, within the underlying Carboniferous rock sequences, some very large-magnitude structures have been imaged on seismic reflection profiles beneath Lincolnshire. One of these is the Brigg Fault, which trends west-north-west where it lies about 10 km northeast of the epicentre. This fault plane dips to the west-south-west, and a plausible average dip of just over 60° would be sufficient for the epicentre to intersect with the fault plane at 18.6 km depth. At this depth, however, the zone of movement within the fault plane would have affected only sub-Carboniferous, 'basement' rocks, probably of Ordovician age locally.

BGS received reports of damage to chimneys and masonry over a wide area, and Gainsborough furnished instructive examples of the types of incident that resulted. A BGS report (Hobbs et al., 2008) notes that the majority of damage involved chimney stacks and chimney pots. Some remained in a precarious state and these areas were mainly cordoned off to pedestrians and in some cases traffic. All observed damage, with one exception, appeared to have occurred on Victorian terraced properties; the exception being a 1922 terraced property. The report goes on to state that: 'The examples of damage to chimneys are typical and were repeated many times over within the area shown. There were several examples of tiles missing and damaged and a couple of broken out-house roofs. These appeared to have been caused by impact from falling chimneys and subsequent making-safe operations. Examples of wall collapse and fresh cracking of outside building walls were not observed, nor was damage to gable ends and roof ridges. Many chimneystacks showed evidence of disturbance by failure of mortared joints resulting in splaying of the stack; individual bricks having dislodged but the whole remaining in place. In some cases individual chimney pots had rotated and tilted or had fallen leaving the stack largely intact'.

Table 1*. Approximate correlations between earthquake magnitude (on the Richter scale) and intensity (on the Mercalli scale), together with the scale and extent of damage caused (from Waltham, 2009).*

There may be grounds for concern about future earthquakes. This is because, in a country of relatively low seismicity on a global scale, the East Midlands is actually a fairly active region, and some significant earthquakes have occurred before. In recent times, one of the largest documented events was the Derby earthquake (actually centred near to Diseworth), in February 1957. It had a magnitude of 5.3 ML and caused widespread damage, not least to the wall of the Blackbrook Reservoir dam in Charnwood Forest; this is the only heavily engineered structure to have been damaged by an earthquake in Britain. Farther back, in 1185, records show that an earthquake caused serious structural damage to Lincoln Cathedral, which is only 20 km south-west of Market Rasen. That event could have been associated with any of the major buried faults in Lincolnshire, and we can only guess where its epicentre was located, or the depth at which it occurred.

If there is a lesson to be learned this time round, it is to ensure that all brickwork, especially old and ornate chimney stacks, are secure and well pointed. Simple precautions like this would not only protect from a future earthquake comparable to the Market Rasen event, but also from strong gales, which may become increasingly common if certain climate change predictions are fulfilled.

Experiencing the Market Rasen event

by John Aram

Our home is in the village of Fulbeck, beneath the escarpment of the Lincolnshire Limestone, about 40 km SSW of Market Rasen and the epicentre of February's earthquake. Shortly before 1.00 am, Carol and I were awoken from our sleep by a noise that was followed by at least six seconds of violent shaking of the bedroom, the furniture, the creaking doors and everything else. The walls shook strongly, though no plaster fell or was cracked, and the pantile roof over our heads in the old stable building could be heard lifting and falling back several times. As soon as I realised that it was an earthquake, and not a lorry crashing into the house, I started counting seconds, since I remembered this was one of the questions normally asked of the duration of the shaking in seismic events. I counted six seconds, but since the shaking had already started I guess it probably lasted in the region of ten seconds in total.

In the morning we noticed that several pictures were hanging at strange angles, a stack of CDs had fallen over and a framed photograph had fallen over and broken. Going outside I was greeted by a large slab of limestone capping that had fallen from the chimney stack on the main part of the cottage, and now lay on a broken slab of York Stone near the door; bits of broken slate, brick and cement were spread around and onto the lawn (Fig. 3). Just below the brick stack (which was intact, as were the two chimney pots), there was a hole in the slate roof and a broken lath was visible, where the capping stone must have fallen on a corner before rolling or sliding down the roof to hit the ridge of the porch over the front door. Here it broke further, sending a smaller part of the stone to one side, damaging slates on both sides of the ridge tiles before reaching the ground.

The insurance inspectors were kept rather busy in Lincolnshire, and other buildings in Fulbeck were also damaged. An adjacent cottage had part of its brick chimney stack fall away, leaving a chimney pot unsupported and leaning at an interesting angle, while the bricks in the stack of another cottage had also separated. Further damage from the earthquake included the snapping of a wooden post that supported an electric light at the entrance to the village churchyard.

Within the village of Fulbeck, eight houses (out of a total of about 150) suffered minor damage, mainly to their chimney stacks. All eight stand in the higher part of the village where they are founded directly on the Marlstone ironstone, while houses in the lower village suffered no visible damage where they stand on the Lias clay. In classical terms, this is the wrong way round, as earthquake waves are amplified in weaker materials, so that the greatest damage is normally on clays and soils. The key factor is the age of the buildings, and the consequent state of their mortar. The damage was all to the older houses (well over a hundred years old), which are those on the dry ground of the Marlstone, while the newer houses in the lower village suffered less even though they stand on clay. This pattern therefore matches that seen in Gainsborough.

Subsequently I heard several further reports of local earthquake damage, including one of a few centimetres of subsidence of a modern bungalow in the nearby village of Bassingham; this lies on the flood plain of the River Witham, so could be a result of compaction of modern sediments. Further data was gathered while manning a RIGS stand at the Lincolnshire County Show soon after. Two chimney pots had toppled in Doncaster, a fridge and washing machine "walked" out from under the work-top in a scullery in Mablethorpe, an old brick farm building had collapsed at Deeping St Nicholas on the peat Fens, and cracks appeared in the plaster of the kitchen in an old (probably Victorian) house at North Hykeham on the Lincolnshire Limestone near Lincoln.

***Figure 3**. Earthquake damage to John Aram's house, where limestone coping fell from the chimney into the front garden.*

The Sichuan earthquake

by Tony Waltham

Two months after the modest Market Rasen event, a major earthquake struck in the Sichuan province of China. At 7.9 on the Richter scale, it caused massive damage (Fig. 4) when it struck at 2.28 pm local time on 12 May 2008, along the western margin of the densely populated Sichuan Basin (also known as the Red Basin). At least 70,000 people died in the earthquake, and another 18,000 were still counted as missing three weeks after the event.

The earthquake originated on the Longmenshan Fault, a well documented reverse fault. The first break occurred 9 km deep beneath the epicentre, close to the town of Wenchuan (which gives the name used in China for this earthquake). Within a minute, the fault rupture propagated towards the northeast reaching to

***Figure 4**. Total failure of concrete buildings after the earthquake hit the town of Beichuan (photo: Xinhua).*

240 km along the fault over a depth of about 20 km. About 1.5 km of surface faulting was observed.

Maps of the Earth's tectonic plates show no boundary through Sichuan, and place it firmly within the Eurasian Plate. But India is moving steadily northwards at about 4 cm per year. This not only compresses and thickens the Tibetan Plateau, but also squeezes it outwards, mainly towards the east - where a plethora of large active faults accommodate the imposed distortion within the Eurasian Plate. On a local scale, the Tibetan block is advancing eastwards and overriding the Sichuan Basin by about 4 mm per year (Fig. 5). The Longmenshan Fault is part of this boundary, and it had been locked until the relentless movement had accumulated enough strain energy to rupture the fault on May 12. Aftershocks, northeast along the fault, reached a magnitude of 6.0, causing yet more deaths and building collapses.

All the world's largest earthquakes are generated on this type of reverse fault, where massive stresses can accrue in zones of crustal convergence and compression. Normal faults in areas of divergence and tension fail under lower stress and so create only smaller earthquakes (faults in situations of pure shear, such as the famous San Andreas Fault, create earthquakes of sizes in between these two extremes). China straddles no convergent plate boundaries, but its slightly smaller intraplate faults that are in compression zones have created many of the world's most lethal earthquakes simply because of the nation's huge numbers of people living around them

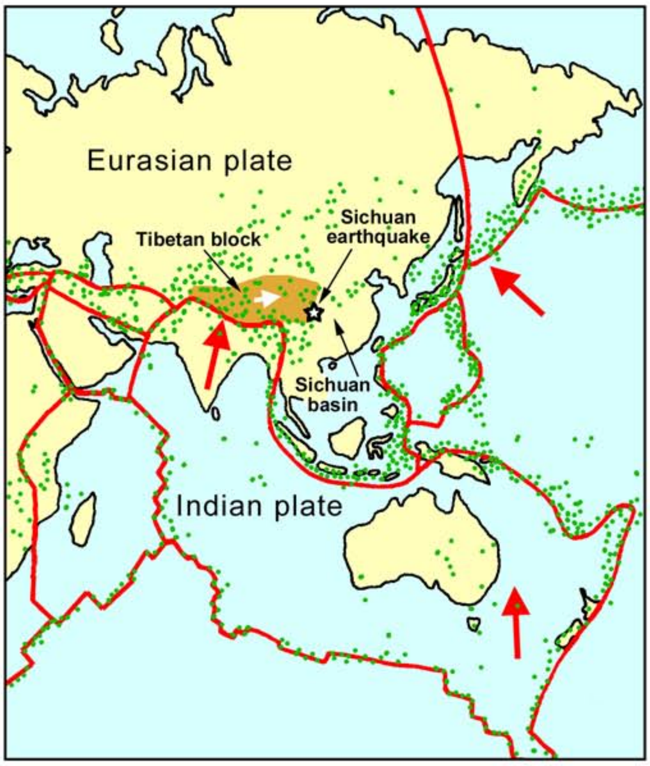

***Figure 5**. The tectonic setting of the Sichuan earthquake; the large dark arrows show plate movements, and the small light arrow shows slower movement of the Tibetan block within the Eurasian plate.*

Mercalli intensity	*Population impacted*	*Features and scale of earthquake damage*
X	600,000	Most buildings collapse (all except those of good reinforced concrete), numerous large landslides, many bridges destroyed.
VIII	4,000,000	Widespread building damage, falling masonry, adobe collapse, many brick houses beyond repair, foundations and roads damaged.
VII	12,000,000 inc. Chengdu 90km away	Damage to poor masonry, plaster falls, chimneys collapse, some small landslides.

***Table 2**. Impact of the Sichuan earthquake, in terms of population and intensity of damage; maximum intensity was recorded as XI.*

Many millions of people were impacted by the Sichuan earthquake (Table 2). More than five million people were left homeless - which is more than the total number in the earthquake's zone of intensity VIII. Over 90 million people experienced ground shaking that was stronger than the strongest experienced at Market Rasen a few months earlier. Concerns about the Three Gorges Dam were totally baseless, as the dam lies 700 km to the east where the Yangtze River cuts through the fold mountains where it drains out of the Sichuan Basin. Like so many other earthquakes in China, the Sichuan event was so destructive because of poor ground conditions - both on the flat land of the alluvial plains and on the unstable slopes of the mountain regions.

Nearly all China's cities and towns (including most of those in the Sichuan Basin) are sited on flat ground - where they are bicycle-friendly. But this also places them on soft alluvial sediments that amplify earthquake waves instead of dampening them; this is the well-known jelly effect (seen when carrying a jelly from kitchen to dining room after turning it out onto a plate as centrepiece for a children's party). Structural damage was exacerbated due to China's recent frenzy of construction, when concrete buildings have not achieved appropriate standards (whether this was due to corruption and bad design or to hasty and inadequate quality control is open to dispute). Especially on soft alluvium, these buildings were among the first to fail (Fig. 6), and when the earthquake unfortunately occurred in mid-afternoon over 11,000 children and teachers died in their collapsing schools. In total, more than five million buildings collapsed in this one earthquake.

The majority of towns built on stable bedrock are those in mountainous areas, where they are then prone to landslide damage. The deeply dissected mountains west of the Sichuan Basin, around the epicentre of the earthquake, are renowned for their slope instability (the tourist trail from Chengdu up to the travertine dams of Jiuzhaigou and Huanglong is a geological treat of landslide features, but is also notorious for the frequent blocking of the roads by fresh landslides in the steep valleys). The May earthquake triggered a host of new landslides. One buried 700 people in a samm town, and another buried a train. There were also 33 landslides whose debris created dams in the valleys, so that towns and villages were drowned by the lakes that were impounded behind them. Such ‘quake lakes’ are a feature of Sichuan’s mountain terrains, and some still survive from the last major earthquake in 1933 in the same region. But these debris dams can fail, as did one in 1933, drowning 2500 people in the resultant flood.

Largest of the quake lakes formed this year is the Tangjiashan, in the valley of the Jian River (Jianjiang or Jianhe in Chinese). Filling to a depth of over 40m, and many kilometres long (Fig. 7) this presented a serious threat should it have been overtopped, when a channel scoured through the landslide debris could release a massive flood wave. The response to such a threat is to engineer a stable spillway across the landslide debris so that the inevitable overflow will cause minimal scour and therefore no great downstream flood. This was done at Tangjiashan, and water began to flow over the debris dam on June 7. Some scouring was inevitable, so that a flood pulse of ten times normal flow caused some further damage in the evacuated towns downstream. Meanwhile, many houses remain beneath the new lake, and add to the toll of this very destructive earthquake.

***Figure 6**. Almost total destruction in the town of Yingxiu, close to the earthquake epicentre (photo: Xinhua).*

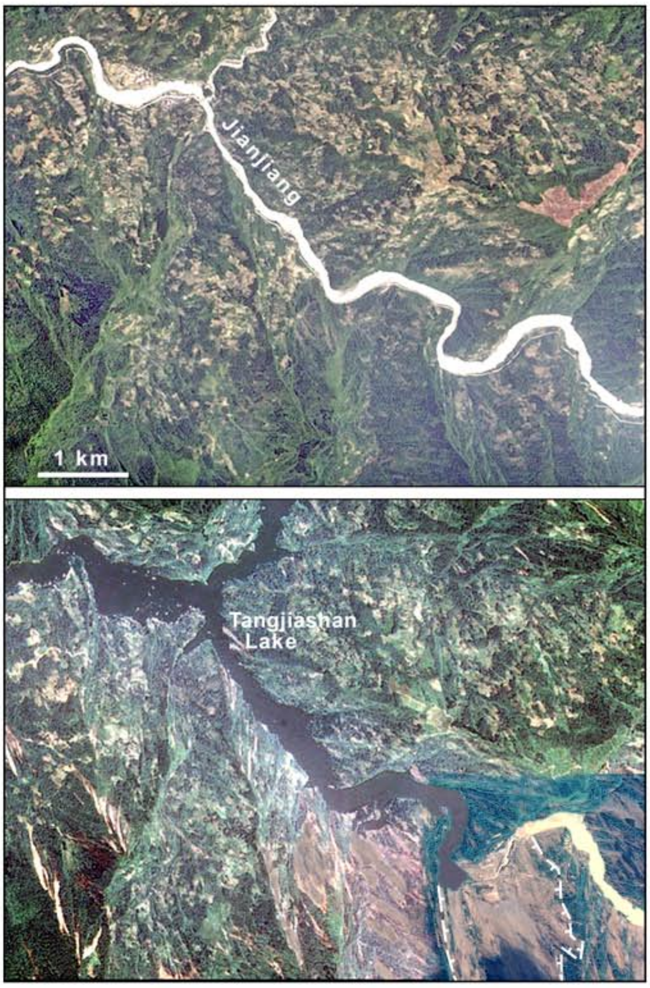

***Figure** 7. A pair of images from NASA’s Earth Observatory, showing the valley of the Jianjiang before and after the earthquake. Deep water in the lake appears dark, while the shallow river and its gravel bed appear light. The lower image, taken on June 8, shows the landslide that dammed the river and just part of the newly created Tangjiashan Lake. The edge of the landslide debris is picked out in white dots, while the new channel cut across it is barely visible except where white water is cascading down its downstream bank to return to the river. Many smaller landslide scars are recognised by streaks of pale soil in areas that are intact forest in the upper image..*

Acknowledgements

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REPORT

On the trail of Lincolnshire plesiosaurs

The search for the Lincolnshire plesiosaurs started with the message 'Geology, not Archaeology', on a Saturday morning telephone call from environmental archaeologist James Rackham. A local builder had just phoned him to report what appeared to be some bones stuck in a stone. Since the discovery had been made in the next village to the author's home in Lincolnshire, he went to have a look.

On the outskirts of Caythorpe, he found Andy Craig, a Derbyshire champion dry stone waller, repairing an old ironstone wall. He had picked up a large stone that had not fitted into the next space, so he had turned it over to see if it fitted better the other way up. There he noticed some dark bone-like patterns. So, well aware that bones of animals or humans found in old walls might be of archaeological significance, he phoned James. A quick inspection and a little gentle washing and brushing to remove some moss and lichen revealed that the stone contained a number of bones, recognisable as the major part of a plesiosaur paddle.

That event started investigations that led back to 1719 and the first known record of what later became known as plesiosaurs. In the process it was revealed that the publications of the Leicester and Cambridge Museums about plesiosaurs contained a number of significant errors concerning their earliest discovery.

The Caythorpe plesiosaur

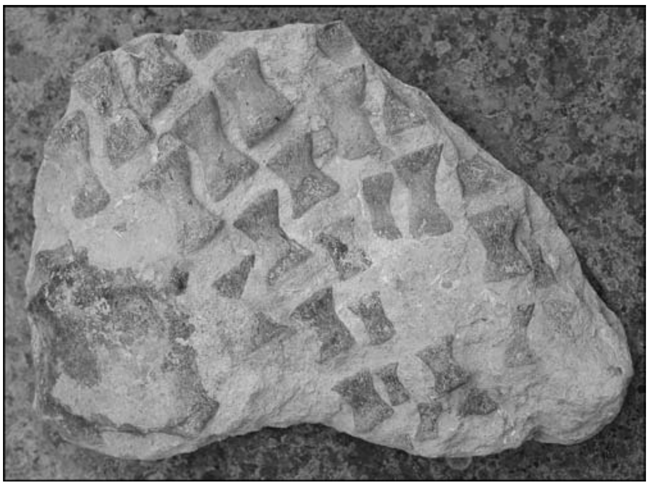
The stone wall under repair was built between 1884 and 1897 by the West Yorkshire Iron and Coal Company when they were extracting iron ore east of Caythorpe village (Squires, 1996). Open-pit quarrying was mainly from an area of over 50 ha acres northwest of the former village railway station on the Lincoln to Grantham line. The Railway Bill for the construction of the line by the Great Northern Railway, was supported by George Hussey Packe of Caythorpe Hall, a local landowner. During construction prior to 1867, a bed of ironstone was encountered for several kilometres along its length near Caythorpe. So, in 1870, George Hussey Packe instigated the mining of ironstone from that part of his land adjacent to the railway. The main purpose of building the original ironstone wall to a height of over 2 m for about a kilometre along the west side of the A607 road towards Fulbeck, was to screen any views of the ironstone workings from his home at Caythorpe Hall.

The Jurassic ironstone bed formed part of the Middle Lias, where the Marlstone Rock is 2.5-4.0 m thick, under a very thin covering of reddish-brown soil (Whitehead, 1952). The beds are believed to have originally been of the minerals chamosite and siderite, later modified by weathering so that they have an average iron content of 20-22%. Production reached a peak of 70,000 tons in 1880 as working proceeded northwards alongside and west of the railway. The Marlstone consisted of two layers that were extracted separately due to their different contents of iron minerals and calcium carbonate.

It seems most likely that the wall was built from the upper layer, a light yellowish-brown, fissile, flaggy limestone that contrasted with the lower, darker, less calcareous beds. Local concentrations of brachiopods occurred in these upper beds, including rhynchonellids (that could be seen in places between the bones on the specimen prior to cleaning). During recent re-mapping of the area the brachiopods were more fully identified and were taken to indicate a Tilton subprovince of the spinatum zone of the Upper Pliensbachian Stage of the Middle Lias, although no zonal ammonites were discovered (Brandon, 1987).

Andy Craig returned to repair the next section of the ironstone wall in 2007. Since making his original find of the paddle bones, he looks more carefully at the stones he handles, even if it slows down his rate of work. This diligence was rewarded by the discovery of an ammonite. Although not well preserved, it was possible to identify the fossil as a *Pleuroceras* species, and probably the zonal fossil *Pleuroceras hawskerense* (Dean, 1961). In this case, the Caythorpe plesiosaur paddle can be attributed with a fair degree of certainty to the top zone of the Upper Pleinsbachian Stage. While the actual species of the Caythorpe plesiosaur remains unknown, there are still many stones to be turned over during the next few years before Andy finishes repairing the wall.

Subsequently Andy took his plesiosaur paddle to a Rock and Gem fair at Newark, where it changed hands and was then professionally prepared by Richard and Mark Hawkes at Stone Treasures of Edwinstowe.



The plesiosaur fossil following a gentle washing and removal of lichens after it was discovered by Andy Craig at Caythorpe; note the fragments of rhynchonellid brachiopod between the bones; the slab is 300 mm long.

The 'Lincoln' plesiosaur

Stimulated by the Caythorpe discovery, and familiar with the 'Lincoln' plesiosaur since school days, the author began to seek further information on plesiosaurs in Lincolnshire. The nearly complete Lincoln specimen had recently been cleaned and mounted by Leicester Museum staff, prior to its display in the new Collections Museum in Lincoln. This specimen was originally presented to the Lincoln City and County Museum in 1906, when the details of its discovery in Foster's Brick Pit were recorded. On the western side of the city, east of the old racecourse, that pit had worked the Upper Lias clays for brick-making, and hence the plesiosaur had been given a Toarcian age. During the recent cleaning and preparation for display, blocks containing some of the bones were found to include zonal ammonites of the Pliensbachian Stage of the Middle Lias, rather than the overlying Toarcian Stage. This cleaning also led to the plesiosaur being more correctly identified as a *Microcleidus*, one of a family of plesiosaurs that were in the early stages of developing the distinctive very long necks characteristic of the later plesiosaurs. The Lincoln specimen thus became the oldest representative of this family in Britain (Richard Forrest, *pers. com.*). The pupils of St. Faith's School, Lincoln, which was subsequently built on the former brickworks site, have now adopted the plesiosaur as their official school badge.

The first known record of a plesiosaur was a specimen believed to have come from Fulbeck, the adjacent parish north of Caythorpe (Taylor & Martin, 1990). In 1719, Dr. William Stukely sent a letter to the Royal Society, including an illustration of the major part of a skeleton of what is now recognised to be a plesiosaur. Stukely described the specimen's 16 vertebrae, nine complete or partial ribs, two thigh bones, a foot with four or five toes and 11 joints of a tail, before concluding that it was not a human and might be a crocodile or porpoise. The actual specimen was later presented to the Royal Society, having been discovered in a slab of 'blue Clay Stone', nearly a metre long and 65 cm wide, that was set by the side of a well in Mr. Smith's parsonage at Fulbeck.

The same plesiosaur fossil after professional cleaning and preparation by Stone Treasures; note that the additional bones suggest there may be parts of two paddles represented here (photo: Richard Hawkes, Stone Treasures).

Although Fulbeck village is built on the Marlstone and has numerous wells, local enquiries have failed to locate a well near the old parsonage sites, and neither is there any record of a Mr. Smith being the parson of Fulbeck in the early 18th Century. Doubts were being raised concerning the location of the discovery of the original specimen, and were confirmed by accessing the original Stukely document (1719) through www.plesiosaur.com. It would seem that Stukely had been informed by a friend, Robert Darwin, (probably a relative of Charles Darwin) of the discovery of what was then believed to be a human skeleton impressed in stone, found at the Rev. Mr. John South's, Rector of Elston, near Newark. After describing the stone as a blue Clay Stone, Stukely went on to state that *it is the same stone (and undoubtedly came from) the neighbouring Quarries of Fulbeck, or thereabouts, upon the Western Cliff of the long Tract of Hills extending quite through the adjacent County of Lincoln*.

Even considering that Stukely was a famous archaeologist and not a geologist, the description of the stone had seemed to be inapplicable to any of the Marlstone or limestone being quarried near Fulbeck at that time. The corrected Nottinghamshire locality for its discovery then raised the possibility that the specimen had come from the Lower Lias, possibly from one of the harder, finely laminated limestones that extend south from Newark and east of Elston.

Examination of the original Stukely specimen, on display in the Natural History Museum in London, helped partly resolve this question. The original specimen (R1330) had been presented to the Museum by the Council of the Royal Society in about 1881. Named *Plesiosaurus dolichodeirus* (Conybeare), its age was given as Jurassic, 208-194 Ma, and the locality was stated on the label as Elston, near Newark, Nottinghamshire. The lithology of the block is, as suspected, quite unlike any material from around the Fulbeck or Caythorpe villages. The closest local match for the lithology would be limestones within the upper part of the Lower Lias clays that underlie the Low Fields west of these villages. As seen locally during the construction of the Leadenham by-pass and in the site investigations for a nuclear waste disposal site at Fulbeck Airfield, many of these limestones are quite distinctive and are commonly rich in *Gryphaea* or belemnite fossils, but no vertebrates have been recorded as far as the author is aware.

At the Museum, a cabinet adjacent to the Stukely specimen held a more complete plesiosaur (14435), from Granby, Nottinghamshire, presented by the Duke of Rutland. Now named *Eretmosaurus rugosus* (Owen) and dated as Lower Jurassic, 208-203 Ma, this specimen is almost certainly the one referred to by Stukely in his original 1719 letter to the Royal Society - *Sir Hans Sloan has a Fish-sceleton amongst his immense Treasure of Curiosities, found near this place, given by the Duke of Rutland*. The matrix of this specimen appears to be similar to that of the Stukely plesiosaur. This raises the possibility that, since both Elston and Granby lie on the western edge of what were formerly known as the Hydraulic Limestones, at the base of the Jurassic, both specimens were from limestone beds close to the base of the Lower Lias.

These beds now form part of the Barnstone Member, at the base of the Hettangian Stage of the Lower Jurassic. In the past, they have been extensively quarried in North Leicestershire and South Nottinghamshire for cement and lime. The Hydraulic Limestones are described as containing a number of limestones and shales that are finely laminated and bituminous, indicating their deposition in anaerobic sea bottom conditions, where benthonic fossils are very rare, but they contain the best preserved vertebrates (Hallam, 1968). This description fits the lithologies of the large, finely laminated slabs containing the Elston and Granby plesiosaurs better than it does the limestones from the higher part of the Lower Lias clays nearer to Fulbeck and Caythorpe. Prior to closure in the 1970s, the Barnstone Cement Works quarries were well known as a source of vertebrate fossils, particularly ichthyosaurs from the lowest beds, and Peter Kent recorded the remains of plesiosaurs from the overlying zones of the Hettangian (Hallam 1968). This seems to further increase the likelihood that the two specimens in the Natural History Museum in London could both have come from these same beds about 300 years ago.

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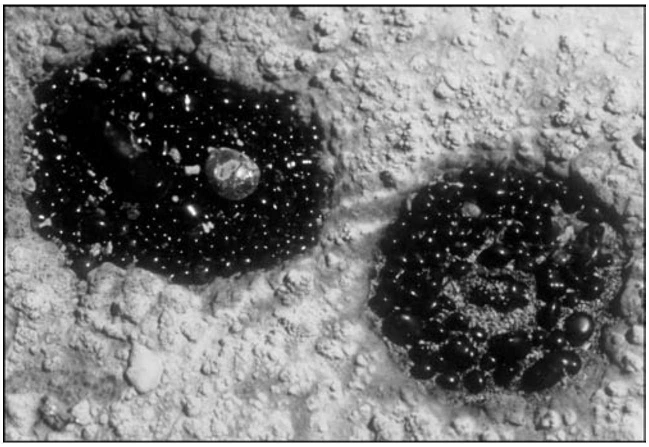
REPORT

Black cave pearls in Derbyshire

Black cave pearls have been found in the Bage Mine, in the eastern part of the Carboniferous Limestone at Bolehill, near Wirksworth. This mine was worked for galena from the 16th century or earlier, until closing in 1908. Its shaft was re-discovered and re-opened in November 1980 by the Wirksworth Mines Research Group. Most of the workings are in the Bage, Butler, Wallclose and Bloodworth Veins, which have been worked on three levels each 17 m apart.

About 200 m north of Hardend shaft, in Bolehill, at the intersection of the Butler and Wallclose Veins on the 200 ft level, the miners worked through a natural cave that rises vertically for 6 m, to grey/black shales exposed in the roof. Meteoric water coming through these iron-rich shales runs down the walls to forms a stalactitic flowstone of hard goethite/limestone, varying in colour from yellow and brown to black. Below these wall deposits, the mine floor is covered in a soft, red, hematitic ochre, which has spread over a large area of the floor on Butler Vein. This part of the mine is generally known as Red Ochre Junction. The miners followed the Butler Vein through the cave by removing a small section of the natural wall.



Water now drips from the exposed mine limestone walls on to the red ochre floor, where several nests of black cave pearls have formed in water that is 8 mm deep. The pearls vary in size up to 6 mm in diameter. Some have been cut to reveal cores of yellow-orange limonite with a honeycomb structure inside a hard, black, shiny, outer shell that is 1 mm thick. This structure appears to originate from a reduction process, whereby a red ochre of soft hematite alters to the lustrous black shell of hard hematite. The drips of water that land in the pearls' pool splash out to form a crust of nearly white calcite on the surrounding red ochre floor. Some pearls have tiny crystalline calcite overgrowths on their black hematite.

(Thanks to Bob King for useful comment on the mineralogy)

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REPORT

Update on Charnian Fossils

These notes record further progress by the Charnia Research Group with documentation and conservation of the various fossils in the Precambrian rocks of Charnwood Forest.

Cliffe Hill Quarry

Numerous old photographs have recently come to light in the Leicestershire Museum Collection, in the archives of Cliffe Hill Quarry and in private collections of retired quarry workers (Figs. 1-5). Of particular interest to geologists were those taken by museum staff Mike Jones and Andy Mathieson in August 1970, when they visited the quarry and collected several ovoid discs that are now in Leicester Museum. They named the discs *Charniodiscus* sp..

Ovoid discs had previously been discovered by Bob King in 1966-67 while searching for minerals. The author's first visits, with an Adult Education group from the University of Leicester in 1976-77, discovered more discs, some quite large, one of which is the holotype of *Cyclomedusa cliffi*, now held in Leicester Museum. In 1980, Trevor Ford collected a further six discs that are now in the Leicester University Geology Department, and in 1995 the large ovoid discs were thought to be medusoids.

In 2006 several of the larger discs in the museum collection were re-examined by the author, and some were found to have large stems (one of which bifurcated) arising from the central boss. It is therefore possible that they should be recognised as *Charniodiscus*, and are not medusoids. Their planes of preservation probably accounts for the fact that a central boss is visible on some, while others have only an outer single ring.

Figure 1. *Large ovoid disc with central boss and faint stem emerging towards the bottom of this photograph from 1970.*

Figure 2. *Large ovoid disc with small convoluted central boss, and bifurcating stem emerging to the right (from 1970).*

The Old Cliffe Hill Quarry (the eastern of the two in Cliffe Hill) is well known for its intrusion of the Charnwood diorite (known previously as markfieldite) into Precambrian volcaniclastic mudstones, siltstones and sandstones of the Bradgate Formation (Fig. 6). These are all overlain by Triassic mudstones and

Figure 3. *The main fossiliferous bedding plane in 1970, (dipping at 55º towards the camera) and overlain by Triassic wadi sediments. A large ovoid disc is visible on the left.*

breccias that crop out in a wadi at the top of the quarry. Access to the quarry is now prevented, and permission for further investigation is not forthcoming. Extraction of rock from the north face is planned to re-start in the future, so the BGS programme of conservation by moulding any accessible discs in the quarry is very important.

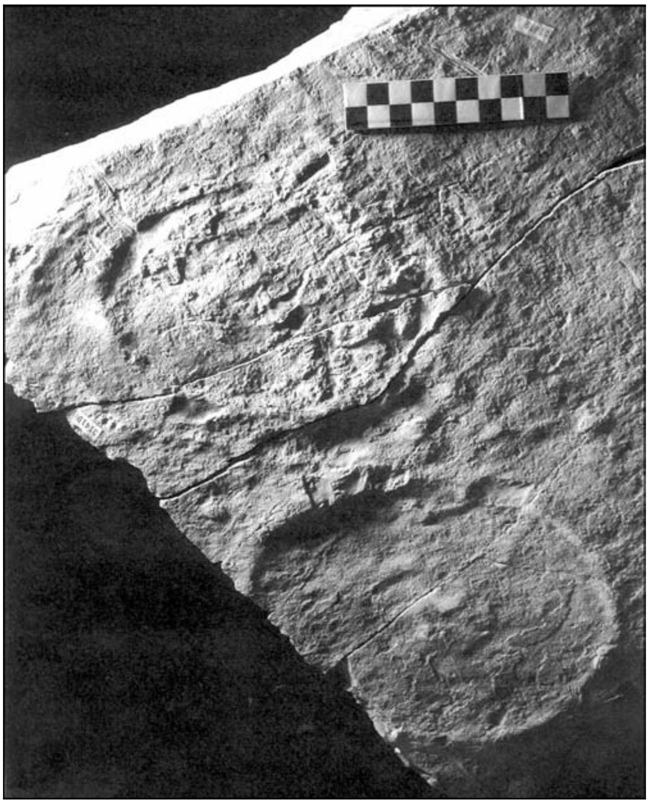

Figure 4. *Cast of the two ovoid discs collected by Trevor Ford in 1980. The lower disc shows a distinct outer ring and central boss, while the upper disc has a wide, flatter outer ring with a more complicated boss.*

Figure 5. *Ovoid disc with central structure and stem emerging on the left.*

Figure 6. *Old Cliffe Hill Quarry looking east towards Markfield, just after the quarry had closed in 1989. The main fossil bedding plane is the most easterly of the three on the upper level, in centre of the picture.*

Outwoods

Three discs were found in the Outwoods, near Loughborough, and represent more evidence to add to the suite of fossils already published (Boynton, 1978). The disc (Fig. 7) on a loose block was given to the author by Ben Bland. It is a multi-ringed disc similar to those on the main bedding plane; it contains three discs and a cast is now held by the British Geological Survey. The two smaller discs (Fig. 8) could be juveniles, as they do not show the multi-rings of the larger specimens. These discs were identified as *Cyclomedusa davidi*, which is a fairly common medusoid within the Ediacarian fauna. Later

Figure 7. *The disc, 45 mm in its longer dimension, on a loose block from Outwoods.*

Figure 8. *Cast of two smaller discs each 18 mm across.*

suggestions however indicate that they may be *Kullingia* (pers comm. Jim Gehling), or a chondrophore comparable with the modern jellyfish *Velella*, or indeed they may be forms of unknown affinity that just lay on the sea floor. There seems to be little evidence of a stem emerging from the discs. They are often found associated with microbial matting that is being increasingly recognised in the Charnian rocks of Charnwood Forest.

Ives Head

Another fossil was discovered on the main bedding plane at Ives Head in northwest Charwood Forest, from where *Ivesheadia lobata, Blackbrookia oaksi* and *Shepshedia palmata* were found previously (Boynton & Ford, 1995). Since the initial discovery, "pizza" discs have been found in Newfoundland, and some have been referred to as Ivesheadia sp.. The new Ives Head fossil is reminiscent of those described from elsewhere. It shows a roughly quadrilateral shape with a possible stem emerging at the left hand side (Fig. 9). Within the margin are numerous raised pimple-like structures which may lie on branches and may be buds from which new colonies grow. On the left side there could be a series of finer branches. This could be another rather weathered *Ivesheadia*, rather than the lobate form *Ivesheadia lobata*, or it could be a new species or a variety of microbial matting.

Figure 9. *The new fossil from Ives Head*

Acknowledgements

Grateful thanks go to Martin Bird, John Carney, Joan Dwyer, Mark Evans, Paul Gostelow, Horace Gamble, David Kibble, John Murray, Maurice Preston, Terry Riley and Gill Weightman for their discussion and loan of photographs.

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Helen Boynton

HOLIDAY GEOLOGY

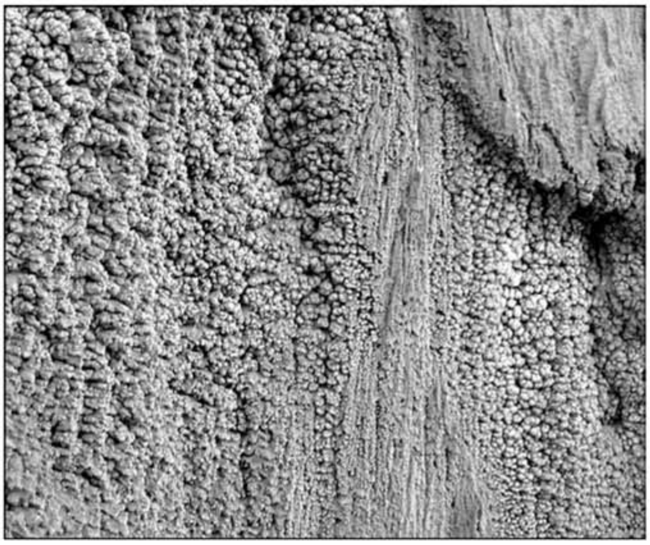
Valle de la Luna, Chile

Northern Chile is almost entirely the product of the subduction of the Nazca oceanic plate under the South American continental plate. This has been going on since before the break up of Gondwanaland, so outcrops include those of a wide age range of rocks that have been uplifted within the convergence zone. The Andes, rising to over 6000 m, encompasses more than 2500 volcanoes, and forms a mountain chain for the entire length of the country along the borders with Bolivia and Argentine. In the northern part of Chile, the parallel coastal mountains rise to 4000 m.

This coast and its hinterland is probably the driest desert on Earth; there are places that have had no significant rain in over 100 years. Snow on the Andes comes from the east, it melts and drains in to basins between the main and coastal ranges, where most of it evaporates in salt lakes. The largest in the world is Uyuni, over the border into Bolivia, while the Salar de Atacama, in Chile, is the second largest. This lies at an altitude close to 3000 m. Much of it is within a national park, which has some great scenery, with snow-clad volcanoes forming the eastern horizon, and the rugged but dry, multiple coastal ranges out to the west. Flamingos and other water birds abound. There are a few oasis villages on the streams feeding the salt lakes, and there is mining in some places. The principal salts are halite and gypsum but there are also valuable deposits of boron and lithium salts, all of which are currently extracted.

Within the Atacama Desert, the Valle de la Luna is a popular day-visit for the many tour groups who stop over in the small town of San Pedro, a few kilometres to the east. They go there to see a desert landscape with small hills, cliffs, gullies and small canyons, all exhibiting typical features of sporadic water erosion in the desert. A key outcrop show signs of sedimentary structure, and then on closer inspection a curious surface texture. It is entirely made of halite, common salt, as the tour guides demonstrate with glee. In this area there are 1400 m of alternating evaporates and other sediments that are mostly reworked volcanic ash. The ongoing tectonic activity of the Andes, and the habit of salt domes to intrude upwards through the sedimentary sequences, keep fresh some splendid landscapes; serrated ridges of upturned strong beds create the barren terrain with their supposed lunar connotations that gives the site its name - inappropriate perhaps, but still very spectacular.

Alan Filmer



Surface texture of the halite rock at outcrop.

The view northeast from a fault scarp within the Valle de la Luna, across the distant Salar de Atacama towards Volcan Lincancabur, 5916 m high.

Strokkur, Iceland

Even if Iceland is only seen in day-trips off a cruise ship, the one essential is the Golden Circle, from Reykjavik out to Thingvellir, Gulfoss and Geysir. And the highlight is at Geysir, for performances of Strokkur.

Geysir itself, the classic geothermal waterspout after which all others in the world are named (though distorted to *geyser*), was the original great tourist attraction in this part of the Icelandic wilderness, throwing water over 30 m into the air. But the intervals between its eruptions steadily increased through the 1800s, until it was barely once a month. Subsequently, eruptions were induced by dropping soap into the vent, but this very un-green practice has now been stopped. Since Geysir's hydrology was modified during an earthquake in 2000, it has again become active on a daily basis, but normally only as modest overflow cycles, though fountains a few metres high do occur occasionally.

Compensation is provided in grand style, by Strokkur, which lies only 100 m from Geysir. This reliably erupts every 5-10 minutes, hurling a burst of water 10-20 m high. It is a magnificent sight, a classic geyser eruption and a tourist winner. While anyone's great geyser tour may justifiably focus on America's Yellowstone, Strokkur probably ranks as the world's finest single geyser because of the unique way in which each eruption starts - with "the dome".

Every geyser eruption relies on the "flashing" of steam, whereby water turns instantly to steam when its confining pressure decreases past a critical limit. This pressure decline is created by the steady geothermal heating of the groundwater in the conduits that feed up to the geyser; some high pressure steam is created, but the heated and expanded water also declines in density. Both these changes force water up and out of the geyser conduits, until the reduced pressure in the system allows more water to flash into steam - and so starts the rapid chain reaction that appears as an eruption. Vent overflow of water is the classic sign of an impending geyser eruption, and is normally followed by little squirts and fountains that rapidly build up into the full-height water spout.

But some freak of its hydrology allows Strokkur to be different. The arrival of its flashing steam is not in dribs and drabs, but is in one great mass - which can be seen rising through the vent pool, and then lifting its surface into a perfect green dome, before this bursts at the top to create the big fountain. The rise of the dome of water lasts for only a second or two, before it is breached, but there is no other sight like it.

From month to month, the interval eruption can vary by a few minutes; so can the eruption height and the amount of steam that may partly hide the view; but Strokkur is always both mesmerising and beautiful.

Tony Waltham

A sequence of images showing the initial stages of a Strokkur eruption, where the mass of steam bubbles rise through the vent pool and lift the water into a smooth dome, before bursting upwards to drive more water to the full eruption height (which goes way off the top of the photograph).

EXCURSION

Oilfields of the East Midlands

Leaders: Paul Guion; Paul Hargreaves (Star Energy), and Kevin Topham (Duke's Wood Oil Museum)

Sunday 18 May 2008

The objective of the field excursion was to examine an outcrop of the Crawshaw Sandstone, the principal hydrocarbon reservoir of the East Midlands oilfields. This was followed by a tour of the surface facilities at the Welton oilfield, near Lincoln, operated by Star Energy, and a visit to the Duke's Wood Oil Museum, on the site of the former Eakring - Duke's Wood oilfield.

Hydrocarbon exploration in the East Midlands was initiated during the First World War as a consequence of government concern about security of supplies, and small quantities of oil were found within early Carboniferous rocks at Hardstoft, Derbyshire, in 1919. However, production was only a few barrels per day, and ceased in 1927. Some exploration took place between the wars, but nothing of major significance was found; however, oil seepages in collieries suggested that oil exploration in the East Midlands may be fruitful. A major exploration effort took place just before and during the Second World War, aided by experts from the USA, resulting in the discovery of the Eakring - Duke's Wood, Caunton and Kelham Hills Oilfields from 1939-43, with the oil being produced mainly from late Carboniferous sandstones. After the war, BP discovered numerous small oilfields in the 1950s and 1960s, benefiting from the wealth of NCB coal exploration data.

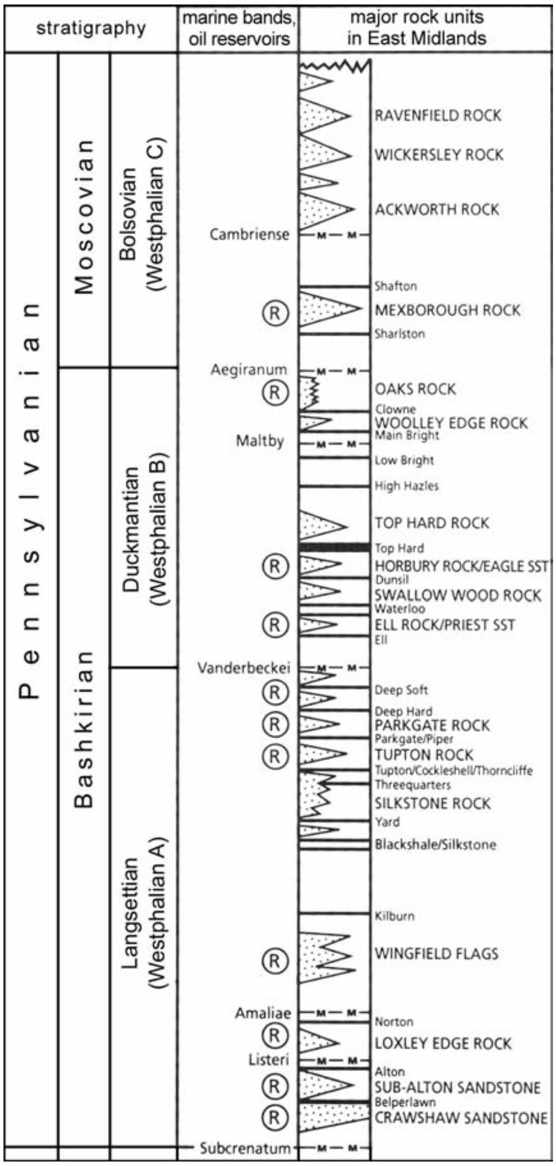
Exploration virtually ceased in the late 1960s, but oil price rises resulting from the 1973 Middle East War prompted a new phase of exploration, leading to the discovery of the Welton Oilfield, Britain's second largest field, several smaller fields, and a significant gas field on the Lincolnshire coast. BP pulled out of the area in the 1980s, and several smaller companies took over BP's interests, continuing to discover and develop new fields. A new round of exploration is now taking place, and further discoveries are anticipated.

Westphalian geology

Although there are minor occurrences in Lower Carboniferous (Visean and Tournaisian) rocks and some production from the Namurian, the majority of hydrocarbon reservoirs are of Westphalian age. These rocks consist of sandstones and mudstones with interbedded coals, which are considered to have been deposited in delta plain environments.

Marine fossils are lacking throughout much of the sequence, but a number of thin, laterally-extensive marine bands, with distinctive goniatite faunas, are present, which have been extensively used to provide a refined biostratigraphical framework, and generally have a good gamma ray response on geophysical logs, enabling correlation between oil wells. Former extensive NCB exploration and production yielded a wealth of data, with coal seams being chemically 'fingerprinted' enabling precise correlation, but further to the east, away from former mining areas, correlation is less certain. Between the marine bands, there is much vertical and lateral variability of rock bodies, creating a challenge for exploration geologists.

In the late Carboniferous, a major basin, the Pennine Basin, existed between landmasses situated in the area of the Scottish Southern Uplands Massif to the north, and the English midlands to the south. This basin is thought to have developed as a result of late-Devonian to early Carboniferous rifting which occurred in response to back-arc lithospheric stretching induced by a northward-dipping subduction zone in southern Europe. This crustal extension gave rise to a series of relatively small, linked sub-basins with their corresponding fault-bound blocks. The formation, position and orientation of these



Stratigraphy of the Westphalian A-C of the East Midlands, with the main hydrocarbon reservoirs, coal seams and marine bands; the column covers about 940 m of strata (after Guion et al., 1995).

The 'Three Ships' outcrops showing planar cross bedding in the Crawshaw Sandstone on Birchen Edge.

extensional sub-basins were controlled in part by inherited Caledonian structures. The basins have an asymmetric profile with thickening of sediment into the hanging wall, typical of tilt-block half-grabens. The basins accumulated thick mud sequences, particularly in the Dinantian and early Namurian. Differential subsidence between blocks and basins produced disproportionate thicknesses of Carboniferous sediments in the troughs or gulfs, with condensed sequences on the blocks.

Namurian deposition took place within the inherited Dinantian palaeobathymetry during a post-rift phase of basin development. In the East Midlands these elongate basins, include the Gainsborough Trough, Edale Gulf, and Widmerpool Gulf. Basins were filled progressively from north to south through the Namurian. By uppermost Namurian times the separate identity of the blocks and basins had progressively reduced, and by the Westphalian A, sedimentation was influenced more by regional subsidence related to thermal sag.

In Namurian times, clastics arrived from a northerly igneous and metamorphic source, thought to be in East Greenland, and were transported and deposited by major fluvio-deltaic systems. These systems carried sediment across the East Midlands shelf, where they consequently swung towards a west-northwest trend, broadly parallel to the axes of the sub-basins, depositing thick sand bodies. More rapid subsidence took place within the basins, which continued to be infilled with sediment. The East Midlands Shelf remained a positive feature throughout Namurian times when thin, condensed, or incomplete sequences formed. Marine bands are sometimes absent or poorly developed on the more elevated shelf areas, which may be either a consequence of non-deposition or erosion. The Namurian sediments generally rest on Dinantian strata. In the basins the contact is often conformable, but on the shelf-basin margins there is commonly an onlap unconformity and sometimes an erosional contact between the Dinantian and Namurian; in parts of the subsurface. especially on shelf areas, the entire Namurian may be absent, with Westphalian rocks resting on Dinantian or older strata.

A gradual change of sedimentary style took place from late Namurian times into the Langsettian (Westphalian A). The basal Westphalian Crawshaw Sandstone is similar in style, provenance and gross petrological characteristics to the underlying Namurian, and contemporaneous tectonics influenced palaeoflow and sand body development. However, higher in the Langsettian, by the time of deposition of the Wingfield Flags, above the level of the Amaliae Marine Band, marine incursions were generally rare, channel sandstones were generally fine grained, contemporaneous tectonic influence was subtle, and a significant change in provenance occurred, with dominant flows from the west.

The Crawshaw Sandstone and its subsurface equivalents form the principal hydrocarbon reservoirs. It outcrops as coarse pebbly sandstones in some areas, and fine to medium micaceous sandstones elsewhere. Production has also been obtained from a number of other Westphalian sandstones, particularly at the horizons of the Loxley Edge Rock and the Tupton Rock. These and other sandstones above the Wingfield Flags of western derivation are finer grained, 'dirtier' and less permeable than the underlying northerly-derived sandstones.

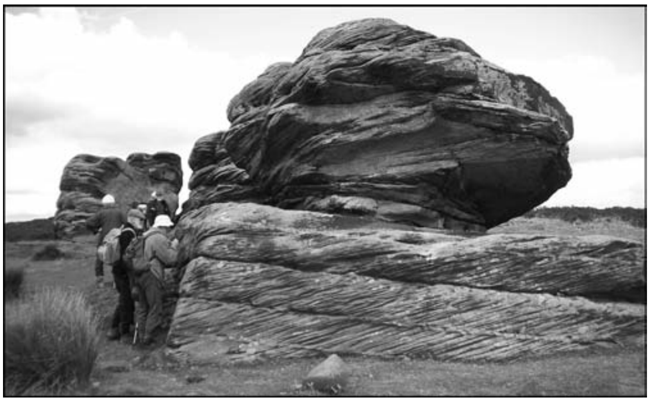
The Variscan orogeny in the late Westphalian to early Permian resulted in the non-deposition or erosion during the latest Carboniferous and early Permian and inversion of half-grabens such as the Widmerpool Gulf, with the development of inversion anticlines. Hydrocarbons accumulated in these structures, if they had sufficient four-way closure, such as at Eakring and Welton. The thick mud-rich sequences within the basins which are considered to be distal prodelta mudstones provided the main source rocks for the East Midlands oilfields. Geochemical studies indicate an origin from mixed marine/terrestrial kerogen. In addition, Westphalian Coals provided an abundant source of gas, but only limited oil. Regional seals in the East Midlands hydrocarbon province are the marine bands, such as the Amaliae Marine band, deposited during episodes of raised sea level.

Birchen Edge, Derbyshire

The party parked at the Eric Byne Car Park near the Robin Hood pub, just off the A619 Baslow – Chesterfield road [SK281722], and followed the ascending path to the outcrop of Crawshaw Sandstone just below Nelson's Monument [SK280728].

Birchen Edge is a west-facing edge typical of those in the eastern part of the Peak District, where up to 15 m of Crawshaw Sandstone are well exposed; however, the thickness at outcrop is undoubtedly less than the full thickness, which is in excess of 30 m in nearby boreholes. The Crawshaw Sandstone is the lowest major Westphalian A (Langsettian) sandstone and lies between the Subcrenatum and Listeri Marine Bands. It is usually overlain by a thin coal, variously termed the Belperlawn, Soft Bed or Coking Coal. Between this coal and the Listeri Marine Band, there is a variable development of strata. In many areas, this interval consists of up to four cycles of thin coals, seatearths and mudstones containing Carbonicola or Lingula. However, sandstone may also be developed in this interval in certain areas, termed the Sub-Alton Sandstone, which may locally be thick and oil-bearing (e.g. Bothamsall Oilfield). The Listeri Marine Band possesses unusually high radioactivity, and thus can usually be readily detected on gamma-ray logs, enabling the underlying Crawshaw Sandstone to be identified in the subsurface. It was previously miscorrelated with the underlying Namurian Rough Rock both during early surface and subsurface mapping, so in the early days of exploration, there was uncertainty regarding which horizons were producing oil.

The Crawshaw Sandstone at Birchen Edge consists of coarse-granular, kaolinitic sandstone with pebbly horizons containing quartz and altered feldspar clasts. Above the main outcrop is Nelson's Monument erected in 1810, and three isolated outcrops with carved names commemorating his ships Royal Soverin (*sic*), Victory and Defiance. These are separated from the main outcrop by unexposed ground, suggesting that the Crawshaw Sandstone occurs as two leaves, separated by soft mudstones. The dominant sedimentary structures, both of the main outcrop and the isolated outcrops above, are planar cross bedding to broad trough cross bedding, with some massive or horizontally stratified beds. Laterally-extensive, low-angle surfaces overlain by pebble conglomerates may be traced along the outcrop. Large sets of cross stratification with smaller 'intrasets' suggest that small bedforms migrated in a variety of directions on the fronts and backs of larger sand bars. In general, there is an upward diminution of set size. Palaeocurrents, measured from the orientation of cross bedding, are mainly directed to the west on the main outcrop, although those on the 'Three Ships' are in a more northerly direction.



Society members examining planar cross bedding in the upper leaf of the Crawshaw Sandstone on Birchen Edge (photo: Tim Pharaoh).

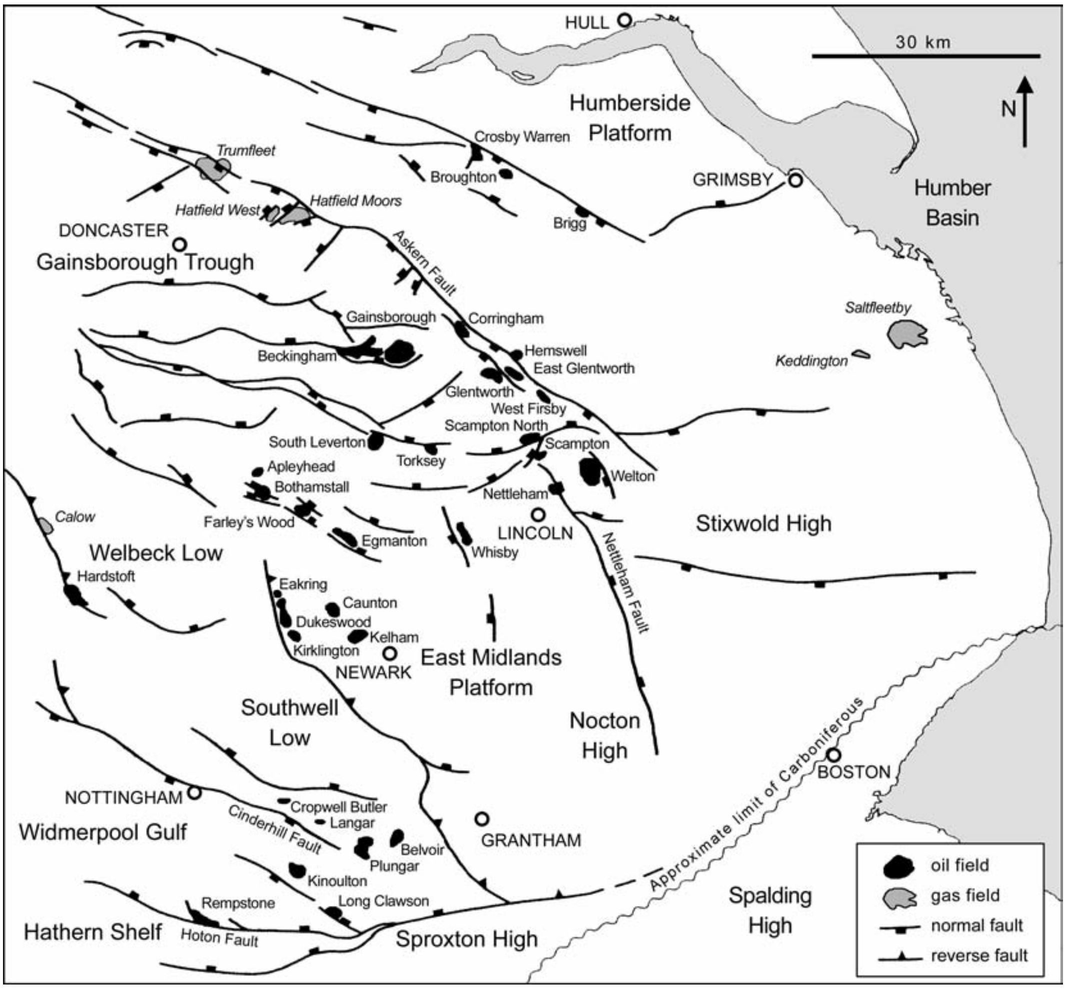
The Crawshaw Sandstone at this locality is interpreted as the deposits of braided low-sinuosity fluvial systems that crossed a delta plain and fed fluvial-dominated deltas. Transverse to lobate bars were present, with superimposed smaller dunes. Gradual upward reduction of set size is attributed to gradual abandonment of given reaches of river, causing bedforms to gradually diminish in size. Birchen Edge coincides with the axial region of the Edale Gulf, and the westerly-directed palaeocurrents are believed to indicate flow of the fluvial system from east to west along the gulf. However, south of Birchen Edge, and on the 'Three Ships', palaeocurrents are generally from a southerly or southeasterly direction. The palaeocurrents from the south were from a slightly later channel system flowing along the Widmerpool Gulf and turned north towards the Edale Gulf.

Thick channel sands are present at this horizon in the Edale Gulf, the Widmerpool Gulf and the southeastern part of the Gainsborough Trough, as well as on some shelf areas. The thickest developments of sandstone appear to be in the Edale Gulf, suggesting higher rates of subsidence than in adjacent areas, possibly as a consequence of movement on bounding faults, or alternatively as a consequence of differential compaction. In addition, the Ashover and Crich Anticlines may have been active during Crawshaw Sandstone sedimentation, causing local deflection of palaeocurrents, lateral replacement of channel facies by overbank and interdistributary facies, and resulting in the development of thick coals on their crests where subsidence rates were lower.

The Crawshaw Sandstone is petrographically similar to underlying Namurian sandstones, with a similar northern provenance, but with an additional contribution from the Wales-Brabant Massif. Tectonic elements, such as the Widmerpool and Edale Gulfs and the Wales-Brabant Massif, deflected the fluvial systems to the west or north, so that in some cases they appear to be flowing towards their source area.

Welton Gathering Centre, Lincolnshire

The Welton Gathering Centre [TF045748], stands near Reepham, situated about 7 km northeast of Lincoln, close to the A158, serving the Welton Field and a number of adjacent fields. Crude oil from the Welton Field, plus a number of satellite fields such as Scampton North, is piped to the Gathering Centre. Water and gas are removed from the oil, which is stored in tanks before being transported to the refinery at Immingham on the East Coast. Gas, which is produced along with the oil, is used to generate electricity on site. The Welton oilfield was originally discovered by BP in 1981, and production commenced in 1984. The Crawshaw Sandstone at the base of the Westphalian is the largest reservoir (of nine) on the field, and has been the principal objective of most wells. It sits with marked unconformity on Visean limestones, and lies at the base of a sequence comprising three stacked channel deposits, termed



Main accumulations of oil and gas, and the major faults, within the East Midlands hydrocarbon province (after Fraser and Gawthorpe, 2003).

Units 1, 2 and 3. These units form a sequence broadly termed the 'Basal Succession' of which the top corresponds to the laterally extensive Amaliae Marine Band. This is a strong seismic reflector and enables the Basal Succession to be mapped on a regional scale. The aforementioned Listeri marine band (top of Unit1/Crawshaw sandstone) is discernible from well logs, but does not provide a strong seismic reflector.

The field is located on the East Midlands shelf near the southeast margin of the Gainsborough Trough. The adjacent Basal Succession fields on the shelf, Cold Hanworth, Nettleham, Stainton, and Fiskerton Airfield, share similar reservoir characteristics.

The Basal Succession at Welton was originally interpreted to be highly compartmentalized by a series of NW-SE faults dissected by NE-SW strike-slip faults. Many of the compartments were thought to have slightly different geochemical and fluid properties. Recent work, including data acquired from newly-drilled wells suggest that many of the faults are not sealing, and fluid contrasts can be explained by a tilted oil-water contact.

The Welton field employs about 70 wells, many of which exist as sidetracks from original 'donor' wells which subsequently watered out. Production also occurs from shallower higher horizons in the Westphalian A, namely the Parkgate, Tupton, Deep Hard, and Deep Soft Rocks. The laterally-extensive Deep Soft Coal is the prominent seismic event used to map this sequence. Numerous re-completions also exist, as rates have declined and lower-rate targets (usually higher in the sequence) are then brought on stream. Production from the Basal Succession has exceeded 13 million barrels, and from the secondary reservoirs, around 3 million.

Extraction takes place by means of beam pumping units or 'nodding donkeys'. Although the plant was designed for much higher production rates, production in May 2008 was 1280 barrels/day. The field has changed hands several times, and is owned by Star Energy, which is now a subsidiary of Petronas, the Malaysian oil company.

The Welton oil is somewhat waxy, in common with other East Midlands oils, and is rather 'sour' (sulfur-rich), in contrast to other oils in the region, and facilities are present for the removal of H_2S gas, which is re-injected into the reservoir. The source rock in believed to have been primarily Carboniferous prodelta mudstones deposited in deep sub-basins such as the Gainsborough Trough.

The geology of the field was explained to the party by Paul Hargreaves, the Star Energy Geologist, followed by a tour of the facilities conducted by Peter Marsh, the Facilities Manager.

Duke's Wood Oil Museum, Nottinghamshire

The museum is situated just to the east of the Kirklington - Eakring road on the site of the former Eakring - Duke's Wood Oilfield [SK677603]. The site is also a nature reserve operated by Nottinghamshire Wildlife Trust. The oilfield is now abandoned, but the combined production from both fields has exceeded 6.5 million barrels. However, there are believed to considerable reserves still in the ground, and studies carried out in the 1990s have suggested that it may be possible to obtain further production from these fields, hence there is recent interest in these and adjacent fields. The oil was trapped in a NNW-trending anticline, bounded by a fault on the west. The main reservoir, originally believed to be the Namurian Rough Rock, has been shown subsequently to be the Westphalian Crawshaw Sandstone. Production has also been obtained from other units, including some from the Carboniferous Limestone.

Kevin Topham, a former Anglo-Iranian and B.P. Exploration oil driller, who is now Curator of the Duke's Wood Oilfield Museum, welcomed the party. He has travelled extensively worldwide, giving talks on the first North Sea Gas strike in 1965, and the disaster on Boxing Day of that year when the Sea Gem offshore rig collapsed and sank with the loss of 15 lives. We were introduced to another ex-oilman, Duggie Wallace, who has drilled wells around the world and was working at Duke's Wood - Eaking in 1943 when American oilmen were drilling there.

The party was shown a short DVD presentation made by the BBC, which gave an invaluable insight into the early history of the fields, especially the role of the American specialists who came over from Noble Drilling of Oklahoma to drill wells and produce oil, which was vital to the War Effort. For example, 'Pluto' and 'Fido' were invaluable during the D-Day landings, and both structures were supplied with oil from Duke's Wood. An account was also given of the invention of the turbo jet drilling bit by Sir Frank Whittle, of jet engine fame. This was a significant advance in drilling technology, which was perfected in working oil wells at Duke's Wood.

Nodding donkey at Duke's Wood Oil Museum.

A number of artifacts were examined by the party at the museum including nodding donkeys and well heads, oilfield paraphernalia and documents, oil and core samples and a statue, the 'Oil Patch Warrior', dedicated to the American roughnecks who spent their time drilling for oil in Sherwood Forest. A duplicate of this statue is situated in front of the Chamber of Commerce at Ardmore, Oklahoma, which was visited by Kevin Topham in May 2008. Members of the party also took the opportunity to examine some of the rare flora in the nature reserve, some of which is believed to have been introduced to the site in drilling mud for the wells. The museum has an excellent website, giving a full account of its background and history, at www.dukeswoodoilmuseum.co.uk, and copies of the DVD may be obtained from Mr Topham.

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LECTURE

Marie Stopes - Palaeobotanist and Coal Geologist

A lecture given to the Society on Saturday 12th January 2008 by Dr Howard J. Falcon-Lang of the University of Bristol.

Marie Stopes (1880-1958) was one of the most controversial women of the twentieth century. My mother tells me that that when she was growing up, it was even considered mildly indecent to utter her name. So how did Stopes come to acquire such extraordinary notoriety? First of all, in 1918, she wrote an early sex manual for women. *Married Love,* as she called it, was an instant bestseller. However, the manuscript was very nearly consigned to the dustbin because publishers thought that if women demanded too much in the bedroom they wouldn't get a man at all! If this wasn't bad enough, in 1923, Stopes set up the first birth control clinics in Britain. Death threats soon followed, and one Catholic doctor even argued that her clinics were tantamount to experimentation on the poor. Then, a decade later, as the storm of war was brewing over Europe, she courted the architects of the Third Reich. Together with many intellectuals of that era, Stopes embraced eugenics and Social Darwinism. Her commitment to this philosophy was such that she even disowned her only son after he married a girl who was short sighted. Stopes later wrote of her fear that her descendents would be disfigured by the necessity of wearing glasses!

Passionate about Palaeobotany

But it was none of these extraordinary events that first brought Marie Stopes to my attention, but rather our mutual passion for fossil plants. Marie Stopes, of course, started her career as a palaeobotanist and coal geologist, and spent nearly two decades of her life at the cutting edge of science. I suppose my connection to Stopes comes via Bill Chaloner, the Emeritus Professor of Palaeobotany at Royal Holloway. Bill was my great inspiration as young graduate student and he actually met Stopes himself, in 1952, about the time he was doing his own doctoral studies at Reading. The occasion was a meeting of Geological Society at Burlington House, and he was thoroughly embarrassed when the awesome Marie Stopes was introduced to him. "Ah, dear boy, this is wonderful!" she remarked when told her about his research on Carboniferous clubmoss spores. "Of course, palaeobotany was my *first* love!" That admission may come as a surprise, even to those with a good grounding in the history of geology. Therefore, perhaps it is in order to share something of the major contributions that the young Marie Stopes made to geological science.

Student Years

Stopes first introduction to science came at University College London (UCL) where she read Geology and Botany from 1900-1902. The death of her father at the end of that period of study saw the family fortunes plunge towards ruin. That event might have scuppered any thoughts of any scientific career, but fortunately Francis Oliver, her botany tutor, came to the rescue. Oliver engaged her as his research assistant for a year and what an exciting opportunity that proved to be! Oliver was on the verge of making a great discovery - none other than the recognition that the fern-like plants in the Coal Measures were not ferns at all, but seed-bearing plants. Together with D.H. Scott at Kew, Oliver named these new plants, Pteridosperms, or seed-ferns, and in doing so revolutionised our understanding of the early evolution of land plants. Stopes contributed to this work significantly, tracking down key specimens that proved the connection of seeds to the fern fronds.

That brief taste of research got Stopes hooked and, in 1903, she set off to Munich to undertake her PhD with Karl Goebel. Funded by a Gilchrist Scholarship from UCL, she completed her doctorate on the reproduction of living cycads in only ten months, the first women to graduate from Munich with such honours. How did she achieve this extraordinary feat? Stopes recorded how she typically laboured twelve hours per day, and at the weekend, sometimes worked thirty hours at a stretch with only a weak beef tea for sustenance. This arduous routine clearly took its toll and period photographs depict her in a semi-emaciated state. Probably she also got significant assistance in her work from Kenjiro Fujii, a Japanese expert on *Ginkgo*, who was visiting Goebel's lab at the time. Fujii and Stopes embarked on a romantic relationship that ebbed and flowed for several years, but eventually came to nought.

From Manchester to Japan, and back again

Back in Britain in late 1904, Stopes was engaged as Demonstrator in Botany at the Victoria University of Manchester, her first academic appointment. There she embarked on a study of plant-bearing nodules from the Lancashire coalmines. These 'coal balls' as the nodules were known contained beautiful anatomically preserved plants and everyone who was anyone in palaeobotany had made a study of them at one time or another. Always with the 'big picture' in mind, Stopes was interested in the origin of coal balls. Flying in the face of popular opinion, she eventually proved that these nodules represented mineralized peat, formed as seawater periodically flooded Carboniferous coal swamps. The research was undertaken with David Watson, who at the time was a nineteen-year-old undergraduate student, but later rose to become one

Marie Stopes (1880–1958), studying what appear to be coal ball slides. Although Bill Chaloner has suggested this photograph dates from her year in Munich (based on her Bavarian attire) she appears slightly older than well-dated images from that interval. The photograph was probably taken in 1905 during her time at the Victoria University of Manchester.

of the most influential vertebrate palaeontologists of his era.

As time went on, Stopes became increasingly restless at Manchester. In 1907, she convinced the Royal Society to fund an eighteenth month excursion to Japan. Her stated aim was to locate the earliest remains of flowering plants, but her correspondence shows that another intention was to reignite her affair with Fujii (he had returned home the year before). It must have been an amazing experience to explore the uncharted wilds of Japan and her published diary of the experience makes for entertaining reading. When visiting the northern island of Hokkaido, the British Government insisted that a large entourage of porters and policemen accompany her to protect her dignity. As not one of these had more than a few words of English it must have been an entertaining trip. Later on, she managed to give her entourage the slip and explored rural Japan on bicycle, alone. In the course of her work, she found what were then the earliest known flowers (beautifully preserved in nodules) as well as stunning insect fossils. All these Cretaceous fossils can still be viewed at the Manchester Museum, where she deposited them on her return to Britain in 1909.

The beginning of the end in Canada

In some ways Stopes's return to Manchester was not a straightforward one. Although the University welcomed back the intrepid Japanese explorer and indeed promoted her to Lecturer in Botany, she felt unsettled in this smoky industrial city. She was kept very busy during her first year home, giving lectures about her trip, writing up her diaries, and embarking on a major new palaeobotany textbook, *Ancient Plants,* to accompany her university courses. However, once the dust settled and she had finished organizing at major international palaeobotany conference in May 1910, Stopes decided to depart Manchester for UCL. Ever since her famous work on Pteridosperms with Oliver, she had long held this to be her true "scientific home". However, she had no job lined up and the decision to move much have been a difficult one. Perhaps given that her mother and sister lived in London and she had many local contacts there, she thought work would be easy to come by.

In fact, she didn't have to wait long for the next job opportunity because within a few weeks of arriving in London, Reginald Brock, the Director of the Geological Survey of Canada, got in touch. Brock had a major headache. He was preparing a new set of geology maps for Atlantic Canada but his staff had radically different ideas about the age of some of the key rock units. Brock needed an independent expert to date the rocks using fossil plants and he'd met Stopes on her homeward journey from Japan as she'd crossed North America. Stopes jumped at the chance and by end of 1910, she was rummaging through old museum drawers in Ottawa and Montreal. However, she got more than she bargained for when, at a conference in St Louis, Missouri, she fell in love and got married. The lucky man was Reginald Gates, a Canadian geneticist. Married or not, Stopes still had a job to do, and after a month of fieldwork in Saint John, New Brunswick in 1911, she was ready to give Brock her opinion on age of the contentious rocks. Her major monograph that resulted from this work still stands as one of the enduring classics in systematic palaeobotany and biostratigraphy. It proved once and for all that the rocks were Carboniferous and not Devonian or Silurian as others had earlier argued.

Back in Britain in late 1911, all was not well with the newly weds. Both were continuing to struggle to find meaningful work in London. Stopes did some contract work for the British Museum, producing a catalogue of their extensive collection of Cretaceous plants. Although a few gems turned up in dusty old drawers, it was mostly uninspiring work. Meanwhile, Gates was forced to lecture to biology students at St. Thomas's hospital, a post far below his academic potential. These difficulties alone would have put strain on a young married couple, but a short time later, they took in a lodger, Alymer Maude. Maude was well-known expert on Tolstoy, and almost immediately Stopes began openly flirting with him. By early 1913, Stopes's marriage to Gates had more or less collapsed. A large part of the problem seems to have been that Gates was impotent and Stopes, sexually frustrated. Little could Stopes have realized that this first marriage would have signalled the beginning of the end of her geological research. However, it was her experiences with Gates that inspired *Married Love*, and eventually took her career off in such a radically different trajectory.

The four visible ingredients of coal

However, there was still one final chapter in Stopes's geological work yet to unfold. During the Great War, Stopes developed a renewed interest in coal. This work was not focused on its botanical make-up so much as on its material properties. Coal was the fuel that drove the twilight years of the British Empire and in wartime it was especially important to understand more about its combustion properties. Stopes set to work, studying hundreds of polished blocks, before writing her seminal paper on the "four visible ingredients of coal" and, in doing so, coined the now familiar terms, clarian, vitrain, durain and fusain. The last of these materials is of especially significance to me because I spent my doctoral years studying fusain (or fossil charcoal) and learning what it could tell us about the role of wildfire in Carboniferous coal swamps. Whenever I pick up a lump of fusain-rich coal and it leaves a dusty mark on my hand (just like modern charcoal), I always think of fires raging through the first rainforests to evolve on our planet, and of course, of that great palaeobotanist who laid the foundation for my own work – the infamous Dr. Marie Stopes!

Further reading

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REVIEWS

Lead Mining in Derbyshire: History, Development and Drainage: 1 Castleton to the River Wye, by J.H. Rieuwerts. Landmark: Ashbourne. ISBN 978-1-84306-343-8. £25.

An inevitable part of any mining is the inflow of water, and the lead miners of Derbyshire were no exception to this problem; their many drainage levels are known as soughs. In 1987, Jim Rieuwerts published privately a limited-edition compilation bringing together 30 years of research into widely distributed archives. It covered the 200 soughs then known and is difficult to obtain today. A further 30 years of research, particularly in the National Archives (Public Record Office) at Kew has uncovered so much more material, and the number of soughs has been doubled. So Dr Rieuwerts has found it necessary to expand his previous work into a three-volume set, of which the present book is the first instalment. It covers the northern part of the orefield, from Castleton to the River Wye, including the Bradwell, Hucklow, Eyam and Stoney Middleton areas. Odin Mine at Castleton had at least four soughs at different times.

Apart from soughs, Dr Rieuwerts has taken the opportunity to describe the industry as a whole, with accounts of who worked which mines and when, and how much ore was produced, where figures survive. Much of the history and development herein discussed relates to the 17th and 18th centuries and demonstrates that the miners knew about the geological relationships of the Carboniferous Limestone and overlying shales long before geology as a science was born. They also knew that the interleaved lavas (toadstones) rarely yielded lead ore and, up to a point, they could forecast where lavas might be met. However, their knowledge had its limitations and this book shows that they ran into problems with Cressbrookdale Lava: it extended much further north and east and was thicker than they expected. They also ran into what appear to be volcanic vents where the toadstone could not be bottomed. Hence a few of their soughs in the Stoney Middleton area were abandoned or diverted when they met toadstone. The traditional categorisation of the mineral deposits into rakes, scrins, flats and pipes is followed, although, as Dr Rieuwarts notes, the "pipes" in this part of Derbyshire are not so much mineralised caves as fissures filled with collapsed overburden containing loose lumps of ore. He also includes comments on the "plumbs" and "hadings" of Longstone Edge where the fissure veins are in vertical or in steeply dipping limestone beds on the south side of the Longstone Edge monocline.

I was sorry to see the unique mining enterprise of the Speedwell Mine at Castleton given rather brief treatment; true, it was not a sough, but it was a unique part of mining history. I have not seen most of the archives, so I cannot criticize much of the detail. However, a few improvements could have been made.

I found it difficult to work out some of the Mining Liberty boundaries; they could have been shown on a separate map or added to the existing maps. The important Stoney Middleton area and Moorwood Sough is split between several maps; an extra map would have helped.

The book is illustrated with sections of the Old Series 25 inches to one mile Ordnance Survey maps with mining details superimposed. There is an excellent set of photographs by Paul Deakin, mostly in colour. The book has a comprehensive index, bibliography and list of archives consulted. I did not notice many spelling or type-setting mistakes, but "Astleton" in the contents list stands out. Also the BSA (British Speleological Association) documents are currently in the Derbyshire Record Office, not Lichfield as stated in the appendix. I understand that the electronic transfer of the book from publisher's office to the printer precluded a proof copy being checked for errors. This book should be on the shelves of anyone interested in the lead mining industry in the Peak District. I look forward to seeing Volume 2 (central Peak District) and volume 3 (southern sector) in the next year or so.

Trevor Ford

The Yorkshire Dales: Landscape and Geology, by Tony Waltham, 2007. Crowood Press: Marlborough. 224 pages, 226 colour photos, 48 diagrams and tables, 978-1-86126-972-0, £16.99.

This is a highly readable, wonderfully illustrated and unconventional book. It is divided into three parts, respectively headed *Starting with the Rocks*, *Creating the Landscape*, and *Imprint of Man*, each part having four or five separate chapters. Unusually, the photographs, diagrams and also many pages are not numbered, which could make it slightly difficult for the reader to connect bits of text to the relevant illustration or to use the index effectively. In addition, nearly a third of the book consists of short essays, mainly of two pages each. Mostly, these develop and provide further interesting detail to particular themes; a few describe the work of certain people and a few others describe walks to particularly famous localities. These essays interrupt the running text and perhaps would have been better placed at the end of chapters.

The book is far from being only a review and compendium of other people's work. It clearly includes many hitherto unpublished observations based on the author's own research and experiences, both at the surface and underground over a long period of time; in particular, his long experience of caving with its close association with karst developed especially in the extensive outcrop of the Great Scar Limestone that dominates much of the landscape. In the chapters entitled *Limestone Country* and *Underground* at the heart of the book, the author's knowledge, experience and brilliant photographic skills come to the fore and will lead many to go and see for themselves. A few may even venture underground and "achieve that special thrill of treading where no man has trodden before, right in the heart of a National Park visited by thousands". For those who don't or daren't, the author's photographs of some of the most sensational and beautiful caves make a fine substitute, especially when combined with convincing explanations of how and when they were formed. The extensive and highly photogenic limestone pavements, the most accessible and visible feature of the Dales karst, are also explained

Finding particular scenes in today's world that are closely analogous to those in ancient times is very difficult and two of those chosen in this book, on pages 24 and 69 respectively, entitled "The Askrigg Block 340 million years ago ...." and "The Yorkshire Dales during one of the Ice Age glacial advances ....", don't work for this reviewer. The latter scene would be fine as an analogue for a rugged mountainous area like the Lake District, for example, but not for an area with generally lower more rounded hills like the Yorkshire Dales.

The effects of the last Ice Age on the landforms of the Dales is well described in considerable detail in the chapter entitled *Carving the Dales*. The fact is emphasized that these landforms were shaped by an ice sheet "that surrounded and covered the Dales". In this reviewer's opinion, most previous authors (including himself) have overemphasized the effects of valley glaciation. Indeed, it is debatable whether there even was a significant length of time when valley glaciation was predominant as opposed to ice streams within the general ice cover eroding pre-existing valleys. Perhaps henceforward, instead of referring to for example "the Wharfedale Glacier", we should refer to "the Wharfedale Ice Stream". An important point is also made in the book regarding bedrock influence on valley profiles: thus "the finest of the Yorkshire Dales", i.e those with the best U-shape such as Chapel-le-Dale and Wharfedale, are flanked by the Great Scar Limestone whereas in the Yoredales country "Wensleydale, though fashioned by a more powerful glacier, has had its slopes degraded to more gentle profiles".

The broad scope of the book is shown by the titles of some of the later chapters: *Soils and Plants*, *Mining Wealth*, *Farming the Rock Landscape* and *Landscape to Enjoy*. It is likely to have a far wider appeal than a book only dealing with the geology and is therefore better suited to the general reader. There are a few minor inconsistencies and errors, perhaps the result of insufficient scientific rigour in the editing. Nonetheless, the book is strongly recommended not only to the occasional or regular visitor to the Dales, but also to people who live and work there. Priced at only £16.99, it deserves, and should receive, a wide and enthusiastic readership.

Neil Aitkenhead

Minerals of Northern England, by R. F. Symes and B. Young. 2008. National Museums of Scotlnd: Edinburgh, ISBN 978-1-905267-01-9, 208 pages, 188 photos, £30.

This is a truly glorious record of the splendid minerals that have been found in the north of England, in both the Lake District and the Pennines (as far south as the Craven faults). The pages open with a concise but very readable introduction to the geology and mineralisation. The veins and flats with their copper-lead-zinc ores, alongside the fluorite and barite, are clearly described, as are the unusual nodules of the Seathwaite graphite. Debate over the origins of the hematite sops is reported but not resolved, though the authors do favour derivation from the Permo-Triassic cover where it lies directly on the limestone, with subsequent deposition in karstic cavities.

The main section of text describes the various mining areas, with an emphasis on the known or collectable minerals, and this does provide a very comprehensive and readable overview of both the mining history and what remains to be seen today, though it is not intended as a guide book. There is then a fascinating section on the great mineral collectors, and a bibliography of nearly 400 items (which are not cited as text references). The whole text is superbly illustrated, but then there is also a gallery of 92 photographs, mostly half-page or larger, of the most beautiful specimens of all the mineral species that we are familiar with in far more modest form. There are thirteen lovely images of coloured varieties of fluorite, and another of a superb nail head calcite that really explains the origin of that term.

This is a superb book. It would be difficult to find two more authoritative authors, and they have produced a volume that is a delight to both view and read, and all at an excellent price. There will be few geologists from anywhere north of Potters Bar who will not want their own copy.

Tony Waltham

Geology of Gravestones in Welford Road Cemetery, Leicester, by Helen Boynton, 2007. 24 pages, 40 photos; £7-50 (from 7 The Fairway, Oadby, Leicester LE2 2HH).

This booklet takes the non-geological reader through the great variety of different rock types that have been used for gravestones in this cemetery, which is something of a landmark in Leicester. Charnwood rocks do of course feature strongly, but there are also granites from elsewhere, the usual limestones, and even Italian marbles. The geology is well explained and is very well illustrated (all in colour), so the pages are a delight to turn, though the book's specialist nature and its short print-run do mean that it is rather more expensive than could have been hoped for.

Tony Waltham

The Last Two Glaciations of East Lincolnshire, by Allan Straw, 2008. Louth Naturalist's Antiquarian and Literary Society, and Lincolnshire Naturalist's Union, 46 pages. ISBN 978-0-9539533-6-3, £6.50.

To give an impression of this sequel to Allan Straw's earlier publication on Welton-le-Wold, which was reviewed in *Mercian Geologist* 16(3), 222-3, I will quote from a covering letter from the author - 'My swansong, another sweeping up and stirring the pot job'. Straw is the undoubted doyen of Lincolnshire glaciations and an opponent of orthodoxy.

In this new work, the focus is on the 'Newer Drift' which is assumed to be solely the products of Devensian Glaciation. For more than 60 years now, the author has argued for the recognition of two separate glacial advance phases from offshore into east Lincolnshire, with the first being slightly more extensive than the latter. Importantly, these are considered to be separated by an erosional interval that significantly reduced the 'freshness' of the glacial landforms produced in the first phase. These two-phase relationships have proved anomalous when extrapolated into the other parts of Britain, and particularly so just across the Humber in Holderness. Accordingly they have tended to be overlooked, yet they still demand an explanation. This is the task which Straw sets himself.

Missing is any mention of Rowl Twidale's (1957) study of the north Lincolnshire 'glacial overflow channels', which adopted the classic Kendelian ice-dammed lake model or the biostratigraphical work by Pat Suggate and Richard West (1959). However, the 'knock-on' effects arising from ice blockage of the Humber in creating large glacial lakes is given full consideration, as is the impact on the Trent drainage system. Personally, I remain unconvinced that the earlier advance phase is Devensian, and the evidence presented on dating the Trent terraces could equally be taken to support an immediate pre-Last Interglacial age i.e. MOI Stage 6.

The text is written for a general reader and a glossary of the more technical words is provided. It demands a knowledge of the geography of the eastern parts of the county, but there are numerous national grid references to locate sites. Your reviewer has the advantage of being born and bred a Grimbarian, and being initiated to camping as a young scout in one of the meltwater channels discussed. There are 12 plates (10 in colour) and two A5 sized colour maps showing the glacial limits, pattern of meltwater channels and outwash zones.

We applaud Allan Straw's initiative of presenting his mature views on the latest glaciations of east Lincolnshire. To have a reflective statement on a life long research programme is invaluable. Many future historians of earth science will be indebted.

Peter Worsley

THEME REVIEW

Charnia's 50th Birthday - Again

The famous fossils from the late Precambrian, *Charnia masoni* and *Charniodiscus concentricus*, were formally named and described in 1958, and a wealth of literature has appeared in the last year or so. Members who wish to keep abreast of the subject may find it useful to consult the following.

The Rise and Fall of the Ediacaran Biota, by P. Vickers-Rich & P. Komarower (editors) 2007. Geological Society Special Publication 286, 456 pp. ISBN 978-1-86239-233-5. £95 (members of the Geological Society £47-50) +£4 p & p.

This is a collection of 38 papers presented at two symposia, one at Prato, near Florence, in 2004 and the other at Kyoto, Japan, in 2006. The papers record recent studies of the stratigraphic and tectonic setting of Neoproterozoic rocks before discussing the many impression fossils in the Ediacaran period (roughly 635 to 543 million years ago), some in areas where they have not previously been recorded, e.g. Argentina and Iran. However, the themes of their evolutionary origin and their extinction, as implied by the title, are not really covered and remain speculative. Several papers discuss the various frondose fossils and there is a useful analysis of the different types of discoid impressions, though the diagram of *Cyclomedusa* shows radial markings as well as concentric in contrast to the usual diagnosis of concentric markings only. A paper on *Kimberella* from the White Sea area of Russia concludes that it was a grazing or predatory mollusc, demonstrating that the biota was not entirely sessile. Particularly welcome are papers on *Charnia* by Laflamme et al., on the variety of discoid fossils by MacGabhann et al., on the probable molluscs from the White Sea region of Russia by Fedonkin et al., and on a possible siphonophoran by Fedonkin and Ivantsov demonstrating that biota was not entirely made of fronds and discs. Though obviously they are complex metazoans, no links between single-celled acritarchs and multicellular organisms have yet been found in the fossil record. Regarding fronds, most were bilateral, but some had three or even four vanes, and it is not easy to see how the latter gathered their nourishment. MacGabhann presents an argument that most if not all discs were holdfasts, but does that mean that the 30 cm diameter discs in Charnwood Forest were super-holdfasts of giant fronds?

While neither the digestive systems nor the reproduction strategies of the fronds can yet be demonstrated, most contributors seem to agree that they gained their nourishment from the water column either by absorbing it directly from sea-water or by catching and consuming particulate matter: the latter method might imply polyps eating plankton but no evidence for polyps has been presented yet. The suggestion of growth of lilo-like mattresses within the sea-floor sediment as argued by Seilacher seems to be out of favour today. Whether the varied length of the fronds reflects a tiered ecology at different water depths is uncertain. There is also doubt as to whether the assemblages in different lithologies reflect a chronological replacement, i.e. diversification with time, or a shallow to deep environmental but synchronous pattern.

Among the topics somewhat marginal to the palaeontological theme is correlation of Ediacaran strata over much of central Australia, partly based on a layer of ejecta from a meteorite, the Acraman event at c.570 Ma. As a whole the book contains essential reading for those interested in Metazoan evolution, but it has a few papers which could have been omitted. e.g. Cambrian Radiolaria.

Ediacaran Biota on Bonavista Peninsula, Newfoundland, by H.J. Hofmann, S.J. O'Brien & A.F. King, 2008. Journal of Paleontology, vol.82, no.1, pp.1-36.

The fossils from some 36 new localities in an area some 300-400 km northwest of the classic Mistaken Point are recorded here. The same stratigraphic units are found here and the fossils are spread through over 1000 m of strata. The lowest beds are of similar age to the volcani-clastic beds of the Blackbrook Formation (Iveshead Member) whilst the upper beds can be correlated with the fossiliferous Woodhouse Beds in Charnwood Forest. *Ivesheadia* and *Blackbrookia* are recorded though the illustrations of the latter are far from convincing.

Spindle-shaped Ediacara fossils from the Mistaken Point assemblage, Avalon Zone. Newfoundland by J.G. Gehling & G. Narbonne, 2007. Canadian Journal of Earth Sciences, vol.44, no.3, pp.367-387.

The abundant but enigmatic organisms found but neither named nor described in detail 40 years ago by Anderson and his student Misra are here named *Fractofusus misrai* and *F. andersoni*. Detailed descriptions with the aid of retro-deformation (i.e. taking out the distorting effects of tectonic deformation) are provided together with statistical analyses based on over 3000 specimens obtained through some 1500 m of beds. Some bed surfaces carry hundreds of specimens. The two species differ in size and shape, *F. misrai* being larger and narrower than *F. andersoni*. They are only known from Newfoundland though a single doubtful and poorly preserved specimen in Charnwood Forest might be an example. No head, tail or means of support can be recognized and the organisms seemed to have rested on the sea-floor with an inflated, possibly quilted structure. Identical upper and lower surfaces bear fractal arrangements of frondlets, each similar to a small scale *Charnia;* this arrangement could only have operated if the organism was flipped over at intervals. As they occur in deep-water sediments any form of photosynthesis seems to be precluded. While most specimens exhibit just the two vane surfaces, the authors discuss the possibility of varieties with three and four-vanes, though it is difficult to see how these functioned. Although classified with *Charnia* etc in the Rangeomorpha, the nature of the organism remains even more puzzling than the frondose fossils.

Ediacaran fronds, by M. Laflamme, & G. Narbonne, 2008. Palaeogeography, Palaeo-climatology and Palaeoecology, vol.258, pp.162-179. (Brief summary in *Geology Today,* vol.24, no.3, May 2008, pp.93-94).

Using some hundreds of specimens from around the world, eight shape morphologies are noted but the fossils are categorized in four generic groups on the basis of their branching pattern: *Arborea* with little evidence of secondary divisions (*Arborea* has elsewhere been relegated to the status of a species within the genus *Charniodiscus)*; *Charnia* has secondary modular elements; *Rangea* has tertiary branching and *Swartpuntia* has close-packed tubular branches. Their architecture may reflect exploitation of different levels in the water column, but no other evidence of the mode of feeding or of reproduction has been found. The captions to the photographs of *Charnia* and *Charniodiscus* wrongly refer to these fossils having been found in Bradgate Park; in fact the type locality is the North Quarry on the Golf Course near Woodhouse Eaves and the type specimens are in Leicester City Museum.

The Vendian (Ediacaran) in the geological record: enigmas in geology's prelude to the Cambrian explosion, by G.J.H. McCall, 2006. Earth Science Reviews, vol.77, pp.1-229.

Joe McCall has here provided a comprehensive review of the literature up to about 2004, with many illustrations taken from the relevant journals. He has included notes on pre-Ediacaran fossils such as stromatolites. He has unfortunately used the obsolete stratigraphic terminology for the Charnian succession.

The Rise of Animals: Evolution and Diversification of the Animal Kingdom, by M.A. Fedonkin, J.G. Gehling, K. Grey, G. Narbonne & P. Vickers-Rich, 2008. Johns Hopkins University Press, Baltimore, 326 pp. ISBN 13-978-0-8018-8679-9. £50.

This a lavishly illustrated book (many in colour) summarizing pretty well all what one could want to know about the Ediacaran Biota, with coverage of the relevant Precambrian environments, Proterozoic glaciations and the potential effects of "snow-ball" or the more likely "slush-ball" Earth. The possible effects of changes of salinity and excursions from the norm of the carbon-13 isotope may mark major environmental impacts on evolution in post-slush-ball times. There are comments on the few pre-Ediacaran fossils found so far, both discs and a few dubious trails. It is suggested that some of the flattened forms such as *Dickinsonia* grazed on microbial mats though if the microbes were photosynthetic the mats are difficult to reconcile with the deep-water occurrences. Possible precursors to the well-known Phanerozoic phyla such as *Tribrachidium* are discussed though the frondose organisms seem to have no obvious links to the later phyla.

The greater part of the book deals in turn with the areas with Ediacaran fossils, notably Newfoundland, South Australia, Namibia, various parts of Russia including the White Sea, Podolia, Siberia and the Urals, and several localities in N.W. Canada. A chapter discusses locations with fewer records of Ediacaran fossils and includes Charnwood Forest (which gets only four pages), Carmarthen, Argentina, China, Iran, India and Mongolia. A few sediments of Ediacaran age are limestones and these sometimes include "reefs" with abundant small conical *Cloudina* and other small shelly fossils of unknown affinity: examples are known in Namibia, California and Siberia. Notes on stromatolites, which have been regarded as marker fossils in Precambrian stratigraphy, are included. There is a chapter on microbes, with a short discussion of the carbonaceous discs of *Chuaria*, once mistakenly regarded as primitive brachiopods but now thought to represent mega-acritarchs. *Chuaria* was first recorded in the Grand Canyon in c.800 million year old strata, though this is not discussed. The genus has been recorded in many other areas including Iran and Canada. Many of the classic areas with Ediacaran fossils are remote with complex logistics even to reach them, and the problems of access and field work are outlined. Some personal backgrounds to the discoverers and researchers are presented making the book a very readable account of the growth of a subject which did not really exist 50 years ago.

There is an illustrated alphabetical index to more than a hundred Ediacaran fossils now known, though a few have been named too recently to be included, e.g. the spindle-shaped fossil, so common in Newfoundland, now known as *Fractofusus,* is not mentioned. The index also has the peculiarity of the photographs of both *Marywadea* and *Spriggina* are of the same specimen! A few other mistakes have crept in: localities 25 and 26 appear twice on the map on page 49; many of the photographs have no scale; the photo of your reviewer on page 186 is reversed. It would have been useful to have geological maps of many of the areas described instead of the minute location maps. The frontispiece (repeated on page 260) of a reconstruction of an Ediacaran sea floor is so anaemic that it is difficult to make out the detail, though the dust jacket has the same picture in full colour. There is a comprehensive bibliography. Fedonkin et al's book is probably the "best buy" on the subject available.

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REPORT

Bibliography of Nottingham's Caves

The third edition of the Society's ever-popular book, *Sandstone Caves of Nottingham*, was published late in 2007. Since this book was written for a wide readership, it does not carry references to source material and available literature. Such however can be very useful for researchers, and the bibliography below is therefore published as a basic resource.

This list includes the main primary sources of information on the caves, but excludes the numerous magazine articles that merely repeat existing data. The Local Studies section of Nottingham' Central Library has a fairly complete collection of the reports that are not in mainstream publications.

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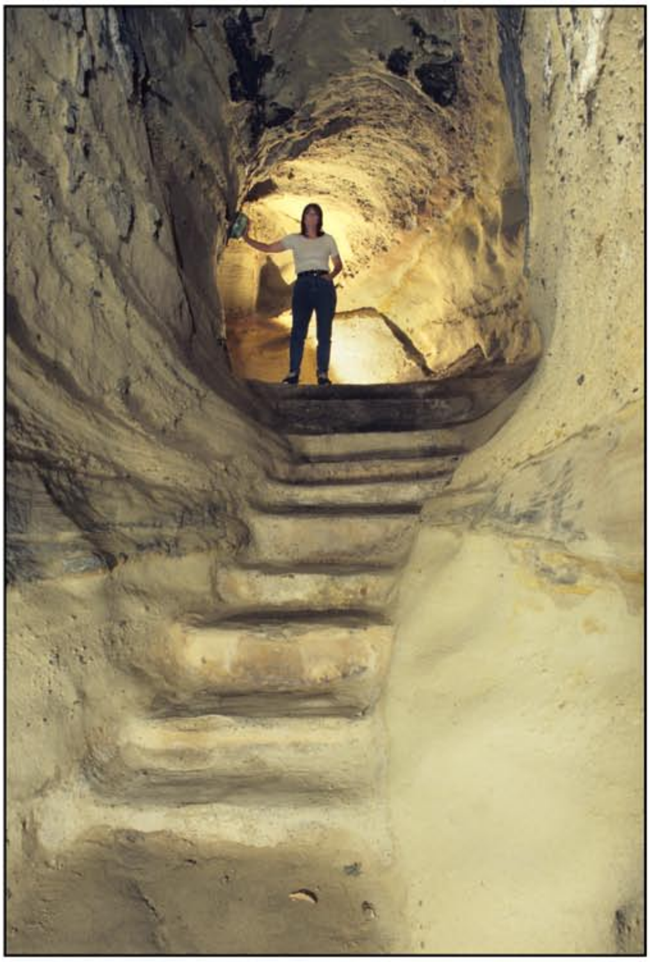

Mortimer's Hole, the cave tunnel that descends through Nottingham's Castle Rock, and is one of the few sandstone caves normally open to visitors.

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