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East Midlands Geological Society

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Front cover: Croft Quarry, Charnwood Forest, seen from the air. The quarry produces strong aggregate stone from a pluton of the South Leicestershire Diorite, and also exposes sections through two Triassic wadis filled with Mercia Mudstone. See paper on page 166. Photo by Tim Cullen.

Back cover: Minerals of Golconda Mine. See notes on page 205. Photos by John Jones.

Contents

MERCIAN NEWS

Erratum

In the supplement Geology of the Mines of Lathkill Dale and the Wye Valley, distributed with the previous issue of Mercian Geologist, small errors crept into three of the figures. In the interests of accuracy, corrected images of Figures 24 and 27 are available on the Publications page of the Society website (www.emgs.org.uk); these are jpegs of correct size that may be downloaded, printed, cut out and pasted in by anyone wishing to perfect their Mercian collection. In Figure 1 of the same supplement, two key items were transposed: EL is the Eyam Limestone, and the grey shading is the Edale Shales. Editorial apologies to honourable author and to respected readers.

That old car

The query about the old car, raised in the Archives note in the last issue of Mercian Geologist, did raise a response; thank you to Jonathan Wood and Mike Rosenbaum for the following.

As the photograph dates from 1904 and the car looks fairly new, we can assume that it was built at about that time and is either French or of Gallic inspiration. Although the motor car was a German invention, dating from 1886, it was the French that took up the concept with the greatest alacrity. On account of its wealth, Britain was France's largest overseas market prior to the First World War, and nearly all pre-1914 British cars were heavily reliant on French designs.

It is difficult to identify the car at the quarry because any distinctive radiator is obscured, and the bodies were often produced by local coach builders to be placed on a chassis constructed elsewhere. But it is fitted with a rear entrance tonneau body, which dates from after about 1897, as earlier cars had bodies largely derived from their horse-drawn predecessors. Note the absence of weather protection and the fact that front and back wheels are of the same size. In the early days of the motor car, front wheels were invariably smaller than the rears; this was to allow the entire axle to swivel to permit the car to turn a corner, before same-sized wheels on a static front axle with swivelling stub axles arrived around the turn of the century.

A loss at Long Rake

Some members may remember the dramatic open stope on Long Rake, west of Youlgreave in the Peak District. It could be seen within the woodlands immediately west of the car park beside the Limestone Way (at SK194645), and was a beautifully clean, vertical cut along the vein still, spanned by a few timber stemples. There were once plans within the Peak District National Park to place a concrete viewing platform across the end of the open stope nearest to the convenient car park; this would have been welcome, as any approach for a good view did require some care. Recently some Society members went to visit the site and were greatly saddened to find no trace of the stope, with its site now lost in new-growth woodland.

It had not been back-filled, but (some years ago now) was covered with massive concrete beams and slabs, which then had a thin soil cover placed over them. This does look like another tragic win for the safety culture that has needlessly destroyed yet more of the great mining heritage within the Peak District. It could well be viewed as heritage vandalism. Is it again a failure of geo-conservation in a field where so many of those involved are aware of little more than bio-conservation? One may wonder if the old mine would have been closed off had it become a bat roost. Conservation policies are much trumpeted, but they have failed at Long Rake. This splendid artefact has already been forgotten, and too many folks even with local concern for the mining now know nothing of it.

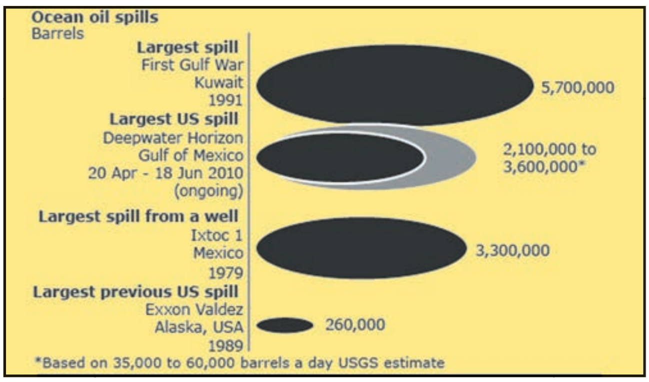
A sight now lost - the view west along the open stope on Long Rake as it was in the late 1970s. The opening was about 5 m wide, and here about 30 m deep, though the visible floor was formed by piles of waste "deads" stacked on timber platforms above open stopes that descended another 60 m or so.

GEOBROWSER

Deepwater Horizon in its context

While President Obama is berating British Petroleum, who have accepted full responsibility for the current oil spillage following the Deepwater Horizon explosion of April 20, the ensuing arguments over litigation, and blame, are likely to be complex. The rig was leased to BP (as it has preferred to be called for the past ten years) in 2008, and the actual operators are Transocean Offshore, an American company which acquired the rig following its take-over in 2000 of another American company, R & B Falcon. Even BP is now largely American; it is mostly active in the USA with two-thirds of its 32,000 workforce American, as are 50% of its board members and 40% of its shareholders, and the company will contribute $4.2 million to American pensioners and investors this year (The Times, June 5 2010). In the meantime, it is appropriate to put some context on the magnitude of what has happened, at least in terms of oil loss, as this diagram shows.

There are many similarities, but also a few important differences between Deepwater Horizon and the similarly massive Ixtoc 1 spill that occurred in the Gulf of Mexico west of the Yucatan peninsula, in 1979 (*Blog by Mike Stopa, Saturday, 29 May 2010*). Both were caused by a blowout (the uncontrolled release of oil following the failure of well control systems), but one major and potentially serious difference between Ixtoc and Deepwater Horizon is that the former was in only 50 m of water while the latter is 1500 m below the Gulf's surface. Because of this, the Ixtoc oil floated fairly readily to the surface while much of the Deepwater Horizon oil has evidently remained deep; in fact previous experiments suggest that no more than about 30% of oil released from such depths may reach the surface. One possible advantage of water closer to the surface is that oil-eating microbes seem to have significantly lowered the overall impact of the Ixtoc spill. It is not clear if such natural clean-up processes will be as efficient in deeper water, but as there is a fundamental linkage between deep and shallow oceanic ecosystems (*Ecosystems of the deep oceans, P. A. Tyler, 2003*) there will inevitably be biological damage to both. The Ixtoc spill was eventually contained by the drilling of relief wells but, ominously, only after 10 months of leakage. While fishing (and shrimping) returned to that region of the Gulf in little over two years, it is still possible that the current oil spill, and the toxic nature of the surface oil dispersants that are being used, will have more serious environmental consequences

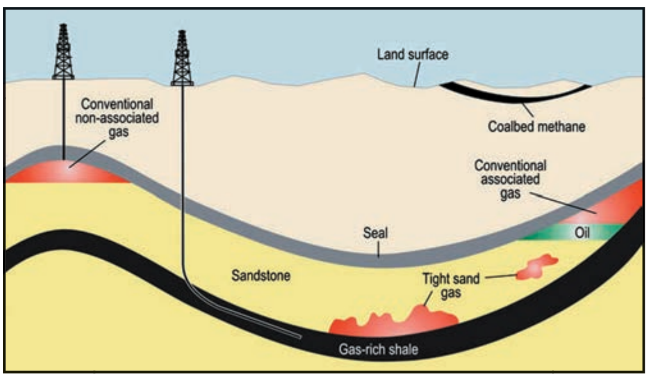


Relative sizes of some major oil spills (from Oil Spill Intelligence Report: Deepwater Horizon Unified Command).

'Greener', safer hydrocarbon resources?

In *Geobrowser 2005*, we reported that with the production price of oil rising beyond $55 per barrel, those hydrocarbon resources producing only marginal profits, such as the 'tar' sands of Athabasca, Canada, might become more economically feasible. Such alternatives are now looking even more attractive, for two reasons. First, since 2005 oil prices have continued to rise, and currently are hovering at around at $75 per barrel. Secondly, environmental concerns following the Deepwater Horizon disaster are now threatening the whole practice of drilling for oil in the deep offshore. The incident has forced the US Administration into an embarrassing U-turn from a few months earlier, when President Obama was opening up new licence areas for deep offshore exploration, to the April 30 moratorium on the drilling of new wells until the reasons behind the accident are known.

This moratorium will almost certainly be lifted; in fact 17 new drilling permits have been issued for Deepwater-type operations in the Gulf since it was imposed (*Center for media and democracy PR Watch. org, May 23*). Nevertheless, its effect has been to focus attention on other more environmentally safer hydrocarbon energy resources. One of these, known as 'shale gas', has been exploited since 1821, but has transformed the US energy industry more recently, with 4185 wells completed in 2007 alone (*AAPG Explorer, July 2008*). Other shale gas resources are now being looked at in Palaeozoic to Mesozoic strata found in Canada, Asia and Australia, as well as in Europe where the Jurassic 'Alum Shales' (the Whitby Mudstone Formation in the UK) are considered prospective. They could be the new hope for energy production (*New York Times, 9 October 2009*) and, unlike tar sand exploitation, could help reduce greenhouse gas



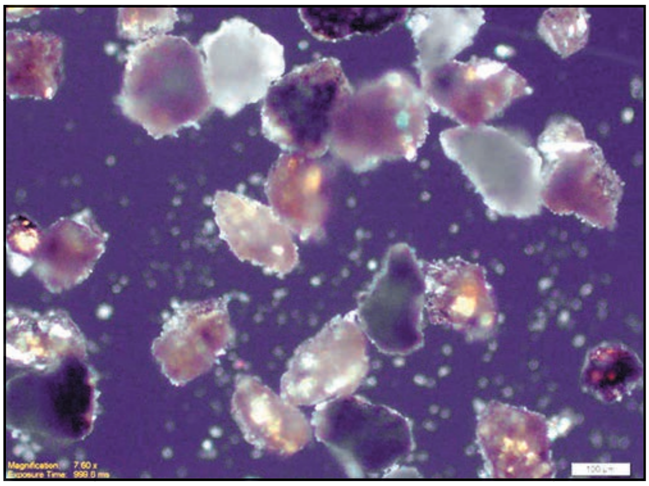
Schematic geology of natural gas resources.

emissions (*White House, Office of the Press Secretary, Statement on U.S.-China shale gas resource initiative, 17 November 2009*). The resource requires shales rich in organic material (0.5-25%), that have experienced temperatures and pressures high enough to convert petroleum to natural gas. Shales are relatively non-porous, causing problems, but when fractured they can act as gas reservoirs. Advances in hydraulic fracturing and horizontal completions are making shale gas wells more profitable, and they seldom fail to produce.

'Tight sandstones' (with low porosity and low permeability), and also limestones, are a further potential producer of natural gas, with 'tight gas' resources in the USA equivalent to 17% of total recoverable natural gas in that country (*US Energy Information Administration, January 2009*). They exist in many other parts of the world, including parts of Europe, but are difficult to exploit, and up till now production has relied on a search for geological situations with natural, open fracture systems in which gas can accumulate and be readily extracted (*NETL 'the energy lab', US Department of Energy*). Recent advances are showing that artificial hydraulic techniques can significantly enhance natural fracture systems, creating larger collection areas through which gases can flow to a producing well.

The wrong type of ash?

On 14 March 2010 the Icelandic volcano Eyjafjallajokull commenced to inject vast amounts of ash into the jet stream, closing down or severely disrupting European air traffic for the following few weeks. Samples collected from the plume over Britain contained particles of around 3 µm diameter, which accounted for much of the mass of suspended ash (*Sanderson, K. Questions fly over ash-cloud models. Nature, v. 464, p. 1253*). In order to determine the composition and morphology of this ash, Eric Klemetti of the USGS took some photomicrographs (*Blog of 21 May 2010*). He noted that while most ash consists of sliver-like, cuspate-shaped glassy filaments, representing the walls of disintegrated bubbles produced by the vesiculating magma, the Eyjafjallajokull ash differs in being blocky and crystal-rich. The ash also contained small crystal fragments, of plagioclase feldspar, pyroxene, olivine and magnetite, which all characterise basaltic magma.



Eyjafjallajokull ash fragments in close-up.

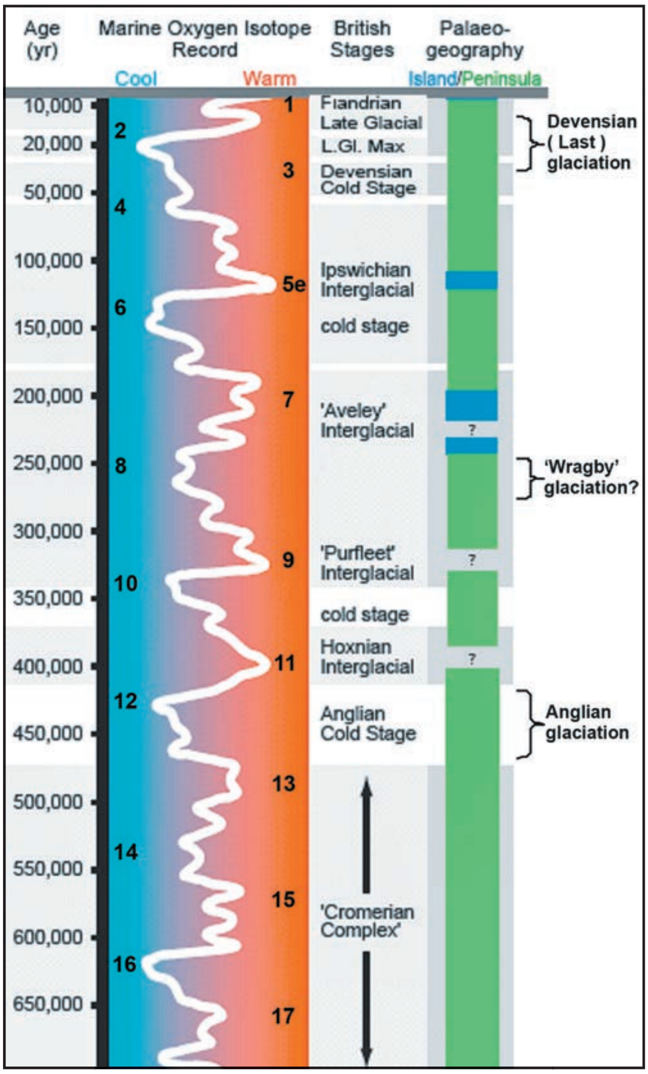
The shapes of the ash fragments are important because, depending upon the degree of interaction between the magma and water encountered from the melting Gígjökull glacier, the eruptions at Eyjafjallajokull have been characterized as anything from strombolian (ash eruptions from a summit crater into air) to phreatomagmatic (ash often produced in large volumes by magma erupted into shallow water or groundwater) to phreatoplinian (a poorly understood type of large-volume eruption caused by the sudden inrush of water to a magma chamber, as at Krakatau). The blocky and crystal-rich nature of the the Eyjafjallajokull ash, Klemetti concludes, is more typical of phreatomagmatic eruptions. This is in keeping with observations of the Iceland eruption, which commenced on March 10 2010 with fire-fountaining in an ice-free area (Phase 1) but then proceeded to the ice-filled summit caldera where large-scale melting occurred. It was this Phase 2 stage, commencing on April 14, that involved the ash-rich phreatomagmatic eruptions that had such a devastating impact upon air travel (*see also the BGS website*). On 21 May the volcano entered its third phase, involving a possible return to dormancy, with only steam erupting from the vent. It may awaken at any time, but now that the phreatomagmatic stage has passed it is debatable whether air traffic disruption will be as extensive as before.

Neanderthal love?

The May 2010, the *Earth Pages* section of the *Geology Today* magazine suggests that the brutish nature often supposed for Neanderthals may be a myth. The Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, has produced a nuclear genome of *Homo neanderthalensis*, based on the bones of three individuals from a Croatian cave (*Science, 7 May 2010*) which have been Carbon-14 dated to 44 to 38 ka (thousand years ago). As this roughly coincides with the first arrival of fully modern humans from Africa, it is very possible that the two hominid species would have come into contact, particularly as the Neanderthals did not finally die out until around 25 ka. Intriguingly, the new data for nuclear (as opposed to mitochondrial) DNA indicates that the Neanderthals, whose forbears departed Africa about 400 ka ago, were more similar genetically to modern Europeans and Asians than they were to modern Africans. This can only mean that successful mating must have occurred between Neanderthals and Eurasian humans shortly after the latter's arrival in the Middle East. The progeny then migrated to east and west forming the modern populations of Asia and Europe, which host 1-4% of Neanderthal ancestry. The data further show that the gene exchange (in other words, sexual intercourse) took place in such a way that the gene 'flow' was from Neanderthal to human and not vice versa. So what traits might those lucky humans share with Neanderthals? The results suggest 15 genomic regions that include those involved in energy metabolism, possibly associated with type 2 diabetes; cranial shape and cognitive abilities, perhaps linked to Down's syndrome, autism and schizophrenia; wound healing; skin, sweat glands, hair follicles and skin pigmentation; and barrel chests. DNA sequencing of other Neanderthal remains and bones of ancient Europeans and Asians will add further details, but as concluded in *Earth Pages*, it is now quite clear that human evolution was a great deal more complicated than the simple Out-of-Africa model that is currently almost universally accepted.

A third East Midlands glaciation?

As the third longest river in England, the Trent has experienced some the planet's most significant climatic fluctuations over the past half million years or so. The evidence for how it has been able to survive these impacts has been pieced together over the past 70 years, starting with the observation of Swinnerton in 1937 (*Trans. Lincolnshire Naturalist's Union, 9, 145*) that the river could have originally flowed through to the Wash, rather than to the Humber as at present, via a prominent gap in the Lincolnshire Limestone escarpment at Ancaster. This suggestion inspired much subsequent research, which has most recently been reviewed in a major article (*Proceedings of the Geologist's Association, 2010, 121, 141-153*). It seems that most workers agree that the course of Swinnerton's 'Ancaster Trent' was profoundly modified by the Anglian glaciation, which overran the whole of central England and which is dated to Marine Isotope Stage (MIS) 12, around 450 ka (thousand years ago). Upon deglaciation, the Ancaster gap was abandoned, but the Trent nevertheless regained the Wash estuary by carving another gap through the escarpment 18 km to the north, at Lincoln. This gap was not abandoned until the 'Lincoln Trent' was diverted northwards to the Humber estuary following the last (late Devensian) major glaciation, which began to ameliorate at about 15 ka in the East Midlands (*Journal of Quaternary Science, 2004, 19, 479*). What happened in between these two glaciations is still a matter for conjecture, but clearly there were three intervening major cold periods, at MIS stages 10, 8 and 6. Did one or more of these produce an onshore glaciation in England, and if so what did it leave behind? The PGA paper suggests that the best evidence for a post-Anglian, pre-Devensian glaciation is the Wragby Till of Lincolnshire. This chalk-rich and flint-rich till is overlain by interglacial deposits dated at MIS 7 (about 190-240 ka), so cannot be attributed to the MIS 6 or Devensian cold stages. Although many have considered it to be Anglian, Allan Straw has consistently regarded the till as being younger than this (*eg. Quaternary Science Reviews, 1983, 2, 239*). The PGA paper concurs, and of the two remaining possibilities, MIS 10 or 8, favours the latter age (about 250 ka) for this additional 'Wragby' glaciation. The



Marine Isotope Stages (MIS) in the late Pleistocene.

arguments are complex; however, involving Quaternary stratigraphies and correlations in the Fen Basin and the Netherlands, and the debate is sure to rage on. One interesting conclusion of the PGA paper is that the chalky Oadby Till of the East Midlands, which strongly resembles the Wragby Till in appearance, is 'probably' Anglian in age. So tills that look the same could have been deposited by ice sheets following similar courses, but during different glaciations.

Squashing the snowball

The original hypothesis of late Precambrian (Neoproterozoic) global glacial conditions (*J. Kirschvink, The Proterozoic biosphere, Cambridge University Press, 1992*) proposes that at times the Earth was encased in glacial ice and sea-ice from pole to pole. Such a view has become less favoured in more recent years (*e.g. Science, 327, 2010*), even though evidence supporting low latitude glaciations continues to emerge. This is because diamictites of glacial origin have commonly been found in association with volcanic rocks that give very precise late Neoproterozoic ages, and also carry a shallow-inclination palaeomagnetic signature indicating low, tropical or equatorial latitudes.

The entire Snowball Earth hypothesis is now in doubt, however, following the discovery of anomalously erratic palaeomagnetic pole positions during latest Neoproterozoic times (*Earth and Planetary Science Letters, 239, 2010*). This study shows that igneous rocks dated between 600 and 550 Ma, in what are now North America and Scandinavia, have original inclinations of the magnetic field that are both steep and shallow, indicating high and low latitudes respectively. Interpreted in terms of our modern magnetic field, these data seemingly indicate rapid apparent shifts, from high to low palaeolatitudes, that cannot be accounted for by any reasonable plate tectonic movement rates. Instead, the authors attribute these abrupt shifts to rapid reversals of the geomagnetic pole. More recently documented geomagnetic reversals feature brief periods during which the reversing poles pass through equatorial latitudes, albeit at very low magnetic field strength. It seems that during late Neoproterozoic (Ediacaran) times, however, the geomagnetic poles remained at tropical latitudes for long periods. At such times, sediments or volcanic rocks forming in the geographic Polar Regions would have apparent tropical or equatorial palaeomagnetic inclinations imprinted on them. These anomalies have not yet been demonstrated for some of the earlier glaciations, during the Cryogenian Period (*see Geobrowser, 2005*), but as noted by *Geology Today*'s *Earth Pages* (*May 2010*), the discovery has the potential to undermine the whole basis for the Snowball Earth hypothesis. Theories on early evolution may also have to change, since global glaciations are being widely implicated for kick-starting the Ediacaran explosion of organised life-forms, such as those found in Charnwood Forest.

THE RECORD

Society membership now stands at 360 with an additional 40 institutional members and we welcome new members who have joined during the year.

Indoor Meetings

Following the March AGM, Members Night had a volcanic theme, with Chilean Volcanoes described by Alan Filmer, Volcanism in the Northern Tanzanian Rift Valley recalled by Gerry & Brenda Slavin, and the Mud Volcanoes of Azerbaijan presented by Tony Waltham.

In April, Neil Ellis explained the Geological Conservation Review, its rationale and the methods used to create this ongoing inventory of the best earth science sites for research in Great Britain. He presented the Society with three of the volumes so far published.

October brought us an update on New Vertebrate Discoveries from Dinosaur Sites on the Isle of Wight, by David Martill and Steve Sweetman.

November's lecture, given by Peter Worsley and entitled Charles Darwin: a Mercian 'glacial' Geologist, focused on his less publicized geological work and personal aspects of his life and travels.

In December, Tony Cooper described problems encountered when structures are built above soluble rocks in lecture My house fell in a hole; this was followed by our Christmas Cheese and Wine.

Ophiolites, petroleum and meteorites in Oman were brought to us by Hugh Rollinson in January.

In February, Tim Colman presented his Presidential Address on the deposits and mining of gold in Britain, past, present and future; this was followed by the Society's Annual Dinner.

We are grateful to Richard Hamblin for organizing this year's successful programme of speakers and to Gerry Shaw for organizing the refreshments.

Field Meetings

The number of members participating in field meetings has this year increased. Once again the programme of Field Trips was organised by Ian Sutton to whom we give our thanks. Also thanks go to the field trip leaders who share with us their time and their knowledge.

May saw the first of two visits to Lodge House Opencast coal site near Smalley, Derbyshire led by Paul Guion in conjunction with UK Coal.

In June there was an evening visit to local Triassic sites around Nottingham with Keith Ambrose.

Another evening visit in June went to Ecton Hill copper mines, led by Tim Colman and Peter Kennett.

During July there was a full and varied weekend visit to Hertfordshire at the invitation of the Hertfordshire Geological Society.

September brought a repeat of the popular visit to Chatsworth House, led by Ian Thomas and members of the Russell Society.

In October, the geology of the Matlock Gorge area was visited, led by Lynn Willies and Colin Bagshaw.

Council

Council met formally on six occasions during the year. It discussed plans for speakers, field meetings, publications and projects together with geological issues that have been brought to its attention and welcomes input from members on any of these.

We have begun to update the Society's publicity stand, and with this in mind BGS has provided us with a new geological map of the East Midlands. It is hoped that when complete the improved stand will be displayed in more locations that in recent times.

The preparation of digital copies of the Mercian Geologist, from Volume 1 onwards, continues.

The Society continues to support geodiversity. It is represented on the East Midlands Geodiversity Partnership, is on Derbyshire's planning authority area consultation list, and has members involved with the RIGS groups in our area. In conclusion I would like to thank all those I have not specifically named in my report who give their time and energy to further the aims of the Society.

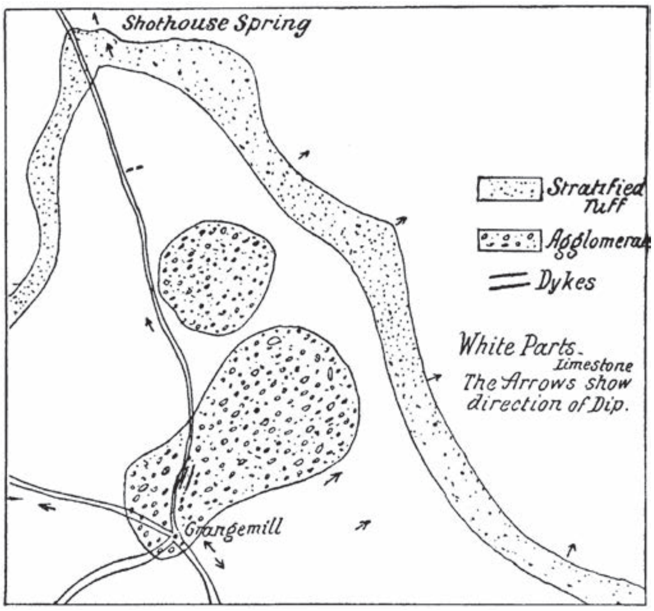
Janet Slatter, Secretary

FROM THE ARCHIVES

Ancient volcanoes at Grangemill

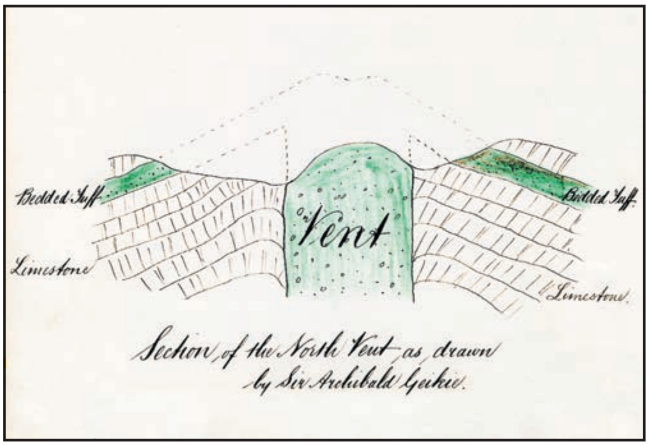
In early 1894, while researching his book The Ancient Volcanoes of Great Britain, Sir Archibald Geikie, then Director-General of the Geological Survey, spent a week examining the Derbyshire 'toadstones' in the company of local geologist, H. H. Arnold-Bemrose. The existence of these basaltic lavas and tuffs in the upper part of the Carboniferous Limestone had long been known, but Geikie was intrigued that no volcanic vents (or necks) had been recognised. He set out to find them, and during the course of his visit discovered 'a group of two, possibly three, vents which rise into two isolated, smooth, grassy dome-shaped hills at Grange Mill, five miles west from Matlock Bath.' He noted that the necks were plugged by a 'dull green agglomerate', while in the limestone scarps that partly encircle Grangemill he recognised the ash deposits (Shothouse Spring Tuff) that had in all probability been erupted from these ancient Carboniferous volcanoes. With Geikie's encouragement, Arnold-Bemrose went on to survey the volcanic succession in greater detail, publishing his now classic account of the Derbyshire toadstones in 1907.

Geikie's Ancient Volcanoes appeared in 1897 and seems have inspired another local amateur geologist, A. T. Metcalfe, to visit and photograph the visible evidence of the 'Ancient volcanoes at Grange Mill.' The resulting small, slim album of ten black and white photographs, dating from 1900, is now in the BGS Library at Keyworth. Metcalfe was born at Retford, Nottinghamshire, in 1855, and spent his entire working life as a solicitor at Southwell, dying there in 1939. Among other things, he published a paper on the gypsum deposits of Nottinghamshire and Derbyshire in



Above: Geikie's plan of the necks, together with the outcrop of the Shothouse Spring Tuff .

Below: Idealised section of the smaller 'north vent', redrawn by Metcalfe from a figure in Geikie's Ancient Volcanoes.



All images of drawings and photographs within this Archive feature are reproduced by kind courtesy of the British Geological Survey, Keyworth..

View, from the north, of the two volcanic necks at Grangemill (from Geikie's Ancient Volcanoes*, 1897).*

the Transactions of the Nottingham Naturalists' Society (1894), of which he was for a time the President. He was also eventually a Senior Fellow of the Geological Society. His manuscript geological papers and photographs (including pictures of the Grangemill volcanoes) are held in the Department of Manuscripts and Special Collections at Nottingham University. Digital versions of the images held by BGS (including those depicted here) may be viewed by visiting the newly accessible BGS OpenGeoscience web pages at www.bgs.ac.uk/opengeoscience .

Bibliography

Arnold-Bemrose, H.H. 1907. The toadstones of Derbyshire: their field-relations and petrography. Quarterly Journal of the Geological Society, 63, 241-81.

Geikie, A. 1894. Contribution to discussion. 643-644 in Arnold-Bemrose, H.H. On the microscopical structure of the Carboniferous dolerites and tuffs of Derbyshire. Quarterly Journal of the Geological Society, 50.

Geikie, A. 1897. The Derbyshire toadstones. 8-22 in The ancient volcanoes of Great Britain 2. London: Macmillan.

Metcalfe, A. T. 1900. Ancient volcanoes at Grange Mill, Derbyshire. Album of photographs, 21x17cm, 18pp, (BGS Library, 449-A).

Gill Nixon, British Geological Survey

Above: View of the 'north vent', by Metcalfe in 1900.

Below: View of Grangemill with the 'south vent' behind, photographed by Metcalfe in 1900.

Notes for authors

Guidance notes for authors intending to contribute to the ***Mercian Geologist*** may be seen on, and printed from, the Society website (www.emgs.org.uk). Paper copies may also be requested by mail or by telephone from the editor for anyone without web access. Contributions are welcome from both members of the Society and non-members.

Sir Henry Thomas De la Beche and the founding of the British Geological Survey

David G. Bate

Abstract. The founding of the Geological Survey by Henry De la Beche in 1835 is a key event in the history of British geology. Yet the Survey's initiation actually began three years earlier when De la Beche secured financial assistance from the Board of Ordnance to map the geology of Devon at a scale of one inch to the mile. The British Geological Survey has thus been in existence for at least 175 years and can justly claim to be the world's oldest continuously functioning geological survey organisation. There were early government-funded geological surveys also in France, the United States, Ireland and Scotland. De la Beche's notable success both in launching and sustaining the Geological Survey demanded a good deal of diplomacy, determination and deviousness! Even so, the Survey was nearly brought to an untimely end in 1837 when De la Beche was publicly criticised for his interpretation, based on lithology and field relations, of the difficult Culm strata of north Devon. The resolution of the 'Devonian Controversy' led to a fundamental change in geological practice, in which the value of fossils as stratigraphic markers, founded on an acceptance of organic change over time, was established beyond question. Fortunately the Survey survived its early trauma and De la Beche went on to extend his influence with the expansion of the Museum of Economic Geology (also formed in 1835), and the establishment of the Mining Record Office and the School of Mines.

The British Geological Survey has often been described as the world's first official geological survey organisation. While this statement may not be strictly accurate, the British Survey can claim to be the oldest such undertaking to have functioned continuously since its inception in May 1832 and formal establishment on 11 July 1835. For this we must thank the Survey's founder and first Director, Henry Thomas De la Beche (Fig. 1), whose single-minded determination succeeded in placing the British Survey on a more permanent footing than earlier but short-lived government-funded geological surveys in France and the United States. The Geological Society of London (founded 1807) also played an important part in assisting the establishment of the Survey, while the support of Thomas F. Colby, Superintendent of the Ordnance Trigonometrical Survey (under the Board of Ordnance), was a critical factor in its initial success and ultimate survival.

This account charts the origin of the Geological Survey and its progress up to the year 1839 — a significant turning point which saw the publication of the Survey's first geological memoir and the appointment of the first Geological Assistants. This latter measure effectively laid the foundation for a permanent organisation — something by no means envisaged by the British government at that time! No account will be given here of the Museum of Economic Geology (now the Earth Galleries of the Natural History Museum) which De la Beche established in the same year that the Survey was founded, initially as a separate entity funded by the Board of Public Works. Neither will reference be made to his other two creations: the Mining Record Office (established adjacent to the Museum in 1839), and the Government (later Royal) School of Mines (established 1851).

Private enterprise and geological mapping

In Britain the politics of *laissez-faire* ensured that the earliest attempts at geological mapping on a national scale were left to private enterprise. Among the early forerunners pride of place goes to William Smith, the 'Father of English Geology' (Sedgwick 1831), whose now famous map, *A Delineation of the Strata of England and Wales, with part of Scotland*, appeared in 1815 at a scale of five miles to the inch (Eyles & Eyles 1938; Eyles 1969). This map is a landmark in the history of British geology and a remarkable achievement for a

Figure 1. *Sir Henry Thomas De la Beche, by William Brockedon, 1842 (© National Portrait Gallery, London).*

single individual, undertaken moreover with limited means of support. Unfortunately for Smith his map was eclipsed in 1820 by the quite independent production of *A Geological Map of England & Wales* under the direction of George Bellas Greenough, founding President of the Geological Society of London. This new map, at a scale of about six miles to the inch, owed much to the 1815 map (though this was only acknowledged many years later), but it benefited from the efforts of the élite membership of the Geological Society (which included an aspiring young De la Beche) and was thus more accurate and more detailed. Its arrival in France in 1820 prompted the French government to initiate a similar undertaking at public expense.

Greenough also encouraged Richard Griffith, another celebrated pioneer, to embark upon the construction of a geological map of Ireland. Griffith began work in 1811, but the difficulty he experienced in procuring an accurate topographical base-map delayed publication of his *Geological Map of Ireland* until 1838. Even then it was issued only in provisional form, at a scale of about ten miles to the inch, to accompany a report of the Railway Commissioners. A more detailed map at four miles to the inch (1:253,440) appeared in the following year. Both of these maps were published at government expense thanks to Griffith's fortuitous appointment to the Railway Commissioners Ireland in 1836. He succeeded in convincing his fellow commissioners of the need to publish a geological map to assist the expansion of railway communications. This included the compilation, under the charge of the Ordnance Survey, of the all important topographical base-map. Much of the geological fieldwork was actually undertaken by unacknowledged assistants employed by Griffith on various commissions under his direction, such as the Boundary and Valuation Surveys. The utilisation of these assistants in the pursuit of geological investigation was effected without official sanction, but their efforts enabled Griffith to realise his personal ambition to publish the first geological map of Ireland (Herries Davies 1983; Archer 1980).

Had things turned out differently, William Smith might have become the first government geologist. He had earlier produced a small outline geological map of England and Wales in June 1801 which, though rudimentary in detail, was the first such map of its kind. This and subsequent embryonic maps, together with his tabulation of the British strata, were displayed at annual agricultural meetings between 1801 and 1807. Sir John Sinclair, sometime President of the Board of Agriculture, was sufficiently impressed with Smith's credentials to attempt in 1805 to have him attached to the government Trigonometrical Survey (under the Board of Ordnance) for the purpose of connecting his 'survey of the strata' with the official one-inch topographical mapping then in progress (Phillips 1844). Nothing came of this proposal, nor indeed of a separate attempt by R. I. Murchison at the end of 1831 to have Smith appointed as 'Geological Colourer of the Ordnance Maps' (Geikie 1875, vol. I, 131-2). It was left to De la Beche to successfully secure this role for himself just months after Murchison's failed initiative. Murchison was one of Smith's keenest advocates, and as such was to play a key role as De la Beche's adversary in the Devonian controversy that would erupt late in 1834.

Early government-funded geological surveys

The claim has often been made to the effect that the British Geological Survey was the first of its kind in the world. This claim has been rightly contested by several writers (e.g. the Survey's own Victor Eyles 1937, 1950, and Harry Wilson 1985) who describe or allude to earlier government-funded geological surveys in France, the United States, Ireland and Scotland.

France

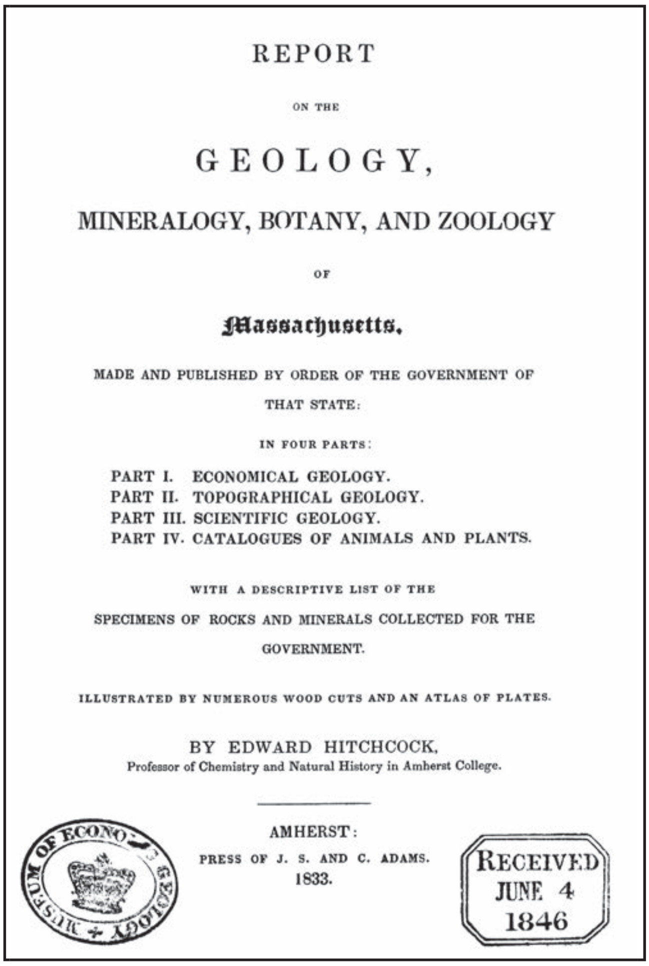
To France belongs the honour of having undertaken the world's first official geological survey on a national scale (Eyles 1950). A plan for preparing a geological map of the country along systematic lines was formulated by the government *Corps des mines* in 1822 and placed under the supervision of the *École des mines* (School of Mines). Two of its mining engineers, Léonce Élie de Beaumont and Armand Dufrénoy, under the direction of André Brochant de Villiers, were given the task of undertaking the survey. For this purpose they looked to England to provide a model of how such an undertaking should be attempted. Although French geologists were aware of William Smith's map, it was Greenough's more detailed map which they now aspired to emulate. The three men began in 1823 by spending six months on a fact-finding mission in England to learn something of the methods of geological mapping employed by Greenough's collaborators. The following year was devoted to writing up their observations and classifying their many collected specimens. Work on an initial *Carte géologique générale* began in 1825 and was completed by 1835 (Brochant de Villiers 1835). However, delays caused by the need to engrave a special topographical base-map meant that publication, in six sheets at a scale of 1:500,000, was not achieved until 1841.

It was further proposed that more detailed geological mapping should be funded by the regional *Départements*, preferably under the supervision of local mining engineers from the School of Mines. In practice, however, the maps that were produced lacked unity, being issued at a variety of cartographic scales, while the grouping, definition and representation of rock formations were frequently inconsistent. After 1845 the project lost momentum as Departments became less inclined to allocate the necessary funds for surveying and publication. The establishment of the Geological Survey of France in 1868, under the directorship of Élie de Beaumont, was in large measure prompted by the failure of the Departmental mapping project. The involvement of local government in geological mapmaking had proved ineffectual (Savaton 2007).

United States

In the USA eight state-funded geological surveys were initiated between 1823 and the middle of 1835, although these were of short duration. The first was undertaken in North Carolina in 1824-28 (the authorising Act being dated 31 December 1823). Other early state surveys were those of South Carolina (1825-26), Massachusetts (1830-33), Tennessee (1831-50), Maryland (1833-41), New Jersey (1835-40), Virginia (1835-42), and Connecticut (1835-42). In Pennsylvania there had been regular but unsuccessful submissions to the legislature to provide for a geological survey of the state from 1832, but approval did not come until 1836. The oldest continuously functioning state Survey is said to be that of New York, established in 1836, although its status after 1843 is questionable. (Sources: Clark 1897, Merrill 1920, Socolow 1988, Stuckey 1965; Hendrickson 1961 provides a useful overview focusing on the role of government).

Among early state surveys, that of Massachusetts is of special significance because it was the first to be formally published and widely disseminated. The state geologist was Edward Hitchcock, who despatched a copy of his full report (Fig. 2) to Henry De la Beche on 28 December 1833 as a mark of appreciation for the value he had derived from reading the latter's *Geological Manual* published in 1831 (letter in Sharpe & McCartney 1998, item 690). A renewal of the survey of Massachusetts, with emphasis on agricultural benefit, was enacted in 1837. The commission included the laudable instruction that 'that which is practically useful will receive a proportionally greater share of attention than that which is merely curious; the promotion of comfort and happiness being the great end of all science' (Merrill 1920, 155).


REPORT

ON THE

GEOLOGY,

MINERALOGY, BOTANY, AND ZOOLOGY

OF

Massachusetts,

MADE AND PUBLISHED BY ORDER OF THE GOVERNMENT OF THAT STATE:

IN FOUR PARTS:

PART I. ECONOMICAL GEOLOGY.
PART II. TOPOGRAPHICAL GEOLOGY.
PART III. SCIENTIFIC GEOLOGY.
PART IV. CATALOGUES OF ANIMALS AND PLANTS.

WITH A DESCRIPTIVE LIST OF THE SPECIMENS OF ROCKS AND MINERALS COLLECTED FOR THE GOVERNMENT.

ILLUSTRATED BY NUMEROUS WOOD CUTS AND AN ATLAS OF PLATES.

BY EDWARD HITCHCOCK,
Professor of Chemistry and Natural History in Amherst College.

AMHERST:
PRESS OF J. S. AND C. ADAMS.
1833.

RECEIVED
JUNE 4
1846

__Figure 2.__ Title page from De la Beche's copy of Edward Hitchcock's 1833 geological survey of Massachusetts.

It is worth noting that Henry Darwin Rogers, the first state geologist of both New Jersey and Pennsylvania, received field instruction from De la Beche in the spring of 1833 during a visit to England. De la Beche was at that time engaged in a geological survey of Devonshire with financial assistance from the Board of Ordnance. Rogers, who up to then had been unsure about the future course of his career, was inspired to set about conducting a state geological survey on his return home. When it became clear towards the end of 1834 that the New Jersey legislature was considering such a survey, Rogers made known his interest, ensuring that the governor of New Jersey was made aware of his qualifications for undertaking 'field research of a scientific kind such as I have witnessed with De la Beche' (Gerstner 1994, 44-7).

Mention should also be made of William Maclure (1763–1840), at one time called 'the father of American geology' (Dean 1989), and George William Featherstonhaugh (1780–1866), 'the first U.S. government geologist' (Berkeley & Berkeley 1988). The former, born at Ayr in Scotland, published his 'Observations on the geology of the United States' in 1809, with a coloured geological map of the regions east of the Mississippi River, surveyed and financed by himself. This map, though highly generalised, later earned him a reputation as the 'William Smith of America'. The other notable pioneer of American geology was English by birth, reputedly related to the Fetherstonhaughs of Fetherston Castle (there are variant spellings) in Northumberland. In December 1832 he made an approach to the U.S. government requesting financial support for a complete geological survey of the United States. In the event he received commissions to undertake reconnaissance surveys over the eastern states from 1834 to 1838. He afterwards returned to England and was appointed in 1844 as British Consul at Havre. During the revolution in France in 1848 he smuggled King Louis Philippe to England by disguising him as Mr William Smith, a half blind uncle!

3.3 Ireland

In 1825 the Ordnance Survey, under the direction of Lieutenant-Colonel Thomas Frederick Colby, began the daunting task of mapping Ireland topographically at a scale of six inches to the mile (1:10 560). As a long-standing member of the Geological Society of London, Colby was well aware of the economic value that would accrue from making a 'Geological and Mineral Survey' in parallel with the topographical survey of Ireland (Herries Davies 1983, 87). Thus, on 14 November 1826 he appointed Captain J. W. Pringle to superintend the geological survey, and in March of the following year Pringle issued instructions for making geological and mineralogical observations. Only limited progress was made owing to a lack of enthusiasm among the topographical field-parties, who for the most part had little interest in geology and no formal training in the subject. Indeed, its unpopularity and the fact that the geological survey was not officially sanctioned by the Board of Ordnance led to the suspension of geological activity in September 1828. This activity, conducted in the counties of Antrim and Londonderry, had amounted to little more than the collection of rock samples (noted in official correspondence from September 1826), with their locations plotted onto a crudely coloured six-inch map, and the drawing of two geological panoramas (Herries Davies 1983, 88-95; Andrews 1975, 67). Despite this setback, Colby was eventually given approval to appoint Lieutenant (soon to become Captain) Joseph Ellison Portlock to resume the geological survey in January 1830.

Portlock had good geological credentials, but he was too pre-occupied with the primary triangulation of Ireland to give much attention to geological matters until late in 1832 (Portlock 1843). It was about this

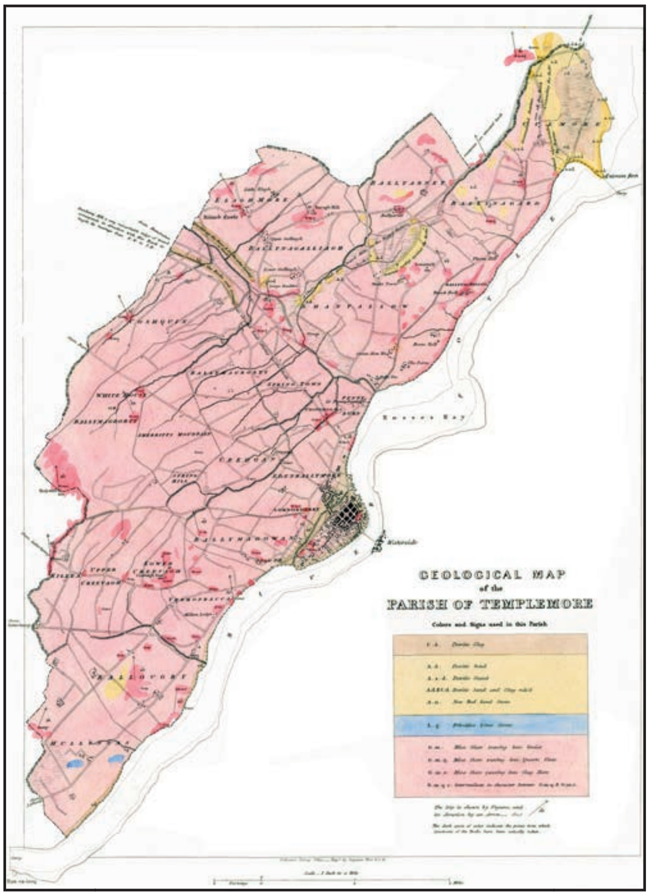


Figure 3. *Geological map of the parish of Templemore, by J. E. Portlock, from the 1837 edition of* Ordnance Survey of the County of Londonderry.

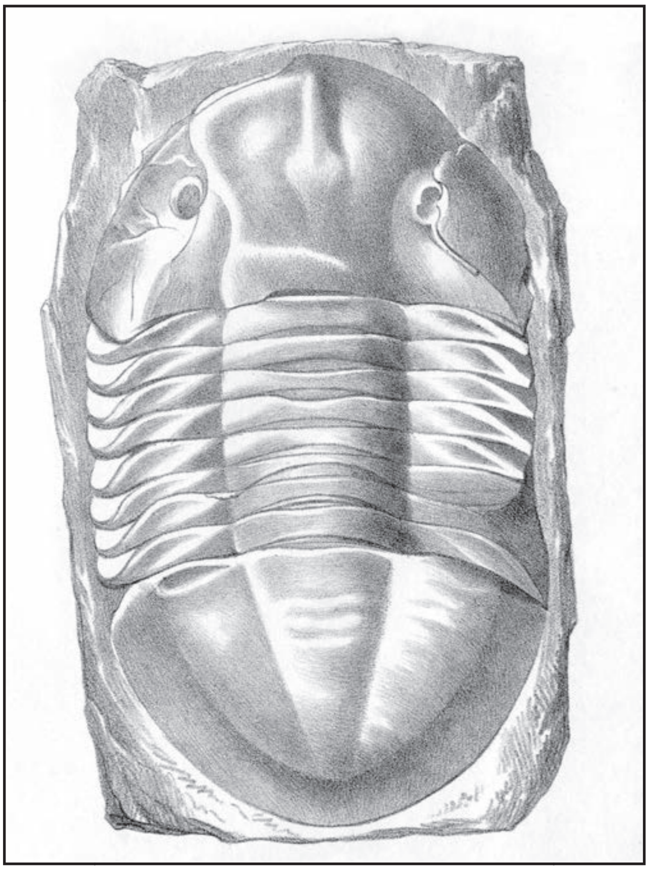


Figure 4. *One of the many fine illustrations (by G. V. Du Noyer) from Portlock's* Report on the Geology of the County of Londonderry, *etc. 1843: a trilobite identified by Portlock as* Isotelus powisii *Murchison.*

time that Portlock set about establishing a geological branch of the Ordnance Survey of Ireland. In 1834 he was asked to contribute to an Ordnance Survey memoir describing the parish of Templemore, which includes most of the city of Londonderry. A provisional edition of this memoir was printed in 1835 for the annual meeting of the British Association for the Advancement of Science, which took place at Dublin in August of that year. The memoir included a hand-coloured plate depicting the geology of the parish of Templemore at a scale of one inch to the mile, being the first official geological map to be published for any part of Ireland (Fig. 3). Formal publication of the memoir did not follow until 1837 (Colby 1837). In this same year Portlock was able to set up an office, museum and soils laboratory at Belfast, thus establishing the Geological Branch for the first time as an organised entity (Andrews 1975, 155; Herries Davies 1983, 100).

Financial and other considerations unfortunately led to the closure of Portlock's department in February 1840, although he was given time to complete his monumental *Report on the geology of the county of Londonderry and of parts of Tyrone and Fermanagh*, published in February 1843 (Fig. 4). Official geological activity in Ireland thus effectively came to an end for the second time, although Colby did not give up without a struggle (Herries Davies 1983, 106-22). The Irish geological survey was not to be formally reinstated until the passing of the Geological Survey Act of 1845, which established the Geological Survey of Great Britain and Ireland under the general directorship of Henry De la Beche. Portlock's *Report*, accompanied by a fold-out geological map at a scale of half an inch to the mile, and his contribution to the Templemore memoir, were the only published products of this early attempt at an official geological survey of Ireland.

It should not be forgotten that Richard Griffith published his geological map of Ireland in 1838 and 1839 utilising a topographical base specially prepared by the Ordnance Survey. From the very beginning he had kept a close watch on the activities of the Survey in Ireland, but maintained a self-interested scepticism of its ability to produce geological maps of a quality comparable to his own (Herries Davies 1983, 48, 91-2).

Scotland

In 1814 John MacCulloch was appointed geologist to the Trigonometrical Survey (as the Ordnance Survey was then called) with orders to locate areas in Scotland where the geology might cause abnormal deflections of the plumbline, so that they could be avoided in the geodetic measurements to establish a meridian for the construction of the one-inch map. At the same time he was asked to discover a mountain more suitable than Schiehallion in Perthshire for determining the mean density of the Earth (Flinn 1981). MacCulloch used this opportunity to carry out a more wide ranging geological survey of the country in furtherance of observations begun by him in 1811 while employed by the Board of Ordnance as chemist (Cumming 1984). According to his own testimony much of this work was done in his own time and at no additional expense to the Ordnance. In June 1821 he submitted a proposal to the Board for completing and publishing a 'mineralogical map' of Scotland. Nothing came of this, notwithstanding an earlier show of melodrama, made in the presence of T. F. Colby, in which he had talked of hanging and shooting himself if he were not permitted to finish the map! (Fig. 5; Flinn 1981). In 1826 he was encouraged to apply directly to the Treasury for financial support, and in this he was successful. On 4 July the Treasury issued a minute sanctioning the continuation of the survey and expressing the view that such a map 'must prove, not only highly interesting in a scientific point of view, but of considerable practical utility to many branches of industry connected with the mineral kingdom' (Eyles 1937).

MacCulloch's survey appears to have been finished by about 1832 (having thus taken at least 18 years to complete), but it required a memorial from the Highland and Agricultural Society of Scotland before the Treasury could be induced to publish the map. A principal hindrance had been the inadequacy of the topographical base published by the firm of Arrowsmith, upon which MacCulloch had been obliged to plot his geological lines, and about which he made continuous complaint (the Ordnance Survey did not begin systematic topographical mapping in Scotland until 1846, having abandoned its earlier attempt in 1828). MacCulloch's geological map was eventually published by Arrowsmith in 1836, a year after its author had died following a carriage accident while on his honeymoon, aged nearly 62. The map (Fig. 6), accompanied by a memoir (MacCulloch 1836), is an impressive achievement, being at the scale of four miles to the inch, but seems not to have had a very lasting impact (Judd 1898). MacCulloch's all too characteristic contempt for fossil evidence (as for much else) made the result less useful to the stratigrapher than it might otherwise have been. (For a more generous assessment of MacCulloch's legacy, see Bowden 2009).

MacCulloch's travel expense claims for his 'mineralogical' survey proved to be so exorbitant that the Treasury was induced to undertake a detailed enquiry, the results of which appeared in a Parliamentary Paper in 1831 (Eyles 1937). The memory of this injury to the public purse was to resurface in December 1839 when De la Beche asked the Board of Ordnance for permission to spend the winter months in London for the purpose of arranging his notes. The Board stipulated that De la Beche's travel allowance be suspended for the period of his residence in London, and in adverting to 'what occurred in respect to the Scotch Geological Survey,' desired that 'special care may be taken to prevent the occurrence of a similar fault in the English Survey' (BGS Archives GSM 1/68, 320; North 1936, 82-5).

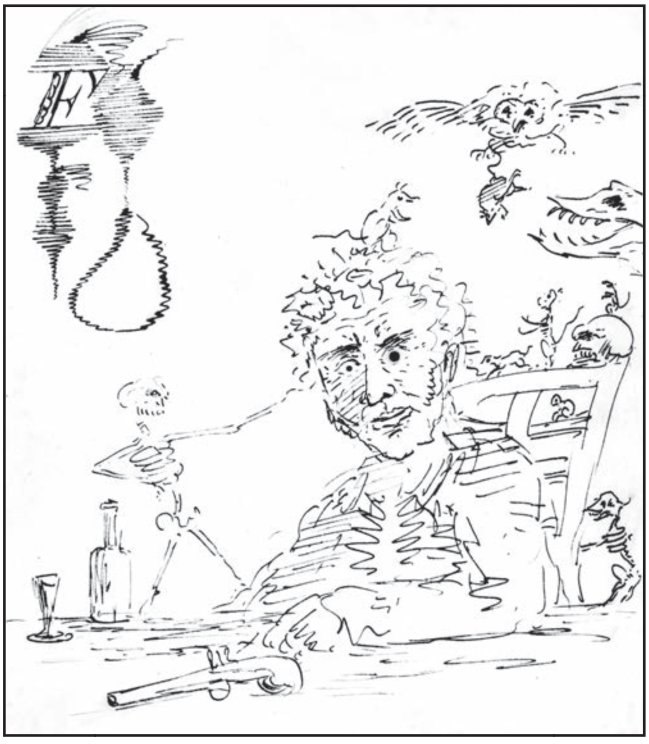


Figure 5. *Self portrait by John MacCulloch: in April 1821 he talked of hanging and shooting himself during a stormy meeting with Thomas Colby (Reproduced courtesy of the Geological Society of London).*

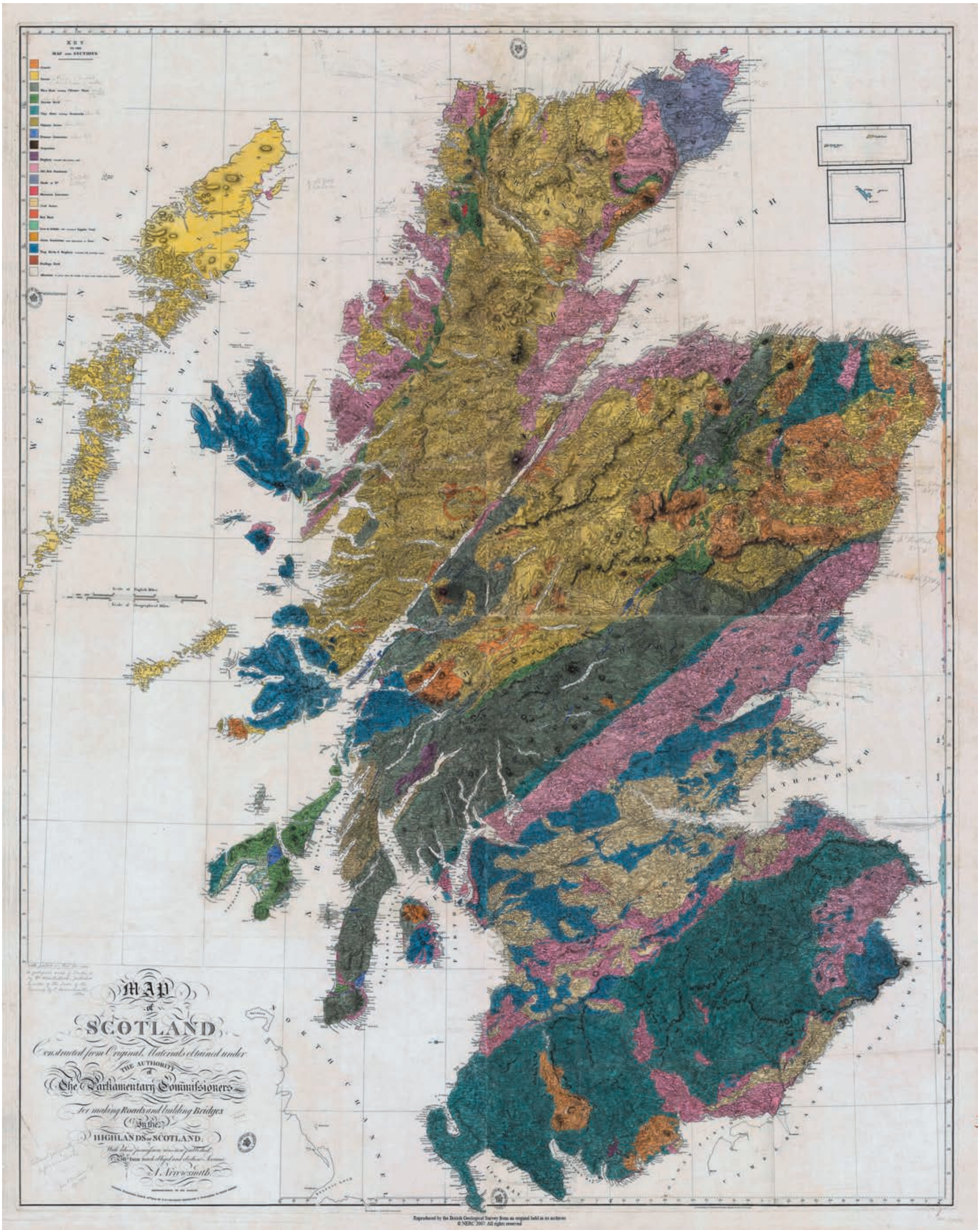


Figure 6. *John MacCulloch's* Geological Map of Scotland *1836; this edition reissued 1840 or later (published BGS facsimile, 2007, © NERC).*

Enter Henry De la Beche

Such, as outlined above, was the climate of officially-sanctioned geological survey activity into which De la Beche was to make his own entrance in the early 1830s. In Britain this was a period of political and social revolution: the Age of Reform, in which for the first time there was a growing recognition of the possibility of improvement for the generality of the population. The 1830s witnessed the Reform Act of 1832, the Abolition of Slavery Act of 1833, the New Poor Laws of 1834, and the growth of the railways leading to a greater demand for coal and a significant increase in the trading of metals. The creation of a Geological Survey, with a remit to make systematic and detailed geological maps for the use of the mineral developer, civil engineer and agriculturalist, would thus appear natural and appropriate in an age where industrialisation, improvement and self-help were the dominant themes. Yet the establishment of the Survey seems to have been the result merely of an accident in the events of De la Beche's life. A few words therefore must now be said about De la Beche himself.

Early years

Henry Thomas De la Beche (pronounced Beach) was born at St Marylebone in London on 10 February 1796. His father, born Thomas Beach (1755–1801), had the family name changed to De la Beche in 1790 on the strength of a tradition that they were descended from an ancient family of that name from Aldworth in Berkshire (Chubb 1958). Henry's grandfather, also called Thomas (1715–1774), had been Attorney General and Chief Justice of Jamaica, and through marriage acquired the estate of Halse Hall in the parish of Clarendon, which included a sugar plantation. Henry was only five years of age when his father died in June 1801 while the family were visiting their Jamaican estate. He returned to England with his mother, and after various moves, mostly in the south-west of England, came to reside at Lyme Regis in Dorset in 1812. Prior to this, in 1810, he had entered the Royal Military College at Great Marlow, where it seems he acquired the skills of surveying and perspective landscape drawing that were to serve him well in later life. He was, however, dismissed from Marlow in the following year for insubordination, bringing to an end any prospect of following in the footsteps of his father who had been a Lieutenant-Colonel in the cavalry (McCartney 1977). At Lyme Regis he made the acquaintance of Mary Anning, the celebrated fossil collector. It is usually thought that his active interest in geology developed at this time, although new evidence suggests that he had an interest from his schooldays (pers. comm., Tom Sharpe).

Geological apprenticeship

De la Beche inherited his father's Jamaican estate, which provided him with a comfortable living (about £3,000 per year) and enabled him to pursue his interest in geology and to become a Member of the Geological Society in 1817, at the age of just twenty-one. His first paper, 'Remarks on the geology of the south coast of England, from Bridport Harbour, Dorset, to Babbacombe Bay, Devon' (Fig. 7), was read before the Society on 5 March 1819 and subsequently published in the Society's *Transactions* in 1822 (see Sharpe & McCartney 1998 for a full list of De la Beche's publications). He followed this in 1821 with the reading of a paper describing the geology of the north coast of France around Caen in Normandy, which he successfully correlated with the sequence observed in southern England. The French geologist Dufrénoy, who, it will be remembered, was one of the principal authors of the 1841 *Carte géologique de la France*, was later to describe this paper as the foundation stone of the study of geology in France (Sharpe & McCartney 1998, item 473: letter to De la Beche dated 25 January 1843).

In 1818 De la Beche married Letitia Whyte at Bristol, the daughter of Captain Charles John Whyte of Loughbrickland, county Down, Ireland (Sharpe 2008). This was followed in the summer of 1819 by a tour of the Continent which lasted a year and included a period of residence in Switzerland. His daughter Elizabeth, always referred to as 'Bessie', was born at Geneva on 2 December 1819. During the course of this tour he made detailed geological notes, established contact with leading geologists and natural historians (such as Georges Cuvier and Alexandre Brongniart) and visited museums and private collections in France, Italy and Switzerland (McCartney 1977). On 23 December 1819 he was elected a Fellow of the Royal Society.

Figure 7. *Fossils from the Lias of Lyme Regis and Axminster, illustrating De la Beche's account of the coast of Dorset and Devon (from* Transactions of the Geological Society, *1822*).

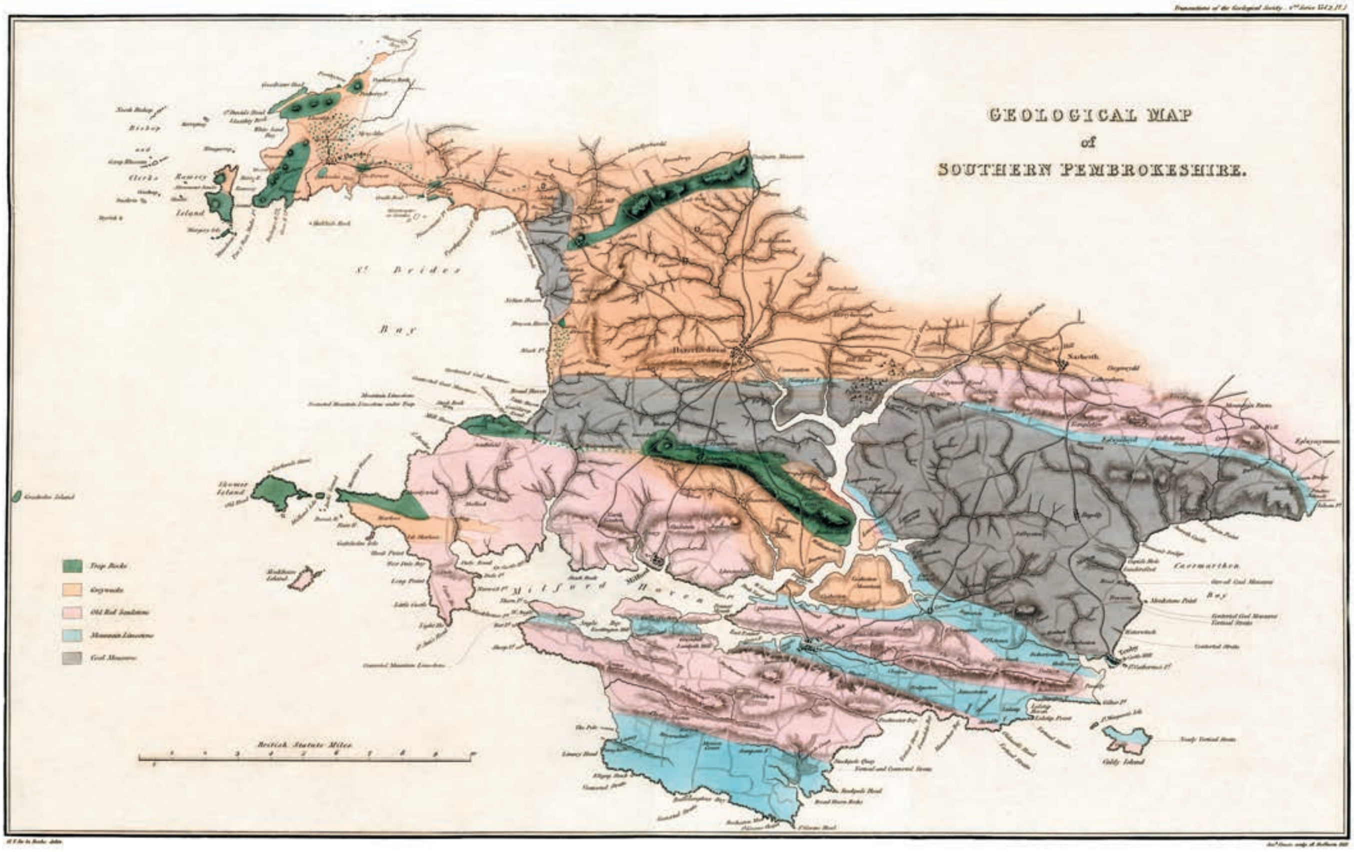
Map of Pembrokeshire, 1822

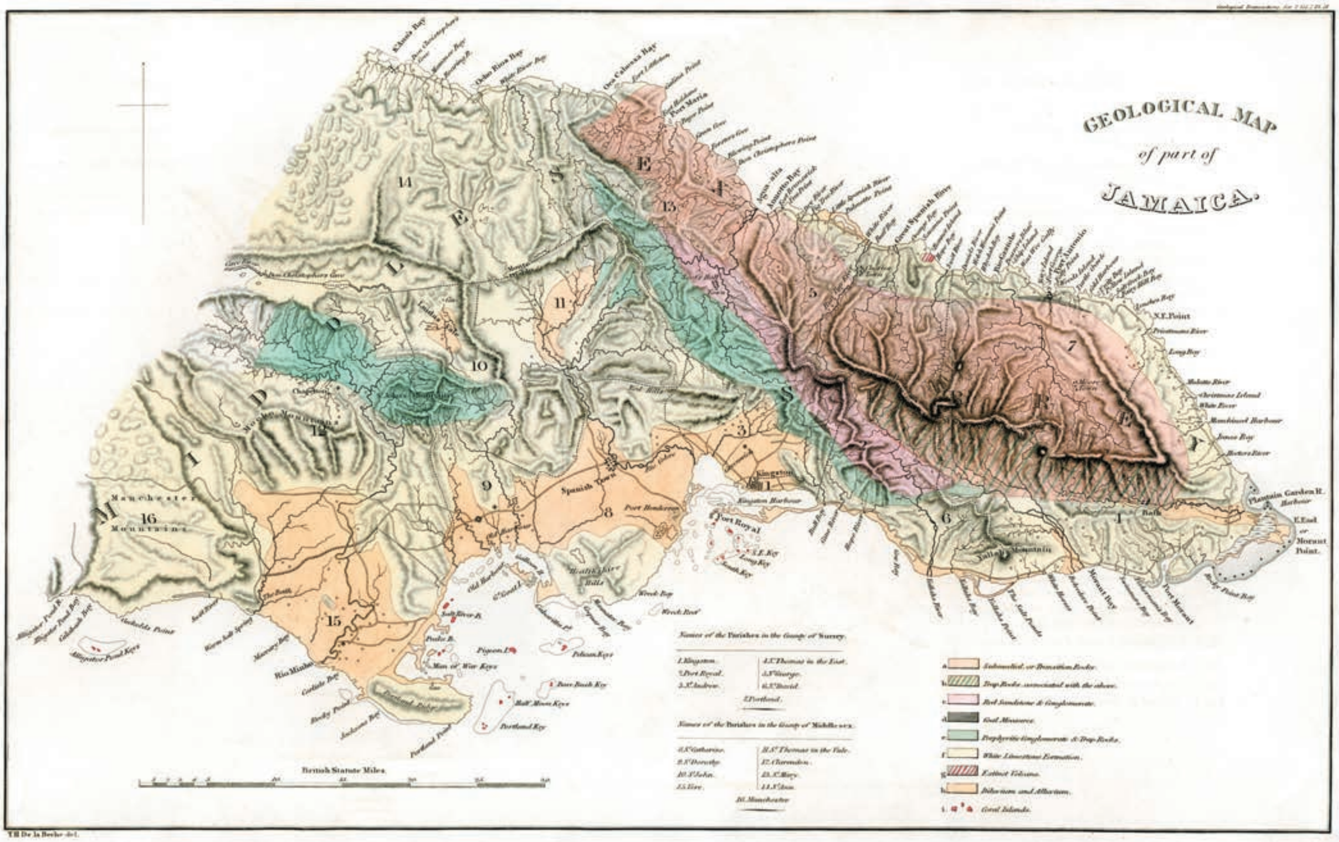
De la Beche decided to spend the summer of 1822 mapping the geology of south Pembrokeshire, the results of which were published in the Geological Society's *Transactions* in 1826. A great difficulty generally experienced at this time was the need to secure an adequate topographical basis for geological maps. The frustration felt by MacCulloch in Scotland on account of this inadequacy has already been mentioned, while the publication of Griffith's geological map of Ireland was delayed many years for want of a reliable base-map. In England and Wales the situation only began to be remedied following the establishment in 1791 of the Trigonometrical Survey, under the Board of Ordnance, which instituted a programme of topographical mapping for publication at a scale of one inch to a mile (1:63 360). The first map, covering Kent, appeared in 1801, but the systematic series, now better known as the Old Series one-inch maps, commenced publication in 1805. When De la Beche came to map south Pembrokeshire, evidently with the encouragement of his good friend, the Reverend William Daniel Conybeare, he was able to utilise the newly published one-inch Ordnance maps for Pembroke (1818) and Haverfordwest (1819). He records how Conybeare had earlier been defeated in his attempt to geologically survey the region for want 'of any thing deserving the name of a map'. With respect to the Ordnance maps, De la Beche felt bound to state that 'it is scarcely possible to appretiate too highly the assistance which this and the other parts of that splendid survey of England are calculated to afford to the geologist' (De la Beche 1826). The geological map that accompanies his paper (Fig. 8) is at a scale of just over two miles to the inch, and uses as its basis a redrawn and simplified version of the Ordnance map. Many years later, on the occasion of De la Beche being awarded the Wollaston Medal, the President of the Geological Society, W. J. Hamilton, was to commend this map 'in which I think we may trace the commencement of that system of geological illustration which he has subsequently perfected in the maps of the Ordnance Geological Survey' (Hamilton 1855).

Trouble in Jamaica ... and at home

In November 1823 De la Beche visited his estate in Jamaica, prompted perhaps by British government recommendations made earlier that year for ameliorating the condition of slaves employed in the British West Indian sugar plantations (Deerr 1950, 303). The government's ultimate aim was the gradual abolition of slavery, so it was unsurprising that its proposals were violently resisted by the West Indian planters, leading in turn to unrest among the slave population. De la Beche may be seen as one of the more enlightened plantation owners, attending to the education and good treatment of his slaves. He published a small book on the subject, pointing out that 'the accidental circumstance of inheriting West Indian property' should not be taken to imply that he supported slavery (De la Beche 1825; Sharpe 2008). He was there for just over a year, while his wife and child remained in England.

Figure 8. *Geological map of southern Pembrokeshire, surveyed by De la Beche in 1822 (from* Transactions of the Geological Society*, 1826).*





In between attending to his business affairs and the welfare of his workforce, De la Beche took time out to study the geology of the island (Chubb 1958), the result of which was a detailed memoir in the Geological Society *Transactions* (De la Beche 1827). It stands as the first systematic account of the geology of any part of Jamaica and is accompanied by a geological map of the eastern half of the island (Fig. 9). In later years De la Beche came to be an authority on scientific matters relating to the island and is today celebrated as the father of Jamaican geology. Some months after his return to England, in 1825, he was confronted by a request from his wife for a legal separation, and in the following year he obtained a divorce in the ecclesiastical court. It appears that De la Beche had not placed sufficient trust in Letitia and had used 'hasty expressions ... being such as to render it impossible for her to live with him' (McCartney 1977, 26). Their daughter Bessie remained in her father's care and lived with her grandmother at Lyme Regis when De la Beche was away.

Despite his domestic troubles, De la Beche conducted further geological investigations of the Dorset and Devonshire coast. He subsequently read two papers before the Geological Society. The first, in December 1825, discussed the Chalk and Upper Greensand in the vicinity of Lyme Regis and Beer; it was followed in November 1827 by a paper 'On the geology of Tor and Babbacombe bays, Devon' (Fig. 10). The latter, as published in the *Transactions* (De la Beche 1829), includes a small geological map at a scale of about two miles to the inch, the topographic base for which was redrawn from part of Ordnance one-inch sheet 22.

Figure 9. *Geological map of the eastern part of Jamaica, surveyed by De la Beche in 1824 (from* Transactions of the Geological Society*, 1827).*

During 1827 De la Beche suffered a decline in his health, possibly brought on by the strain of separation and divorce. To escape the northern European winters, he undertook two further tours of the Continent, the second of which was concluded in June 1829 (McCartney 1977, 26-7). Over the next two years he published numerous papers and several books, including his widely acclaimed *A Geological Manual* (1831). This book went into three English editions, followed quickly by French, German and American editions. These successes, however, were to be overshadowed by further problems in the West Indies which would oblige De la Beche to relinquish his status as a gentleman of independent means and assume the role of a government employee.

Figure 10. *Sketch by De la Beche showing folded Carboniferous Limestone near Torquay, south Devon (from* Transactions of the Geological Society*, 1829).*

Beginnings of the Geological Survey

In 1830 De la Beche began a more systematic geological examination of south Devonshire utilising the Ordnance one-inch map as a base. His detailed notes, together with sections, may be found in a notebook preserved in the Library of the British Geological Survey (GSM 1/123). The region covered by these recorded observations is confined largely to Ordnance sheets 22 and 23 (see Fig. 15 below). The area previously mapped around Tor and Babbacombe bays was now revisited and fleshed out in greater detail. This was for De la Beche a recreational activity that depended on his receiving a regular income from his plantation in Jamaica. But by 1831 this was in jeopardy. For some years the price of sugar had been declining steadily, due in large part to overproduction. This excess was most notable in Cuba, where sugar production more than doubled in the years between 1829 and 1836. In 1831 the average price of raw sugar fell to a lower level than at any time previously. Many plantations in the English colonies, including De la Beche's, were by this time heavily mortgaged, causing yet more distress to the owners (Deerr 1949-50).

It remains unclear whether, as De la Beche was to claim, he began the geological mapping of whole Ordnance map sheets purely for his own recreation, or whether this was done from the start with an eye to selling the idea to the Ordnance Survey. He was in regular correspondence with Élie de Beaumont, who at this time was engaged in mapping the geology of France at government expense. Thus the French geologist wrote to him in May 1830 with the news that he was then engraving the map of France (Sharpe & McCartney 1998, item 492). Whatever his reasons, the year 1831 saw De la Beche pressing ahead with his fieldwork in south Devonshire, driven by a sense of urgency that kept him there through the rainy months of late autumn.

Mapping Devonshire, 1832-35

On 28 March 1832, De la Beche addressed a letter to the Master General of the Board of Ordnance with a proposal 'for supplying the data for colouring Geologically eight Sheets of the Ordnance Map of England, viz. Nos. 20, 21, 22, 23, 24, 25, 26 & 27, comprising Devonshire, with parts of Cornwall, Somerset, & Dorset' (GSM 1/68, 44-8). De la Beche took care to address his proposal from the offices of the Geological Society, of which he was then Secretary, thereby ensuring that it would receive serious consideration. The proposal ran as follows:

'Having applied myself to the Study of Geology for many years and having directed much of my attention to the Geological relations of this my native country … and being convinced of the great practical utility of what I am about to propose, I offer no apology for intruding myself on the notice of your Hon^{ble} Board with a view to obtain the completion of an undertaking which has for some time past occupied much of my time and attention; one that I had set out with the intention of accomplishing at my own proper cost, but in which I am defeated by the failure of certain funds I had intended to apply to that purpose. I am induced therefore to offer to your Hon^{ble} Board the fruits of my labours at a price that I am well assured will be considered *very moderate* knowing as I do that it will be much below the sum they will have cost me when completed. ... For the sum of £300, I undertake, within two years from the present time, accurately to determine for the use of the Ordnance solely the Geological structure of the district comprised within the eight sheets specified above and to lay down the detail accurately to scale and properly coloured upon each of those sheets, in so clear and intelligible a manner as to admit of its being readily transferred upon the Ordnance Copper Plates. I will also attach to the margin of each sheet an index scale of colours descriptive of the rocks and beds comprised within it.'

De la Beche followed this with a detailed cost benefit analysis. Thus, for an Ordnance sheet currently retailing at 12 shillings, the addition of geological data would increase the selling price by a further 2 shillings. He had little doubt that the Ordnance would fully recover its costs on the sale of these maps, and saw every prospect that the work would confer 'a great benefit on a Science that is every day increasing in interest and importance', while the resulting maps 'would be of great practical utility to the Agriculturalist, the Miner, and those concerned in projecting and improving the Roads, Canals, and such other public works, undertaken for the benefit and improvement of the Country.'

De la Beche had already completed the geological mapping of Ordnance sheet 22 (Fig. 11) at the time of writing his proposal. It was probably this sheet also that he despatched to Élie de Beaumont, who thanked him in a letter dated 8 April 1832, expressing the hope that this initiative would lead to the completion of the remaining sheets (Sharpe & McCartney 1998, item 497). Clearly, De la Beche must have been confident of a successful outcome.

The Board forwarded the proposal to Lt-Col. Thomas Colby, Superintendent of the Ordnance Survey (Fig. 12), for his opinion. De la Beche's proposal fitted well with Colby's ambition to increase the utility of Ordnance maps by the addition of geological information as was already being tried, albeit with limited success, in Ireland. Colby was also cautiously encouraging his English surveyors to include geological observations on their maps, so long as it did not impede the progress of the topographical survey (Harley 1971; Murchison 1833, 446-7). He had even issued a 'Table of Letters and Colors by which the Rocks and Strata of most ordinary occurrence will be expressed' (Colby 1830). It therefore comes as no surprise that in his reply to the Board, dated 9 April, Colby acceded to the proposal, though on certain conditions: firstly, that the index of colours to be used should be referred to the Council of the Geological Society for their decision; secondly, that De la Beche 'shall undertake, at his own cost and risk to publish all these indexes of Colors, Geological Sections, Memoirs, and other matters which may be necessary to illustrate the use of the Map where Geologically colored.' The sum of £300 would be paid in eight instalments of £37 10s upon delivery of a sheet geologically coloured for engraving (GSM 1/68, 52-3).

On 2 May De la Beche was formally invited to accept the Board's offer subject to the above conditions. In his reply to Colby he quibbled only at the necessity of referring his index of colours to the Council of the Geological Society, warning that a speedy decision would be unlikely and could only delay matters. Some formal consultation with the Society did however take place, and De la Beche discussed the matter privately with G. B. Greenough (a close friend and future ally) who was then preparing a second edition of his *Geological Map of England & Wales*. The two of them agreed a provisional scheme of colours, which De la Beche then applied to the finished sheet 22. This sheet he delivered to the Ordnance Map Office at the Tower of London on 9 May, the same day on which he formally accepted the Board's offer (GSM 1/68, 56-65, 83). Although impatient to begin fieldwork, he delayed his departure in order to attend a meeting of Council on 16 May, at which an agreement by committee was reached on the

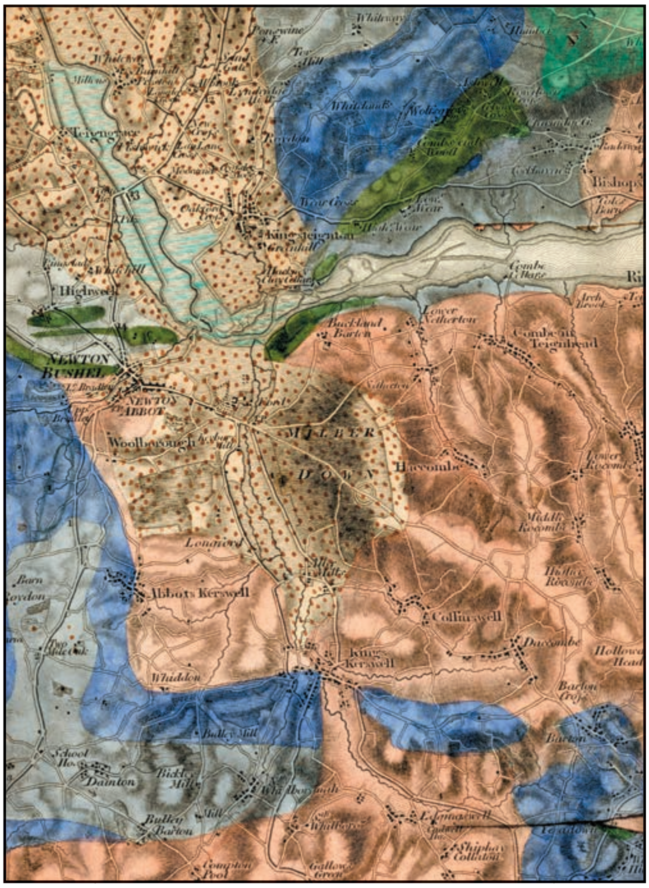


Figure 11. Detail (Newton Bushel) from old series one inch geological sheet 22, south-east Devon, surveyed 1830-31, published 1834: the first Geological Survey map to be submitted for engraving (from De la Beche's own copy, BGS Library AM 1112 S, set A).

***Figure 12.** Thomas Frederick Colby, Superintendent of the Ordnance Survey, by William Brockedon, 1837 (© National Portrait Gallery, London).*

scheme of colours, as appears from a manuscript table of 16 colours preserved in the Library of the British Geological Survey (GSM 1/85; Woodward 1908). These colours were chosen to match the prevalent tints of the rocks themselves, a practice recommended by Abraham Werner of the Freiberg Mining Academy in Saxony, and advocated in Britain by Robert Jameson (Jameson 1811). William Smith had applied the same general principal in colouring his maps (Smith 1815).

Further deliberation on the scheme of colours appears however to have taken place during the winter of 1832, evidently because De la Beche discovered a need for additional colours during the course of mapping. The Council sought the advice of the sculptor and painter, Francis (later Sir Francis) Chantrey, a member of the Society well regarded for his experience in the applied arts (Cook 1987). The subsequent colour indexes issued by De la Beche may therefore owe something both to the Wernerian principal and to Chantrey's design sense, although the scheme would evolve in the years to come as more geological formations were identified and additional colours and patterns needed (Fig. 13).

No official correspondence survives from the two-and-a-half-year period during which De la Beche worked on the Devonshire sheets. However, in his February 1834 presidential address to the Geological Society, Greenough was able to report that 'Mr. De la Beche, one of our Vice-Presidents, acting under the direction of the Board of Ordnance, has produced a geological map of the county of Devon, which, for

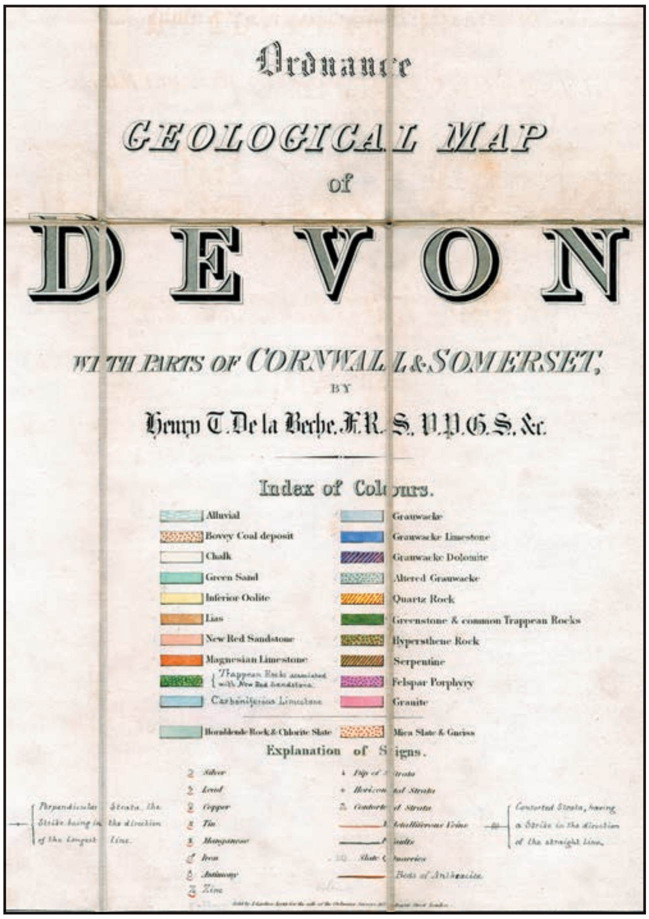


Figure 13. *First Index of Colours and Signs, pasted onto sheet 23 of the* Ordnance Geological Map of Devon *1834-5. This copy includes MS additions by De la Beche, made probably in the light of his re-examination of Devonshire in 1837 (BGS Library AM 1112 S, set A).*

extent and minuteness of information and beauty of execution, has a very high claim to regard' (Greenough 1834, 51). In his next address the following year we learn that 'The researches of your Vice-President in the counties of Devon and Somerset have been carried on this year [1834-35] with increased energy. Of the eight sheets of the Ordnance Map upon which he has been engaged, four were published last spring [probably sheets 22-25], three others are complete, the eighth is nearly complete, and an explanatory memoir with sheets of sections applying to the whole are to be published before our next anniversary.' Greenough had been carefully primed by De la Beche, and he ended with the plea: 'Let us hope that this work so admirably begun may not be suffered to terminate here' (Greenough 1835, 154; Rudwick 1985, 123-4).

The Ordnance Geological Survey, 1835

From the very start of De la Beche's survey there was an understanding that it might in due course be extended to other parts of the country. This understanding is reflected in the 1832 correspondence recorded in the Ordnance Survey letter books. It was also widely reported, prompting at least one provincial geologist to recommend his mapping skills to the Board of Ordnance. Thus, Dr Henry L. Boase of Penzance wrote to the Board on 30 June 1832 offering his services to 'delineate on your Map, the various rocks and the principal metalliferous veins of *Cornwall*' (GSM 1/68, 80-2). Colby advised the Board that it would be wise to defer a decision on Dr Boase's offer until the Devonshire survey had reached a more advanced state. In the event, nothing further seems to have transpired respecting this offer. Dr Boase's competency as a geological observer was brought into disrepute in 1834 following the publication of an ambitious *Treatise on Primary Geology* and the reading of a paper at the British Association meeting in Edinburgh, where he showed himself to be ill-informed about the difficulties of interpreting the older rocks of south-west England (Rudwick 1985, 88-9).

On 25 May 1835, De la Beche wrote to the Board to announce 'that the Geological Map of Devonshire, with portions of the adjoining counties ... executed in compliance with the order of the Honble. Board of the 2nd May 1832, is now completed...' In concluding his letter he expressed the hope 'that the Honble. Board will be pleased to examine the result of my labors; and if they shall find that it is desirable to continue the Geological Survey, I would willingly devote my time to the Geological examination of another portion of country' (GSM 1/68, 93). The Board wasted no time in calling upon the President of the Geological Society (at that time Charles Lyell), and two of its most prominent and respected members, William Buckland and Adam Sedgwick, to report on De la Beche's work and on the expediency of extending the survey to other parts of the country.

The Society's report, dated 12 June, was full of praise: 'Our opinion is that the execution of the geological survey of Devonshire is the result of great labour combined with great skill, and that no geological Map of such extent has been published in Europe equal to it in the minute accuracy of its details. We regard its publication as reflecting great honor on the Board of Ordnance, with whom it originated, and at the same time as a benefit to European Science. We are further of opinion, from this evidence, but still more from our personal knowledge of the unusual combination of qualifications which are united in Mr. De la Beche, that it would be highly honourable and useful to the Nation to continue his services, in the extension of a geological survey on one uniform system over other parts of Great Britain' (GSM 1/68, 98).

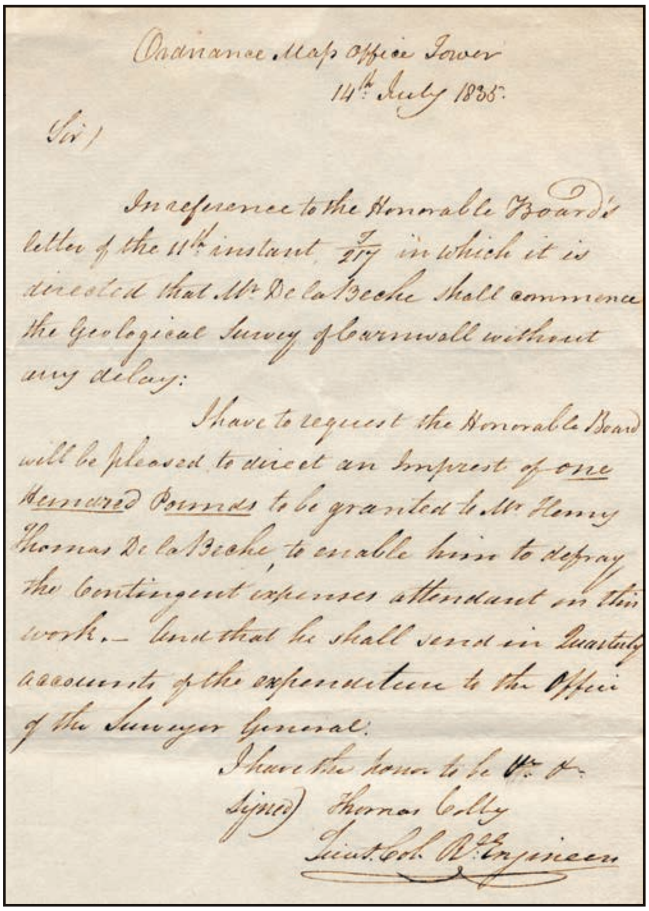
The report goes on to examine the economic advantages of good geological maps — these are: (1) to aid the search for coal and metals, and thereby reduce wasteful speculation; (2) to locate the best materials for making and repairing roads; (3) to indicate the situation in which water may be obtained at the least expense in sinking wells; (4) to assist in the construction of canals, rail-roads and tunnels; (5) to indicate where good limestone, brickearth and building stone may be encountered; and (6) to support agriculture by pointing to the occurrence of lime, marl, gypsum and other materials for the artificial improvement of soils. The foregoing is expressed in similar terms to that of an undated note written by De la Beche some time before 1835 (North 1936, 47-8).

In terms of organisation, the report advised the establishment of a subordinate branch of the Ordnance Survey under the control of Thomas Colby, consisting of De la Beche and any assistants that might be considered expedient. It was recommended (on the advice of Colby) that De la Beche receive a salary of £500 per annum, together with £1000 to cover the appointment of assistants and for defraying other contingent costs. On 18 June the Master General of the Board of Ordnance gave approval for the recommendations to be carried forward for Treasury authorisation. The Treasury responded favourably on 30 June, stating that 'they will cheerfully give their sanction to any measure which may facilitate so desirable a result, if it can be obtained at a moderate expense.' With this last consideration in mind the Treasury not unreasonably asked the Board for an 'Estimate of the *time* which they consider will be required for the entire completion of the whole undertaking' (GSM 1/68, 107). The question was therefore referred to De la Beche, who replied on 4 July that 'In answer to your question respecting the *time* required to complete the Geological Survey of Great Britain, I beg to state ... that depending as it must do upon the amount of competent aid which I may receive ... I consider that the Geological Map will keep pace with the Geographical Map, and consequently that both Maps will be completed at the same time' (GSM 1/68, 113).

Unsurprisingly, the Lords Commissioners of the Treasury were not about to be disarmed by a cleverly evasive response. Francis Baring, Secretary to the Treasury, asked De la Beche privately for an estimate of the time required 'to perfect the Geological Survey of that part of England and Wales which has already been completed by the Ordnance.' De la Beche replied that it would take 21 years to survey the current 66 Ordnance sheets, assuming that he worked singly and was unassisted. If, however, he received the aid of two or three competent assistants, as was envisaged, and was able to purchase local information as occasion might require, he could complete the geological mapping of the published part of the Ordnance Map in only seven years. On this basis he estimated that, with the necessary aid, 'the Geological Map of England and Wales may be completed in about 10 years' (GSM 1/68, 119-20). It would be surprising if De la Beche believed this to be a realistic estimate, and he certainly changed his mind a few years later.

Behind the scenes, De la Beche was doing everything he could to ensure a successful outcome to the Treasury decision. He asked Sedgwick to use his personal influence with both the Marquis of Lansdowne, Lord President of the Council and a prominent supporter of science, and Thomas Spring-Rice, Chancellor of the Exchequer. His financial situation had worsened during 1833-34 owing to a further decline in the value of West Indian property, while his fee for the Devonshire survey had not even covered his expenses (Rudwick 1985, 103, 125). De la Beche's livelihood was now very much in the balance.

Relief arrived when De la Beche was forwarded a written communication from the Board of Ordnance, dated 11 July 1835 and addressed to the Inspector General of Fortifications (under whose control the Ordnance Survey resided), which informed him that the Treasury had sanctioned a 'Geological Survey of Cornwall.' The Lords Commissioners still felt that his estimate of expenditure for the whole survey was 'insufficiently ascertained', but hoped that a better estimate of the annual rate of progress and expense might be obtained following the completion of the Cornish survey (GSM 1/68, 117-8). With this letter of appointment the Geological Survey as an institution may be said to have been born (Fig. 14). As a branch of the Ordnance Trigonometrical Survey it assumed the title of 'Ordnance Geological Survey,' under the overall control of Lt-Col. Thomas Colby.


Ordnance Map Office Tower
14th July 1835.

Sir!

In reference to the Honorable Board's letter of the 11th instant in which it is directed that Mr De la Beche shall commence the Geological Survey of Cornwall without any delay:

I have to request the Honorable Board will be pleased to direct an Imprest of one Hundred Pounds to be granted to Mr Henry Thomas De la Beche, to enable him to defray the Contingent expenses attendant on this work. – And that he shall send in Quarterly accounts of the expenditure to the Office of the Surveyor General.

I have the honor to be &c &c

Signed) Thomas Colby
Lieut. Col. Rl. Engineers

Figure 14. *De la Beche's copy of a letter from Colby to the Office of Ordnance, requesting an imprest of £100 to be granted to De la Beche in respect of his appointment on 11th July 1835 (Reproduced courtesy of the Department of Geology, National Museum of Wales, NMW 84.20G.D.261).*

Controversy and consolidation

Henry Thomas De la Beche, at 39 years of age, now saw himself set on a course that would lead ultimately to a 'Geological Survey of Great Britain' (GSM 1/68, 121). Yet the future of the fledgling Survey was by no means assured, for the seeds of future trouble had already been sown several months earlier. Between 1834 and 1839 De la Beche became embroiled in a major scientific controversy that would have far-reaching repercussions.

In the late summer of 1834, while working on sheet 26 of the Devonshire survey (Fig. 15), De la Beche collected some fossil plants in strata closely associated with culm, an inferior coal, near Bideford in north Devon. He arranged for these to be identified by John Lindley, then the foremost authority on palaeobotany, who pronounced them all to be of plant species well known in the Carboniferous Coal Measures. This surprised De la Beche, who expected only a rough affinity, for in his view the immense thickness of otherwise poorly fossiliferous slaty mudstones and sandstones within which the coal seams occur could only belong to the so-called Transition or Greywacke strata below the Old Red Sandstone, and thus well below the Carboniferous.

Devonian Controversy

De la Beche arranged for a short notice of his findings to be read at a meeting of the Geological Society in December of that year (De la Beche 1834). His contention that the plant remains came definitely from the Greywacke, and were thus pre-Carboniferous, caused heated debate. In opposition to this, Roderick Murchison, whose view was supported by Charles Lyell, insisted that the fossil evidence established a clear correlation between the 'Culm' strata and the Coal Measures. In accepting the value of 'characteristic fossils' as a means of determining the relative age of rock formations, Murchison was unconditionally advocating the precepts laid down by William Smith. Yet Smith's views were far from being widely accepted at that time.

The significance of this argument, which dragged on for several years, was not only of academic interest, but had important economic implications. Murchison was keen to demonstrate that land plants, the raw material of coal, did not exist before the Old Red Sandstone, and thus it was futile to search for coal deposits in rocks of Transition or Greywacke age. De la Beche's insistence on the existence of Greywacke plants undermined this argument. However, even Murchison was not prepared initially to regard the whole of the Culm succession as Carboniferous in age, and was convinced that De la Beche had somehow overlooked a major unconformity.

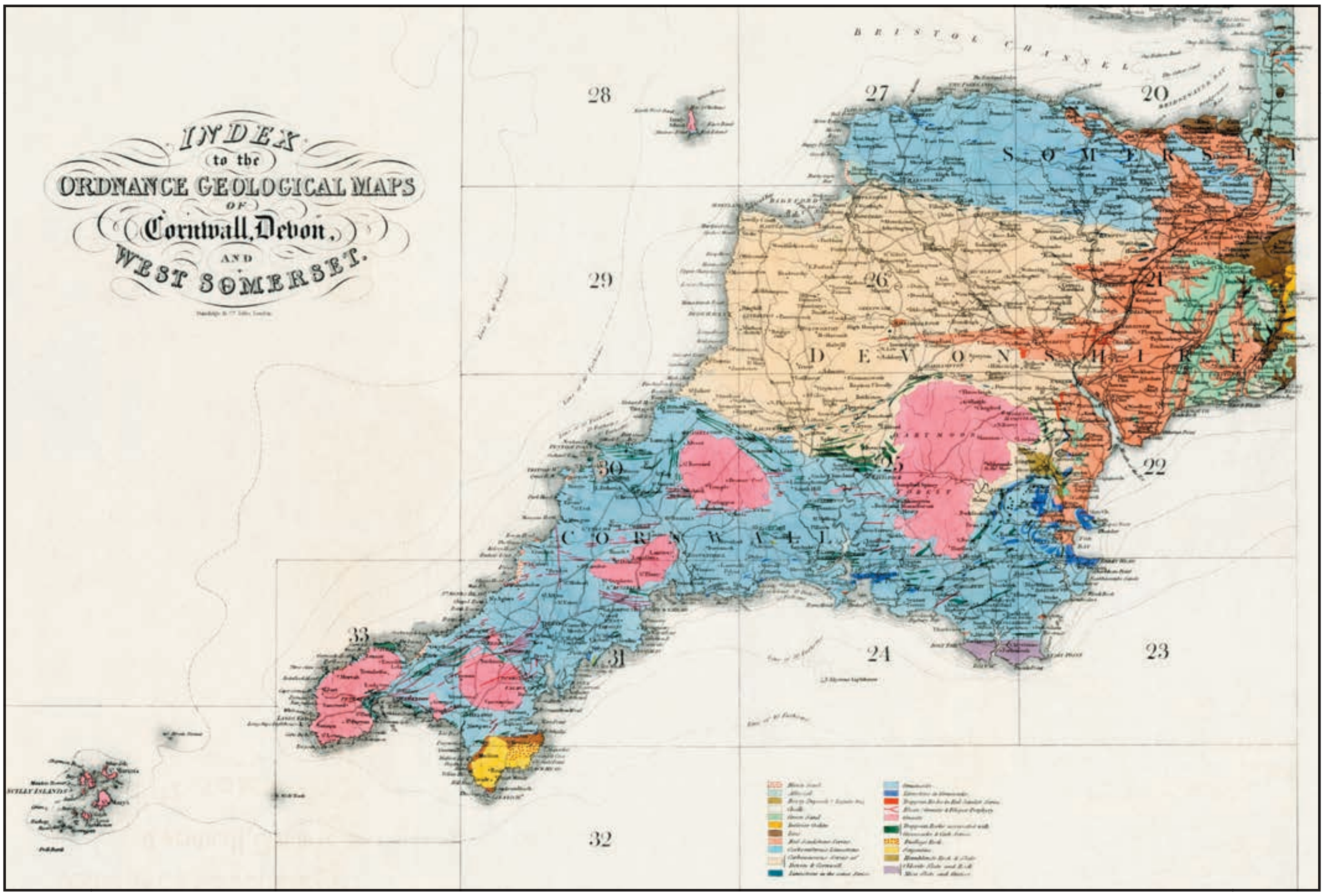


Figure 15. *Index map from De la Beche's* Report on the Geology of Cornwall, Devon, and West Somerset, *1839, showing the constituent one-inch sheets.*

At the annual meeting of the British Association at Bristol in August 1836, Murchison, with Adam Sedgwick, put forward a fundamentally different interpretation of the structure and position of the Culm strata of Devonshire. It was a severe blow to De la Beche's integrity as a field observer. Furthermore, some influential figures were present at the meeting, including Spring-Rice, the Chancellor of the Exchequer. De la Beche now became concerned that this public criticism of his work might prejudice the future of the Survey. In a letter to Sedgwick he expressed his fears that the government's continuing patronage of science, and in particular of geology, was a sensitive point because 'they have been so often jobbed, and infernally jobbed, under the old systems, that they are always afraid of being jobbed again' (Rudwick 1985, 175). He may have had John MacCulloch's recently published *Geological Map of Scotland* in mind (Fig. 6), a map whose compilation had cost the Treasury an exorbitant sum of money. De la Beche's depressed state of mind at this time is conveyed in a sketch that he sent to his daughter, Bessie (Fig. 16).

The Survey under attack

In February 1837, following some further acrimony between De la Beche and Murchison, the latter began to put about that he considered De la Beche to be grossly incompetent as a government surveyor (Rudwick 1985, 202). These accusations reached official ears, with the result that on 3 April Colby despatched a letter to De la Beche informing him that 'extremely unpleasant but not tangible reports of the inaccuracy of your Geological Survey are in circulation' (GSM 1/68, 198-9). As things stood, the geological survey of Cornwall was due to be finished by the end of June 1837, and De la Beche had already submitted cost estimates and received approval from the Treasury for an extension of the survey into the South Wales coalfield — curiously, the Treasury made no allusion to the unresolved question of the total expenditure and time that would be required to complete the geological survey of Great Britain, although the matter would resurface in 1839. Colby now recommended that priority be given to the publication of a full report on the geology of Devon and Cornwall, De la Beche having so far delayed publishing anything on the former until he had completed his mapping of the latter.

In his reply to Colby, De la Beche could only complain that 'I have personal enemies, and unfortunately it is equally clear that they are actively employed against me. While I toil day after day without rest, endeavouring to do my duty to the public and to return zeal and the best use I can make of my abilities for the confidence reposed in me, they can, and it appears do, buzz their accusations about, not neglecting the quarters when they conceive they can do me the most mischief, so that do what I will I have no chance' (GSM 1/68, 200-1). His letter finished on an ominous note: 'My feelings tell me I should resign, but I would prefer an inquiry' (his threat of resignation was omitted from the Ordnance Survey letter book, probably at Colby's request, but the original letter survives: NMW 84.20G. D.378). Close allies advised De la Beche not to think of resigning, and he was soon urging his good friend Greenough to lobby in influential quarters on his behalf (Rudwick 1985, 203-4). This potential threat to De la Beche's livelihood quickly subsided, thanks in part to the efforts of Greenough. Indeed, the episode had a beneficial outcome, since Colby now conceded that the memoir on Devon and Cornwall should be published by the government and not at De la Beche's personal expense as originally proposed (GSM 1/68, 203).

De la Beche spent about a month in the autumn of 1837 re-examining parts of Devonshire in order to resolve some of the issues raised by the Devonian controversy. In December of that year he moved his base of operation to Swansea in the South Wales coalfield. February 1839 saw the publication of the Survey's much-awaited first memoir: *Report on the Geology of Cornwall, Devon, and West Somerset*, a substantial work of 648 pages with folding map, sections and plans (it was without a detailed index, this being issued separately in 1903). A revised version

Figure 16. *Sketch by De la Beche in a letter to his daughter, Bessie, dated Jan 1837. He shows himself looking disconsolately out of the window of his lodgings in Cornwall, while outside the heavy winter rain pours down. Note the picture on the wall, and another above his head, both of which show two figures boxing –an allusion no doubt to the Devonian controversy. The meaning of the two mice is less clear! (Private collection, reproduced courtesy of the Department of Geology, National Museum of Wales).*

of the eight sheets of the one-inch geological map of Devonshire appeared in the same year. De la Beche had by this time conceded to the separation of the Culm from the remainder of the 'Grauwacke' (he employed the original German form of the word), but was still unprepared to accept a Carboniferous age, preferring instead to designate the Culm lithologically by the term 'Carbonaceous Series.'

Resolution

Despite De la Beche's reservations (or stubbornness!) a Carboniferous age for the Culm became increasingly difficult to deny as more 'characteristic' fossils came to light towards the end of the 1830s. In March 1839 Murchison resolved the difficulty of accommodating the great thickness of associated Greywacke, which he had wrongly assumed to be unconformable with the Culm, by correlating it with the Old Red Sandstone whose lithology and organic remains is otherwise quite dissimilar. In a joint paper with Adam Sedgwick, Murchison grouped these two series into a newly erected Devonian System. In the Welsh Borders it was clear that the Old Red Sandstone lay between the Carboniferous Limestone above it and the formations of Murchison's recently erected Silurian System below. But the similar age of the Devonshire Greywacke only became apparent because its fossils exhibited affinities that were intermediate in character between those of the Carboniferous and Silurian Systems.

Charles Lyell considered 'the culm question' to be one of the most important theoretical issues ever to be discussed at the Geological Society (Rudwick 1985, 195-6). The resolution of the Devonian controversy proved to be of global geological significance. It firmly established the value of fossils as stratigraphic markers, founded on an acceptance of organic change over time, although the manner and mechanism of this change had yet to be explained in terms of Darwinian evolution — that particular controversy was still to come!

Consolidation

Immediately following the publication of his *Report* in early February 1839, De la Beche made an application to the Board of Ordnance for the appointment of Geological Assistants. Since 1835 he had worked largely on his own, with some limited assistance from two geologically-minded Ordnance Surveyors (Henry McLauchlan and Henry Still). The Geological Society's generous recommendation of a contingency fund for the employment of assistants, made in its 1835 report, had never been fully acted upon. The Board responded testily, and once again pressed De la Beche for an estimate of the total cost and time involved in completing the whole survey. In his reply, De la Beche attempted to explain the difficulty of making such an estimate, given the varied geological complexity and economic development of the different regions of the country. Though exasperated at De la Beche's unwillingness to provide the required information, the Board nevertheless felt compelled to accede to his request, though only after further prompting from Colby. With respect to the annual allocation of funding, it was simply agreed 'from year to year to take such a sum as may be deemed advisable' — and so it was left at that! (GSM 1/68, 282-98). On 17 April 1839, David Hiram Williams was appointed as the first Geological Assistant, soon to be followed by others. From this moment onward, De la Beche had effectively secured the long term future of the Geological Survey.

De la Beche was knighted in 1842, and died while still in service in 1855. Ironically, the person who succeeded him as Director-General of the Geological Survey was his old former adversary, Sir Roderick Impey Murchison, whose accession was to mark another impressive chapter in the Survey's history.

Acknowledgments

This paper grew out of a lecture presented to the East Midlands Geological Society in November 2006. First and foremost I would like to thank the staff at the Library of the British Geological Survey for effectively treating me as one of their own, and for giving me unlimited access to the Survey's rare-book collection and archives. Tom Sharpe of the Department of Geology, National Museum of Wales, is thanked for helpful comments and for allowing me to reproduce Figures 14 and 16. Except where otherwise attributed, all figures have been scanned and edited by the author. This paper is published with the permission of the Executive Director of the British Geological Survey

References

Andrews, J. H. 1975. *A paper landscape: the Ordnance Survey in nineteenth-century Ireland*. Oxford. (Reprinted with new preface by Four Courts Press, Dublin, 2002, 350 pp.)

Archer, J. B. 1980. Richard Griffith and the first published geological maps of Ireland. In: *Richard Griffith, 1784–1878*, Herries Davies, G. L. & Mollan, R. C. (eds.), Royal Dublin Society, 143-171.

Berkeley, E. & Berkeley, D. S. 1988. *George William Featherstonhaugh: the first U.S. government geologist.* Tuscaloosa & London: University of Alabama Press, 357 pp.

Bowden, A. J. 2009. Geology at the crossroads: aspects of the geological career of Dr John MacCulloch. In: The making of the Geological Society of London, edited by C. L. E. Lewis & S. J. Knell. *Geological Society Special Publication*, **317**, 255-278.

Brochant de Villiers, A. 1835. Notice sur la carte géologique générale de la France. *Compte rendus hebdomadaires des séances de l'Académie des sciences*, **1**, 423-429.

Chubb, L. J. 1958. Sir Henry Thomas De la Beche. *Geonotes: Quarterly Newsletter of the Jamaica Group of the Geologists' Association*, **1**, De la Beche memorial number, 26 pp.

Clark, W. B. 1897. The first state geological survey, 1834–41. *Maryland Geological Survey,* **1**, 57-64. (It was actually preceded by a reconnaissance survey in 1833 and not formally abolished until Feb 1842)

Colby, T. 1830. *An uniform system of indicoclature ... in the geological plans and sections connected with the Ordnance Survey.* Ordnance Survey, 4 pp. (BGS Archives GSM 1/85)

Colby, T. 1837. *Ordnance Survey of the county of Londonderry, volume the first: memoir of the city and north western liberties of Londonderry, parish of Templemore*. Dublin: Hodges & Smith for H. M. Government. (Geology by J. E. Portlock, pp 3-9 & geological map opp. p 1; appendix on fossils, pp. 1-6, plates 1-3).

Cook, K. S. 1987. Design sources of the first Ordnance Geological Survey map: Henry T. De la Beche and the Geological Society of London. *Paper presented at the 12th International Conference on the History of Cartography, Paris*, Sept 1987, 7 pp.

Cumming, D. A. 1984. John MacCulloch's 'Millstone Survey' and its consequences. *Annals of Science*, **41**, 567-591.

Dean, D. R. 1989. New light on William Maclure. *Annals of Science*, **46**, 549-574.
Deerr, N. 1949-50. *The history of sugar.* London: Chapman & Hall, 2 vols, 636 pp.
De la Beche, H. T. 1825. *Notes on the present conditions of the negroes in Jamaica.* London: Cadell, 64 pp.
De la Beche, H. T. 1826. On the geology of southern Pembrokeshire [read May 1823]. *Transactions of the Geological Society of London*, for 1829, ser. 2, **2** (1), 1-20, plates I-II.
De la Beche, H. T. 1827. Remarks on the geology of Jamaica [read Dec 1825 & Jan 1826]. *Transactions of the Geological Society of London*, for 1829, ser. 2, **2** (2), 143-194, plates 18-22.
De la Beche, H. T. 1829. On the geology of Tor and Babbacombe bays, Devon [read Nov 1827]. *Transactions of the Geological Society of London*, for 1835, ser. 2, **3** (1), 161-170, plates 18-20.
De la Beche, H. T. 1831. *A geological manual*. London: Treuttel & Würtz, 535 pp.
De la Beche, H. T. 1834. On the anthracite found near Biddeford in north Devon. *Proc. Geological Society of London*, **2**, 106-107.
Eyles, J. M. 1969. William Smith (1769–1839): a bibliography of his published writings, maps and geological sections, printed and lithographed. *Journal of the Society for the Bibliography of Natural History*, **5**, 87-109, plate I.
Eyles, V. A. 1937. John Macculloch, F.R.S., and his geological map: an account of the first geological survey of Scotland. *Annals of Science*, **2**, 114-129, plates VI–IX.
Eyles, V. A. 1939. Macculloch's Geological Map of Scotland: an additional note. *Annals of Science*, **4**, 107, plate V.
Eyles, V. A. 1950. The first national geological survey. *Geological Magazine*, **87**, 373-382.
Eyles, V. A. & Eyles, J. M. 1938. On the different issues of the first geological map of England and Wales. *Annals of Science*, **3**, 190-212, plates IV-VII.
Flinn, D. 1981. John MacCulloch, M.D., F.R.S., and his geological map of Scotland: his years in the Ordnance, 1795–1826. *Notes and Records of the Royal Society of London*, **36**, 83-101.
Geikie, A. 1875. *Life of Sir Roderick I. Murchison, Bart., K.C.B., F.R.S., sometime Director-General of the Geological Survey of the United Kingdom.* London: John Murray, 2 vols.
Gerstner, P. 1994. *Henry Darwin Rogers, 1808–1866: American geologist.* Tuscaloosa & London: University Alabama Press, 311 pp.
Greenough, G. B. 1834. Address delivered at the anniversary meeting of the Geological Society, on the 21st of February 1834. *Proceedings of the Geological Society of London*, **2**, 42-70.
Greenough, G. B. 1835. An address delivered at the anniversary meeting of the Geological Society of London, on the 20th of February, 1835. *Proc. Geological Society of London*, **2**, 145-175.
Hamilton, W. J. 1855. Award of the Wollaston Medal ... to Sir Henry T. De la Beche. *Quarterly Journal of the Geological Society of London*, **11**, xxi-xxiii.
Harley, J. B. 1971. The Ordnance Survey and the origins of official geological mapping in Devon and Cornwall. In: *Exeter essays in geography*, edited by K. J. Gregory & W. L. D. Ravenhill. Exeter: University of Exeter, 105-123.
Hendrickson, W. B. 1961. Nineteenth-century state geological surveys: early government support of science. *Isis*, **52**, 357-371.
Herries Davies, G. L. 1983. *Sheets of many colours: the mapping of Ireland's rocks, 1750–1890*. Royal Dublin Society, 242 pp.
Jameson, R. 1811. On colouring geognostical maps [read Apr 1808]. *Mem. Wernerian Natural History Society*, **1**, 149-161.
Judd, J. W. 1898. The earliest geological maps of Scotland and Ireland. *Geological Magazine*, dec. 4, **5**, 145-149.
MacCulloch, J. 1836. *A geological map of Scotland.* London: Published by order of the Lords of the Treasury by S. Arrowsmith, 4 sheets, scale of four miles to the inch; accompanied by *Memoirs to H. M. Treasury respecting a geological survey of Scotland*. London: Samuel Arrowsmith, 141 pp. (See Eyles 1937 & 1939 for a bibliographic history of the several issues of this map)
McCartney, P. J. 1977. *Henry De la Beche: observations on an observer*. Cardiff: Friends of the National Museum of Wales, 77 pp.
Merrill, G. P. 1920. Contributions to a history of American state geological and natural history surveys. *Bulletin, United States National Museum*, **109**, 549 pp.
Murchison, R. I. 1833. Address to the Geological Society, delivered on the evening of the 15th of February 1833. *Proceedings of the Geological Society of London*, **1**, 438-464.
North, F. J. 1936. Further chapters in the history of geology in South Wales: Sir H. T. de la Beche and the Geological Survey. *Trans. Cardiff Naturalists' Society*, **67** (for 1934), 31-103.
Phillips, J. 1844. *Memoirs of William Smith, LL.D.* London: John Murray, 150 pp. (Republished in facsimile by The Bath Royal Literary and Scientific Institution in 2003)
Portlock, J. E. 1843. *Report on the geology of the county of Londonderry, and of parts of Tyrone and Fermanagh.* Dublin: HMSO (Preface pp. iii–xi, for a sketchy but first-hand account of the history of the Geological Branch of the Ordnance Survey of Ireland)
Rudwick, M. J. S. 1985. *The Great Devonian Controversy: the shaping of scientific knowledge among gentlemanly specialists*. Chicago: University of Chicago Press, 494 pp.
Savaton, P. 2007. The first detailed geological maps of France: the contributions of local scientists and mining engineers. *Earth Sciences History*, **26**, 55-73.
Sedgwick, A. 1831. The first award of the Wollaston Prize. *Proceedings of the Geological Society of London*, **1**, 270-280.
Sharpe, T. 2008. Slavery, sugar, and the Survey. *Open University Geological Society Journal*, **29** (2), 88-94.
Sharpe, T. & McCartney, P. J. 1998. *The papers of H. T. De la Beche (1796–1855) in the National Museum of Wales*. Cardiff: National Museums & Galleries of Wales, Geological Series, 17, 257 pp.
Smith, W. 1815. *A memoir to the map and delineation of the strata of England and Wales, with part of Scotland.* London: John Cary, 52 pp.
Socolow, A. A. (ed.) 1988. *The state geological surveys: a history*. [Grand Forks, ND]: Association of American State Geologists, 499 pp.
Stuckey, J. L. 1965. *North Carolina: its geology and mineral resources*. Raleigh: Department of Conservation and Development, 550 pp. (History of the first state geological survey, pp. 224-234).
Wilson, H. E. 1985. *Down to earth: one hundred and fifty years of the British Geological Survey.* Edinburgh: Scottish Academic Press, 189 pp.
Woodward, H. B. 1908. Notes on the indexes of colours issued by the Geological Survey of Great Britain, and on the dates of the earlier published maps of Cornwall, Devon, and West Somerset. *Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology* for 1907, 158-161.

Archival sources

British Geological Survey Library, Keyworth, Nottingham

GSM1/68 (now reclassified as GSM/DR/Bc/A/1): Extracts from Ordnance Survey letter books, Mar 1830 to Feb 1833, and May 1835 to Oct 1841: photocopy of typewritten transcript held at National Museum of Wales, Cardiff. (This transcript was made by F. J. North, Keeper of Geology at the NMW, from original letter books later destroyed during the air raids on Southampton in 1940. The letter book for Mar 1833 to Apr 1834 is believed to have been destroyed in 1841 in a fire at the Tower of London, where the Ordnance Map Office was then located).

GSM 1/85 (now reclassified as GSM/DC/S/3): Indexes to colours and signs employed on Geological Survey and other maps.

GSM1/123 (now reclassified as GSM/DR/Bc/S/1): Notebook of Henry De la Beche, *c.*1830–31.

National Museum of Wales, Cardiff

De la Beche Collection: NMW 84.20G.D.1–2283. A full catalogue with abstracts is in Sharpe & McCartney (1998).

Geological Society of London

Sketchbooks by John MacCulloch (no date attributed): LDGSL 1091, vol. 2.

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Magma mixing in the South Leicestershire Diorite: evidence from an Ordovician pluton at Croft Quarry

John N. Carney

Abstract: At Croft Quarry, exposures of a pluton belonging to the South Leicestershire Diorite suite have revealed a complex history of multiple intrusion. Soon after emplacement of the main-stage quartz-diorite, the partially crystallised pluton received an influx of magma which became dispersed and is now seen as partially assimilated dioritic xenoliths. A much later episode of intrusion occurred when the pluton had cooled sufficiently to be capable of fracturing. It resulted in a spectacular swarm of synplutonic quartz-diorite/tonalite sheets with contacts indicating that the host quartz-diorite was locally remobilized, disrupting and net-veining the later sheets. These features are typical of 'magma mixing' phenomena, and suggest an underlying process that may account for some of the geochemical and petrographical variations previously noted within the South Leicestershire diorites.

The conical landmark of Croft Hill (SP510967), 60 m high, surmounts the largest of several quarried inliers (Fig. 1) exposing the South Leicestershire Diorite suite of intrusions (Worssam and Old, 1988). These inliers protrude above an unconformable cover of Triassic strata and are intriguing because many are now only partly accessible, due to flooding or vegetation overgrowth, yet provide tantalising insights on the nature and evolution of igneous activity within the Precambrian to early Palaeozoic 'basement' to the outcropping Carboniferous and Mesozoic strata of the East Midlands (Le Bas, 1968; 1972, 1981). The rocks at Croft have been exploited since at least Roman times, and today they are superbly exposed within the adjacent aggregate quarry, which is one of the largest in Europe (see air view on front cover).

The significance of the intrusive rocks to Midlands basement geology in part revolves around their age. A U-Pb date of 449 ±18 Ma was obtained by merging the data for zircons separated from plutonic rocks exposed at Enderby, to the north-east of Croft (Fig. 1), with values for zircons from granodiorites of the closely related Mountsorrel Complex (Pidgeon and Aftalion, 1978, recalculated by Noble et al., 1993). This age confirms that the South Leicestershire Diorites and Mountsorrel Complex were emplaced during an intrusive event of Ordovician (late Caradoc) age, contemporary with the subduction-related, Caledonian magmatism of central Wales and the Lake District (Pharaoh et al., 1993). Boreholes in the region (Le Bas, 1972) indicate that from Hinckley to at least as far as Leicester in the east, the South Leicestershire Diorite intrusions and Mountsorrel Complex are emplaced into mudrocks of Lower Cambrian to Tremadoc (earliest Ordovician) age. These strata are part of the Stockingford Shale Group, which is exposed 15 km farther west at Nuneaton (Bridge et al., 1998), and their considerable extent has been attributed to tectonic repetition within a structurally complex basement (Carney, 2007). In the Croft area, this basement represents part of a tectonically-bounded crustal block known as the Midlands Microcraton (Pharaoh et al., 1987), which although faulted and folded largely resisted the main effects of late Caledonian deformation. Structures attributed to the latter event(s) are suggested by Pharaoh et al. (1987) to be mainly developed within the adjacent 'Eastern Caledonides', a concealed early Palaeozoic orogenic belt forming the basement to the east of the Mountsorrel Complex (Fig. 1) and extending eastwards beyond the North Sea coastline.

The geochemistry of the South Leicestershire Diorite intrusions and Mountsorrel Complex supports a subduction zone tectonic setting similar to that of the age-equivalent rocks of Wales and the Lake District. On

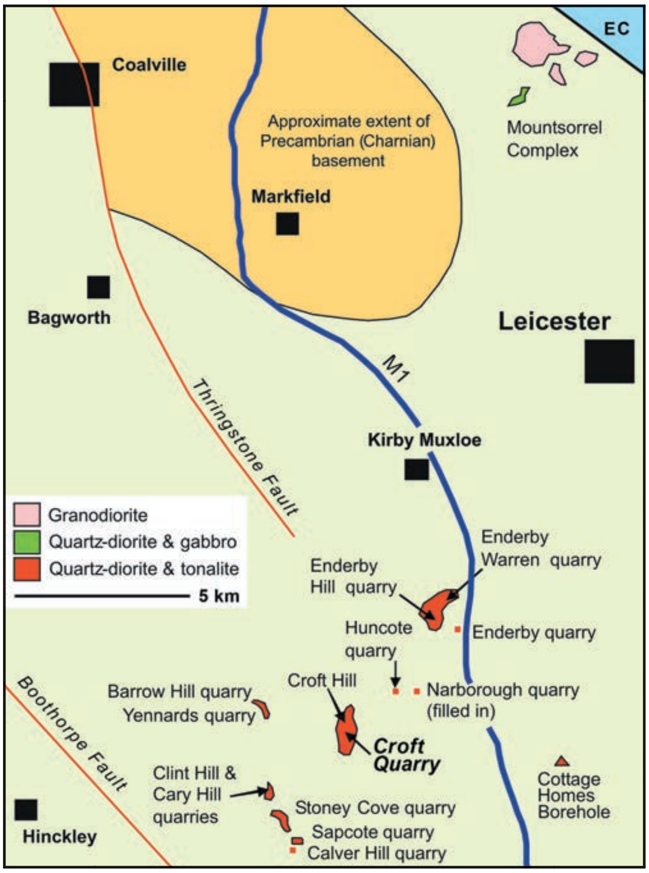

Figure 1*. Sub-Triassic inliers of South Leicestershire Diorite and Mountsorrel Complex in relation to major basement structures. Most of the map area has Midlands Microcraton (early Palaeozoic) basement beneath Late Carboniferous to Mesozoic cover strata. EC = inferred sub-Mesozoic extent of Eastern Caledonides basement.*

an FMA major element variation diagram they exhibit a strong calc-alkaline variation trend (Le Bas, 1972, 1981; Webb and Brown, 1989). Furthermore, trace element abundances for the Croft rocks show moderate enrichments of large ion lithophile (LIL) elements (K, Rb and Ba), Th and Ce, and relative depletion of Nb and Ta, which are patterns typical of calc-alkaline magmas arising within a volcanic arc founded on continental crust (Pharaoh et al., 1993). The subduction zone above which the magmas were generated may have been situated to the east of the present-day English coastline in late Ordovician times, its activity related to a phase of plate convergence which closed the Tornquist Sea, located between the continents of Avalonia and Baltica (Noble et al., 1993; Pharaoh, 1999). That event pre-dated collision along the Iapetus Suture Zone by about 50 million years.

Regionally, the South Leicestershire Diorites and Mountsorrel Complex represent only the westernmost part of a much larger Caledonian plutonic province in the East Midlands. The partially exposed plutons shown in Fig. 1 are emplaced into the Midlands Microcraton, but farther east a number of wholly concealed plutons occur within the adjacent Eastern Caledonides basement block. These include the granodiorites proved in boreholes at Rempstone and Kirby Lane (Wreake Valley), respectively 8.5 km to the north and 16.5 km to the east of the Moutsorrel Complex (Carney et al., 2004), as well as a scattering of granitoid plutons suggested by Pharaoh et al. (1993) to extend as far east as The Wash. The evidence for these easternmost plutons is provided by a Bouguer gravity survey showing a series of small, circular to oval anomalies (Evans and Allsop, 1987). With regard to local basement structure, shown in Fig. 1, the South Leicestershire Diorites are developed in an area where the geophysical expression of the Thringstone Fault appears to die out. That structure uplifted the Precambrian rocks of Charnwood Forest during end-Carboniferous time, but it may also have a Caledonian inheritance as it is parallel with the Midlands Microcraton boundary, shown in the north-eastern corner of Fig. 1. The intrusions are evidently confined to the east by the north-west trending Boothorpe Fault, a displacement hidden beneath thick Triassic cover in the study area but detected by its geophysical trace (Allsop and Arthur, 1983). This structure may be of greater magnitude than the Thringstone Fault as it coincides with a prominent linear Bouguer gravity anomaly gradient (Worssam and Old, 1988; fig. 28) interpreted as a major axis of basement uplift.

Petrographic variation within the South Leicestershire Diorites

The Croft rocks have been studied petrographically by several researchers covering a long period of time. They were originally described as syenites (Hill and Bonney, 1878) before Whitehead (in Eastwood et al., 1923) suggested that they were mineralogically more comparable to quartz-diorite or tonalite.

Le Bas (1972) proposed that, at depth, these rocks may form part of a composite batholithic body about 16 km wide at maximum. A broad compositional zonation within this batholith was suggested on the basis of petrographic studies (Le Bas, 1968; 1972) that indicated variations in the proportions of quartz, alkali feldspar and plagioclase feldspar (Q-A-P), between the various exposures shown in Fig. 1. A map was constructed (Le Bas, 1968; 1972), showing that diorite and quartz-diorite occupied the western part of the batholith, exposed at Barrow Hill and Stoney Stanton (Cary Hill and Clint Hill quarries of Fig. 1), with tonalite occupying a central position at Croft and the quarries at Enderby Hill and Enderby Warren. Microtonalite, exposed in the small quarries at Enderby and Narborough, and proved at depth in the Cottage Homes borehole at Countesthorpe (Poole et al., 1968), forms the eastern zone of the pluton.

Modal analysis was carried out by Worssam and Old (1988) on ten thin sections from the South Leicestershire Diorites. All contained less than 8 per cent modal alkali feldspar; however Worssam and Old's findings, particularly with respect to modal quartz content, departed somewhat from those of Le Bas (1972). Of the six samples analysed by Worssam and Old (1988) from Croft, Narborough and Stoney Cove, five samples were classified as quartz-diorite on the Q-A-P triangular diagram, although with quartz contents of between 15-22% (mean of 18%) they verge towards tonalite (>20% quartz). A further four samples, from Enderby and The Yennards, also fall within the quartz-diorite classification, but have much lower quartz contents of 7-12% (mean of 10%) and in mineralogical composition are therefore closer to diorite (<5% quartz). A petrographic survey of thin sections from the collection by Eastwood et al. (1923), from the small quarries between Clint Hill and Calver Hill, showed that most were quartz-diorites (Bridge et al., 1998), with between 10 and 15 per cent modal quartz (visual estimates only). Some diversity is suggested at Cary Hill Quarry, however, where inequigranular quartz-diorites contain up to 20 per cent quartz and thus verge towards tonalite in mineralogical composition. There are also finer grained varieties ('rammel' in quarrymen's terms), which have only 5-10 per cent quartz. Some fine-grained diorites with intergranular textures show fluxional alignment of plagioclase laths, such as might occur along the margins of a late intrusion into the main body of magma.

These petrographic surveys hint at a more complex distribution of igneous rock-types than was originally portrayed by Le Bas (1972). Such differences may be due to 'laboratory' variations in modal analytical procedures, but they may also be an artefact of ad hoc sampling, either between different workers or, in the case of the larger quarries, without regard to a thorough assessment of the variability presented by these exposures. This article will show that the plutonic rocks at Croft Quarry have experienced a complex history of multiple igneous intrusion, which may be relevant to the underlying causes of compositional variation within the South Leicestershire Diorites and could even operate within the confines of a single exposure.

Igneous structure of the Croft pluton

Further investigations have been made during recent visits to Croft Quarry (Fig. 2), although in many places it was not possible to approach the faces due to safety concerns. Sufficient evidence has been gathered, however, to indicate that the rocks there are more heterogeneous than previously thought, with four major igneous components recognised:

a) Quartz-diorite host rock, typically with a coarsely inequigranular texture,
b) Dioritic xenoliths showing all stages of assimilation by the host rock,
c) A swarm of synplutonic intrusive sheets, of quartz-diorite to tonalite composition,
d) Coarsely inequigranular tonalite, newly exposed at the base of the quarry.

Host quartz-diorite

This component is most conveniently viewed at the natural exposures around Croft Hill, where its inequigranular texture is emphasized by conspicuous, 4-7 mm size, pale grey plagioclase phenocrysts set in a yellow or brown, medium-grained weathered groundmass. In the very extensive exposures on the western quarry face, below Croft Hill, the inequigranular texture features abundant crystals of pale grey euhedral plagioclase up to 6 mm long (Fig. 3A). These are enclosed within a grey to pink, medium-grained quartz-feldspar matrix studded with black, euhedral Fe-Ti oxides (magnetite). Dark green-grey, somewhat amorphous areas comprising about 20-30 per cent of the rock indicate the sites of mafic silicates and their alteration products. In a thin section (Fig. 3B) the large plagioclase crystals are euhedral and optical determinations indicate that they are zoned, from labradorite cores outwards to grainy, inclusion-filled albite rims. Surrounding them are aggregates of smaller, inclusion-filled sodic plagioclase, some partly euhedral but most forming interlocking granular aggregates that include quartz and minor amounts of untwinned K-feldspar. Clinopyroxene forms sporadic euhedra and aggregates that are largely altered to intergrowths of pale green amphibole and chlorite (the dark green-grey areas seen in hand specimens); there are also small flakes of partially chloritised brown biotite and about 5 per cent of scattered, opaque euhedra of magnetite. Alteration of plagioclase by the growth of albite patches and veinlets is all-pervasive. Pumpellyite occurs interstitially, and in other samples Webb and Brown (1989) noted radial prehnite infilling cavities and zeolites occupying veins. These minerals are related to pervasive, and locally intense alteration of the pluton (e.g. King, 1968).

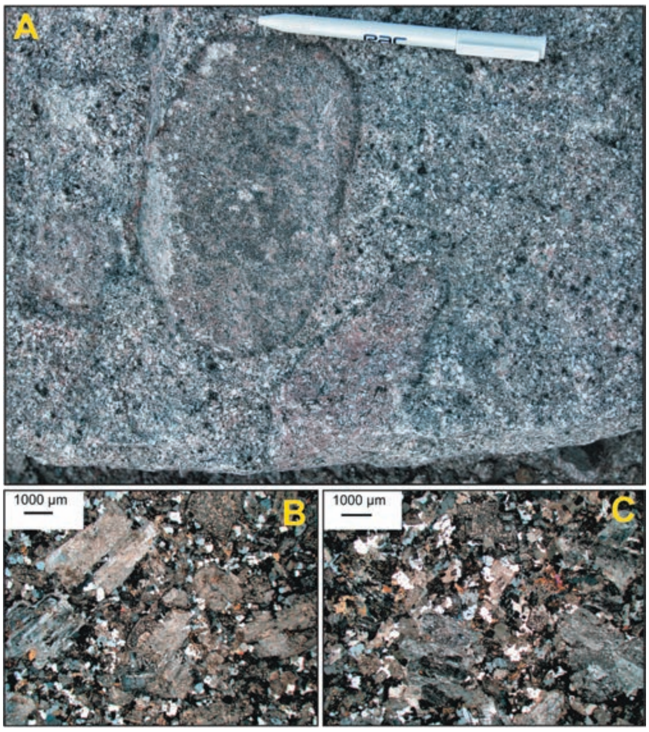

***Figure 3**. **A:** Quartz-diorite of the main Croft intrusion, showing inequigranular texture featuring abundant plagioclase phenocrysts (pale grey to white). Early-stage xenoliths are emphasized by their dark rims; they contain sporadic clusters of pale grey plagioclase phenocrysts (e.g. below tip of pen). **B**: Photomicrograph of host quartz-diorite, showing large, grey, inclusion-filled plagioclase phenocrysts; quartz is represented by white to pale grey areas within the granular matrix surrounding the phenocrysts (x-nicols). **C**: Photomicrograph of synplutonic sheet, showing plagioclase phenocrysts. The granular matrix is texturally identical to that in 3B but is slightly more quartz-rich (x-nicols).*

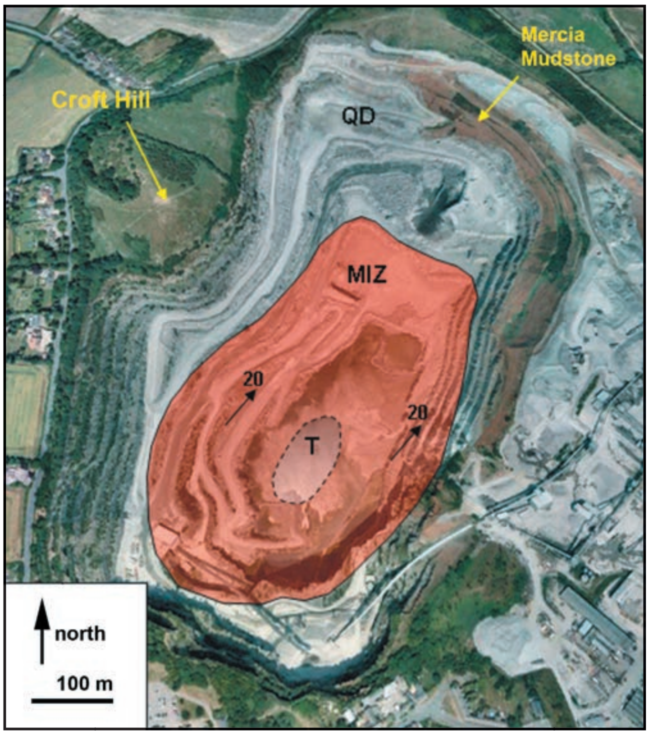

***Figure 2**. Geology of Croft Quarry. QD, quartz-diorite host rock; MIZ, Magma Injection Zone; T, tonalite (not exposed in 2006). Arrows show the approximate dip of synplutonic sheets in the MIZ. (Topography derived from Google Earth 2006, by Infoterra, Bluesky and Tele Atlas)*

Diorite xenoliths

These are ubiquitous in all parts of the host quartz-diorite that were accessible for examination, although they vary in proportion, from very sporadic to common and closely packed. As shown in Fig. 3A, they are typically pink to grey in colour, with rounded outlines and shapes that vary from roughly spherical to ovoid or ellipsoidal. Sizes range from a few centimetres to about 15 cm. The xenoliths were not examined in thin section; however, Le Bas (1968) notes that they consist of sericitised augite-microdiorite, with pale green hornblende, Fe-Ti oxides and minor quartz. There appears to be limited compositional variation between xenoliths, with some darker grey in colour, and thus possibly more basic, than others. Most xenoliths are finer grained than the host quartz-diorite. They are also more equigranular, although some xenoliths contain isolated crystals or clusters of pale grey plagioclase phenocrysts, identical to those in the host rock (Fig. 3A). This is reminiscent of the 'xenoporphyritic' texture described by Blundy and Sparks (1992) and attributed by them to a process of mixing and assimilation between xenolith and host. Most xenoliths are surrounded by a prominent rim of dark grey, fine-grained chlorite-hornblende intergrowths, which may be a reaction interface formed after incorporation of the xenolith into the host rock. Xenoliths without such rims have extremely diffuse, shadowy outlines and in this respect appear to be in more advanced stages of assimilation into the host.

Synplutonic intrusive sheets

These were first reported within the host rock by Carney and Pharaoh (1999), and are currently visible in the c.100 m high western and eastern faces of Croft Quarry. The sheets are suggested to delineate a magmatic injection zone (MIZ), shown in Fig. 2. Most sheets are between 1 and 2 m thick and together they form a swarm of several parallel bodies generally spaced at intervals of between about 3 and 10 metres (Fig. 4A), although some also bifurcate along their length. The swarm as a whole is inclined to the north-east at angles of between 15 and 20°. An easterly dip of about 20° was, however, estimated for

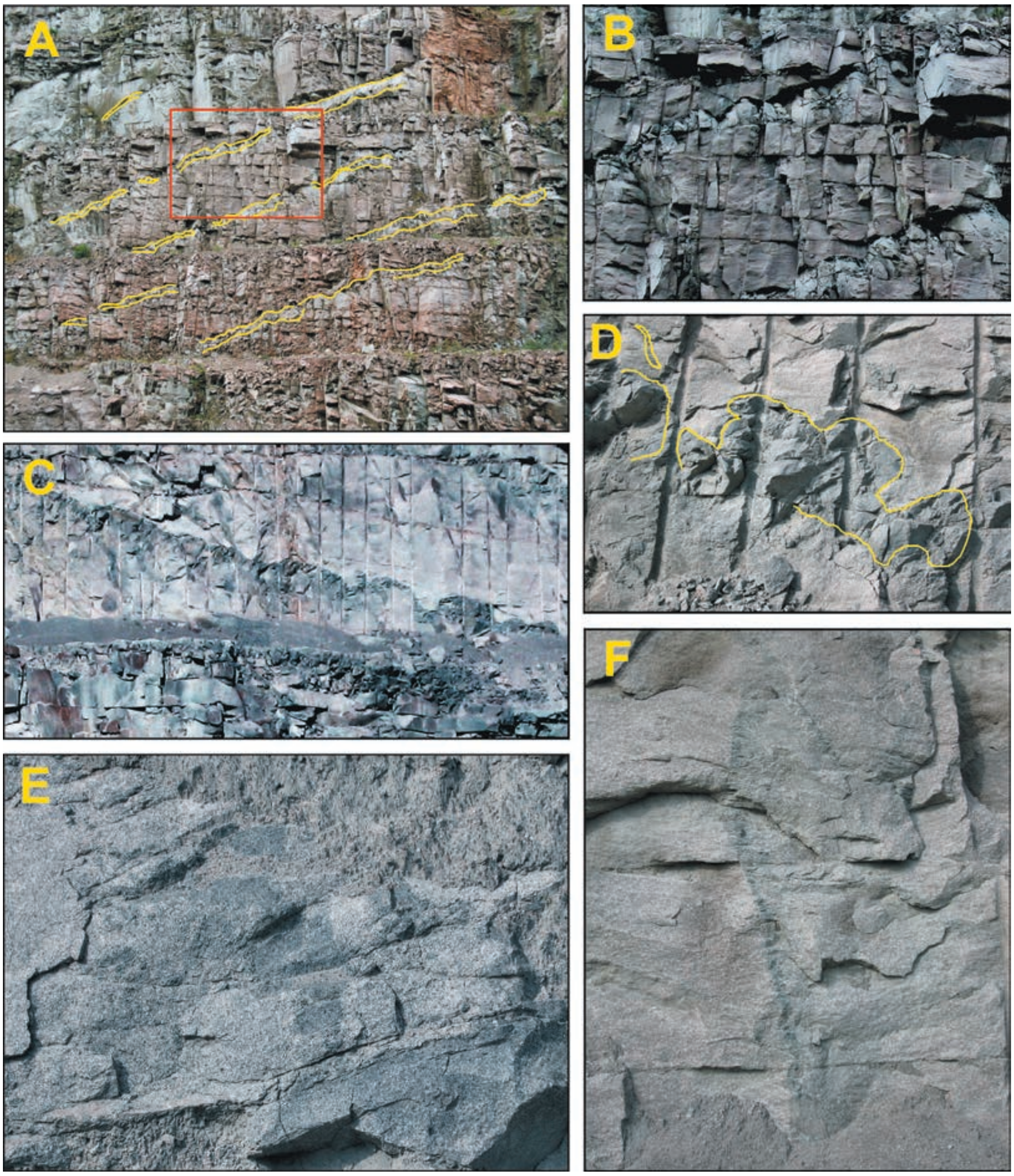

Figure 4*. Aspects of the Magma Injection Zone (MIZ).*
A*: View of the eastern quarry face, showing synplutonic sheets (outlined in yellow for clarity). The height of this exposure is about 30-40 m.*
B*: Zoomed-in view of red rectangle in 4A, showing cuspate upper contact of a synplutonic sheet about one metre wide.*
C*: Zoomed-in view of the western quarry face, showing a synplutonic sheet with strongly cuspate upper margin. The height of this exposure is estimated to be 10-12 m.*
D*: Close-up of disrupted synplutonic sheet on the western quarry face, showing crenulated ('pillowed') upper margin (yellow outline) against the host quartz-diorite. Note disconnected subvertical offshoot at upper left. Vertical height of exposure is 1.5 m.*
E*: Net-veining of synplutonic sheet (dark grey areas) by the host inequigranular quartz-diorite, western quarry face. Height of exposure is c0.8 m.*
F*: Strongly elongated, dark-rimmed xenolith on western quarry face, interpreted as a disrupted vertical offshoot to a synplutonic sheet close by. Height of image is about 0.6 m.*

one sheet in a new face opened at the base of the quarry during 2009, and as the quarry is progressively deepened further complexities will doubtless be revealed.

The synplutonic sheets are of a medium- to dark-grey colour and thus stand out against the pale grey host rock. In detail sheet margins are irregular and in particular, the upper contacts are markedly cuspate (Figs. 4B and C), with pillow-like forms locally developed (Fig. 4D). The latter example shows that in places the sheets have been completely disrupted by the host rock, which also back-intrudes the sheets resulting in net-vein complexes (Fig. 4E). Thin, subvertical intrusions are seen in the vicinity of the larger sheets (Fig. 4F) and in places merge into them, suggesting that they are offshoots. These thinner sheets show greater susceptibility to disruption by the host diorite, some appearing to be reduced to shadowy, ellipsoidal inclusions (Fig. 4D, F), similar to the diorite xenoliths found elsewhere (cf. Figs. 3A and 4F). They appear to have chilled margins (Fig. 4F), but generally no significant chilling marks the contacts between the larger intrusive sheets and the host quartz-diorite.

In thin section (Fig. 3C) the synplutonic sheets are of similar mineralogy to the host rock, but have marginally higher quartz contents (c. 20-25%, visual estimate), which places them in the tonalite field on the Q-A-P diagrams. Mafic minerals are less abundant than in the host rock; they consist of chlorite-green hornblende aggregates and about 3 per cent magnetite. The example shown in Fig. 3C has an inequigranular texture due to the presence of large plagioclase crystals; however, overall these are generally less abundant than in the host quartz-diorite.

Tonalite

Only now being revealed by blasting in the lowest parts of the quarry, tonalite with a quartz content estimated to be in excess of 20%, represents a further, newly-discovered component to the Croft body. This rock has an inequigranular texture, which in part is caused by the presence of large plagioclase crystals. An additional feature, however, is the presence of sporadic but prominent ‘eyes’ (ocelli) of grey, glassy quartz; these are generally several millimetres in size, but some consist of xenolith-like masses up to 20 mm across (Fig. 5).

***Figure 5**. Tonalite newly exposed in the floor of the quarry. The pale grey ‘eyes’, or ocelli, consist of quartz, a cluster of three being present to the right of the large oval quartz xenolith seen above and to the right of the hammer head. The dark grey mottling represents mafic-rich areas within a pink to grey, granular matrix of quartz and plagioclase feldspar.*

Magmatic evolution

Outstanding features of the Croft intrusion are the abundant dioritic xenoliths in various stages of assimilation by the host rock, and the swarm of synplutonic tonalitic sheets that make up the MIZ. Such phenomena are widely recognised in other parts of the world, in plutons ranging in age from Cenozoic (Blundy and Sparks, 1992) to Jurassic (Wiebe et al., 2002), late Caledonian (El-Desouky et al., 1996), Neoproterozoic (D’Lemos,1992) and Palaeoproterozoic (Lundmark et al., 2005). Mostly the lithologies involved belong to the granite-tonalite-granodiorite-diorite clan, and so are comparable to the range of igneous rocks making up the South Leicestershire Diorites and Mountsorrel Complex (Le Bas, 1972).

The relationships between the synplutonic sheets and host quartz-diorite seen at Croft are typical of igneous associations where processes of closely simultaneous intrusion, resulting in ‘magma mixing’, have been proposed (e.g. Blundy and Sparks, 1992). The intricate nature of the contact developed along the intrusive sheets suggests the operation of at least three, interrelated magmatic processes. First, the cuspate, crenulated outlines of the sheet margins are attributed to cooling of the intruded magma against the host quartz-diorite, resulting in shapes analogous to the pillows that form when magma is discharged into water or water-saturated sediment. These pillowed contacts, however, also indicate that the host rock was hot enough to flow around and therefore to accommodate the developing pillows. Second, the sheets must have cooled sufficiently to undergo brittle deformation, resulting in the fractures that allowed the host to invade and in places net-vein the sheets. This mobility of the host quartz-diorite is attributed to a third process, whereby the heat transmitted from the sheets was sufficient to locally re-melt the host, thus lowering its viscosity. The fact that the synplutonic sheets lack fine-grained, truly ‘chilled’ margins against the host rocks is further evidence that both were at similar, elevated temperatures during intrusion of the sheets.

Parallel synplutonic sheet swarms with similar contact relationships to those seen at Croft have been described from California by Wiebe et al. (2002), who attributed them to the successive flowage of hybrid dioritic magmas across the floor of a crystallising pluton below a more fluid, crystal-poor granitic magma. At Croft, the quartz-diorite host rock shows little evidence for fluidity, crystal accumulation or convection required for such a process of large-scale ‘macrorhythmic’ magma influx, which in any case is unlikely to occur in more viscous magmas of intermediate composition. Therefore, at Croft, introduction of the sheets by lateral intrusion is the preferred explanation. This mechanism operated within a dioritic host that, although still-hot, was solid enough to undergo brittle deformation, splitting to produce a stack of low-angle fractures that was exploited by the later magmas. Space is required for such a process to operate, suggesting that the magma chamber occupied by the host was capable of expansion and therefore was probably still rising into the East Midlands crust.

These field relationships are consistent with the suggestion of Furman and Spera (1984), that new batches of magma can reactivate an otherwise cooling intrusion, initiating a process of thermal equilibration that results in the re-fusion and remobilization of the nearly solidified host immediately adjacent to the fractures that acted as conduits for the new magma. They further proposed that when magmas interact like this, a continuum of mixing states is possible, depending on magma chemistry and physical properties. Their calculations suggest that for a granodioritic pluton of 20 km diameter hosting magma with low crystallinity, of about 30-50 per cent, mixing can be found at exposure-scale and will include disconnected inclusions or trains of inclusions. The small, isolated xenoliths found in the Croft quartz-diorite are consistent with this relatively early stage of magma introduction and mixing. In these xenoliths, the 'xenoporphyritic' texture indicates that the larger plagioclase crystals of the host had been able to enter the newly introduced magma, suggesting that both were in a largely molten condition. By contrast, when the host is still hot but has cooled sufficiently to undergo brittle deformation, new magma influxes will crystallise as intrusive sheets that are relatively coherent. These new intrusions, however, will be capable of localised disruption by the host wherever the latter has been remobilised as a result of additional heat transferred from them. This physical condition of the host represents a crystallinity in excess of 70 per cent (Furman and Spera, 1984), and could plausibly reflect the situation at the time of intrusion of the synplutonic sheets at Croft. The calculations of Furman and Spera (1984) further suggest that such conditions might prevail about a million years after initial emplacement of the host magma.

Regional implications

The Croft quartz-diorite has experienced a complex history of multiple intrusion, which is speculated to have spanned a period of about a million years. Following initial emplacement of the pluton, a batch of magma was added when the crystallinity of the main body was relatively low (30-50 per cent), sufficient to support movement and mixing between host and introduced magma. The composition of this new magma cannot now be determined as it was effectively dispersed and mixed with the host, and is now recogniseable only as isolated, small, partially assimilated dioritic xenoliths. A rather later introduction of tonalitic magma occurred when the host quartz-diorite was still hot but had largely solidified, with a crystallinity probably in excess of 70%. This event was structurally controlled, perhaps by fractures generated during continued inflation of the main pluton. It resulted in a swarm of synplutonic sheets showing intricate contact relationships that support a process of thermal equilibration between intrusion and host, the latter having been locally remobilised along the sheet margins. The significance of the quartz-eye tonalite, newly uncovered at the base of Croft Quarry, remains to be evaluated.

A similar history of multiple intrusion can be suggested for other East Midlands Ordovician intrusions. For example, granodiorite of the Mountsorrel Complex is xenolithic and contains stock-like bodies of hornblende gabbro and quartz-diorite. Close to the latter, at Kinchley Hill, the granodiorite contains abundant diorite xenoliths with intricate boundaries against the host. The features recorded suggest that the xenoliths represent a batch of magma emplaced prior to solidification of the host, and subsequently partially dispersed within it (Lowe, 1926; Le Bas, 1968; Carney et al., 2009).

The magmatic features at Croft may help to explain the regional variability of compositions within these Ordovician intrusions, and is a complication to the zonal scheme of diorite-tonalite-microtonalite bodies proposed for the South Leicestershire Diorites by Le Bas (1972). For example, Blundy and Sparks (1992) suggest that during early-stage magma mixing, represented by the xenoliths at Croft, there may be significant chemical modification of the host magma as a result of reaction with, and partial assimilation of the new magma influx. On the other hand, emplacement of the synplutonic sheets represents a later stage at Croft, when the host quartz-diorite was largely crystalline. It would not have greatly influenced host rock compositions, but when added to the evidence of the xenoliths it draws attention to a process that could have continued throughout the emplacement history of the Croft pluton, profoundly influencing its composition.

These findings suggest that Croft Quarry would be an ideal subject for geochemical studies aimed at constraining more closely the petrogenetic evolution of the South Leicestershire Diorites. The scope of such a project could be widened to include similar studies on age-equivalent rocks of the Mountsorrel Complex.

Acnowledgements

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References

Allsop, J.M. & Arthur, M.J., 1983. A possible extension of the South Leicestershire Diorite complex. *Report of the Institute of Geological Sciences*, 83/10, 25-30.

Blundy, J.D. & Sparks, R.S.J., 1992. Petrogenesis of mafic inclusions in granitoids of the Adamello Massif, Italy. *Journal of Petrology*, **33**, 1039-1104.

Bridge, D.McC., Carney, J.N., Lawley, R.S., & Rushton, A.W.A., 1998. Geology of the country around Coventry and Nuneaton. *Memoir of the British Geological Survey*, Sheet 169 (England and Wales).

Carney, J.N. & Pharaoh, T.C., 1999. Croft Hill. *Caledonian igneous rocks of Great Britain.* Geological Conservation Review Series, **17**, 221-223 (Peterborough: Joint Nature Conservation Committee).

Carney, J.N., 2007. Geological evolution of central England with reference to the Trent basin and its landscapes. *Mercian Geologist*, **16**, 231-240.

Carney, J.N., Ambrose, K., Brandon, A., Lewis, M.A., Royles, C.P. and Sheppard, T.H., 2004. Geology of the Melton Mowbray District. *Sheet description of the British Geological Survey*, 1:50,000 Series, Sheet 142 (England and Wales).

Carney, J.N., Ambrose, K., Cheney, C.S. & Hobbs, P.R.N., 2009. Geology of the Leicester District. *Sheet description of the British Geological Survey*, 1:50,000 Series, Sheet 156 (England and Wales).

D'Lemos, R.S., 1992. Magma-mingling and melt-modification between granitic pipes and host diorite, Guernsey, Channel Islands. *Journal of the Geological Society of London*, **149**, 709-720.

Eastwood, T., Gibson, W., Cantrill, T.C., & Whitehead, T.H., 1923. The geology of the country around Coventry. *Memoir of the British Geological Survey of England and Wales*, Sheet 169.

El Desouky, M., Feely, M. & Mohr, P., 1996. Diorite-granite mingling and mixing along the axis of the Galway granite batholith, Ireland. *Journal of the Geological Society of London*, **153**, 361-374.

Evans, C.J., & Allsop, J.M., 1987. Some geophysical aspects of the deep geology of eastern England. *Proceedings of the Yorkshire Geological Society*, **46**, 321-333.

Hill, E., & Bonney, T. G. 1878. On the pre-Carboniferous rocks of the Charnwood Forest, Part II. *Quarterly Journal of the Geological Society of London*, **34**, 199-239.

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

Le Bas, M.J., 1981. The igneous basement of Southern Britain with particular reference to the geochemistry of the pre-Devonian rocks of Leicestershire. *Transactions of the Leicester Literary and Philosophical Society*, **75**, 41-57.

Le Bas, M.J., 1968. Caledonian igneous rocks. 41-58 in *The Geology of the East Midlands,* P.C. Sylvester-Bradley and T.D. Ford (eds), Leicester University Press.

Le Bas, M.J., 1972. Caledonian igneous rocks beneath Central and Eastern England. *Proceedings of the Yorkshire Geological Society*, **39**, 71-86.

Lowe, E.E., 1926. The igneous rocks of the Mountsorrel district. *Transactions of the Leicester Literary and Philosophical Society*, 49 pp.

Lundmark, C., Billstrom, K. & Weihed, P., 2005. The Jokkmokk granitoid, an example of 1.88 Ga juvenile magmatism at the Archaean-Proterozoic border in northern Sweden. *Geologiska Föreningens i Stockholm Förhandlingar*, **127**(2), 83-98.

Noble, S.R., Tucker, R.D. & Pharaoh, T.C., 1993. Lower Palaeozoic and Precambrian igneous rocks from eastern England, and their bearing on late Ordovician closure of the Tornquist Sea: constraints from U-Pb and Nd isotopes. *Geological Magazine,* **130**, 835-46.

Pharaoh, T.C., 1999. Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone (TESZ): a review. *Tectonophysics*, **314**, 17-41.

Pharaoh, T.C., Brewer, T.S. & Webb, P.C., 1993. Subduction-related magmatism of late Ordovician age in eastern England. *Geological Magazine*, **130**, 647-56.

Pharaoh, T.C., Merriman, R.J, Webb, P.C. & Beckinsale, R.D., 1987. The concealed Caledonides of eastern England: preliminary results of a multidisciplinary study. *Proceedings of the Yorkshire Geological Society*, **46**, 355-69.

Pidgeon, R.T. & Aftalion, M., 1978. Cogenetic and inherited U-Pb systems in granites: Palaeozoic granites of Scotland and England. 183-200 in *Crustal evolution in Northwestern Britain and adjacent regions*, D.R. Bowes and B. E. Leake (eds), Seel House Press: Liverpool.

Poole, E.G., Williams, B.J. & Hains, B.A., 1968. Geology of the country around Market Harborough. *Memoir of the British Geological Survey*, Sheet 170 (England and Wales).

Webb, P.C. & Brown, G.C., 1989. Geochemistry of pre-Mesozoic igneous rocks. 95-121 in *Metallogenetic models and exploration criteria for buried carbonate-hosted ore deposits - a multidisciplinary study in eastern England*, Plant, J.A. and Jones, D.G. (eds). Institution of Mining and Metallurgy: London, and British Geological Survey: Keyworth.

Weibe, R.A., Blair, K.D., Hawkins, D.P. & Sabine, C.P., 2002. Mafic injections, in situ hybridization, and crystal accumulation in the Pyramid Peak granite, California. *Geological Society of America Bulletin*, **114**, 909-920.

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

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Gold in Britain: past, present and future

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Abstract: Britain is a country with modest gold deposits. At least six tonnes, possibly up to ten tonnes, of gold have been recovered from numerous localities in Britain. Recent discoveries have revealed another six tonnes in Scotland and over 30 tonnes in Northern Ireland, with the likelihood of more to be found. A new mine in Northern Ireland is producing several thousand ounces of gold per year. These are small figures compared to the current annual new mine production of around 2500 tonnes and the total world tonnage of gold mined to date of around 180,000 tonnes.

Gold has long been prized for its colour, durability, malleability and density. It has been recovered from streams by simple hand methods such as hand picking and panning. One origin of the legend of the Golden Fleece of mythology is the use of sheep skins to collect gold in gold-bearing streams. This paper contains an overview of the past gold production in Britain, the current position with several recently discovered deposits in Scotland and Northern Ireland and a brief view of future possibilities. Gold in Britain belongs to many genetic types, and has been recorded at many localities (Fig. 1); not all of these are described in this brief review.

Historic gold production

The discovery of Pre-historic, Bronze and Iron Age gold artefacts in various parts of Britain, such as beautifully wrought torcs, rings and other ornaments, often associated with the burial of high status people, shows that gold mining and working was active during those times and had reached considerable sophistication. The gold must have come from somewhere, and it may not all have been imported. Alluvial sources are the most likely as they are the easiest to work and the most likely to be discovered. Even today, a number of river valleys in Scotland, Wales and Ireland, as well as on mainland Europe, contain pannable gold. There are considerable problems in trying to date and assign early mine workings, especially alluvial deposits, as later workings as well as normal erosion under climatic variations may have removed or considerably altered any traces left behind.

The earliest known production in Britain was in Roman times from the Dolaucothi deposit (also known as Ogofau) near Pumpsaint in southwest Wales. Here undoubted Roman artefacts have been discovered and the remains of sophisticated dam and leat systems. The dams were to hold back water that was suddenly released to wash downhill, ripping off the topsoil and exposing bedrock. Water would also have been extensively used in washing the ore to release gold, and in operating crushing and pumping machinery. The Romans built a fort at Pumpsaint and were apparently in the area within six years of the Roman invasion. This may mean that they were already aware of gold at the site, and there may have been prior active mining. The Romans were expert prospectors and miners, and had numerous gold mines in Spain and elsewhere. They would have preferred to work alluvial deposits and also the shallow weathered gossanous zones containing free gold, above deeper primary deposits where the gold was contained within pyrite and other minerals. This ‘locked’ gold would have required quite sophisticated smelting techniques to liberate it, as well as supplies of fuel and water.

It has been estimated that the Roman workings at Dolaucothi produced up to a tonne of gold from about half a million tonnes of rock (Annells and Burnham, 1995). This was probably from the oxidised gossanous

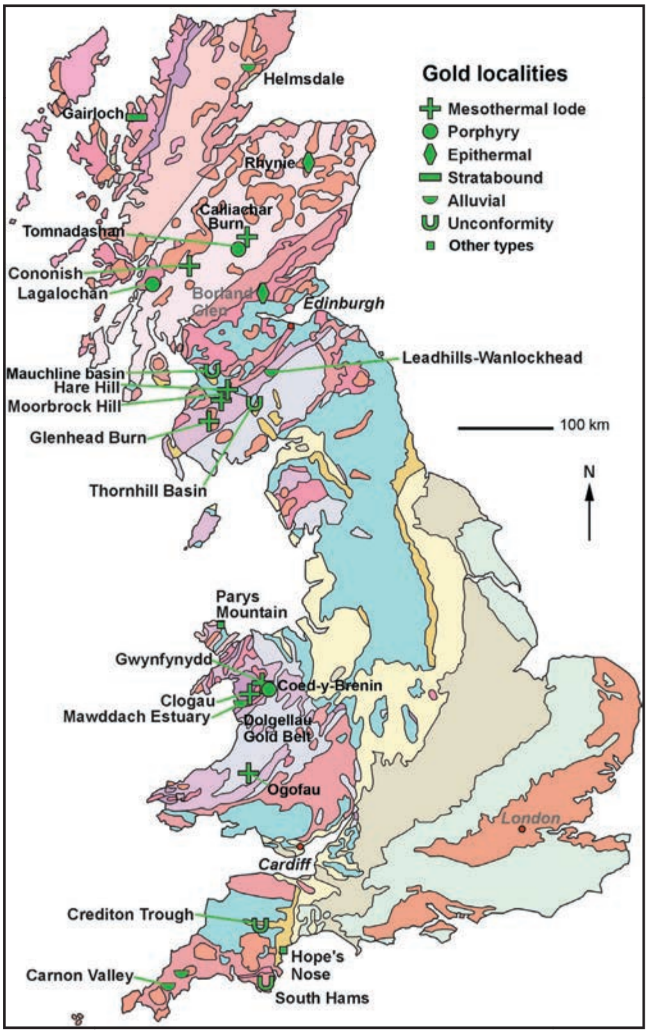

Figure 1. Gold localities in Great Britain; other types include mafic hosted, breccia pipes and volcanogenic massive sulphide deposits (after BGS).

zone above the unweathered primary material. A 'Roman Lode' has been inferred at Dolaucothi, and shallow workings to a depth of about 45 m are attributed to Roman working. They did not have explosives and therefore had to use metal picks to break the rock. They also used fire setting, where the rock is heated with a wood fire before water is poured on to split the rock as it contracts. Wooden objects, one of which appeared to be part of a drainage wheel, have been radiocarbon dated at 90 ±70 BC (Burnham, 1997), showing the Roman, and possibly pre-Roman, age of the site.

Following the Roman occupation there is little hard evidence of gold mining in Britain. After the Norman conquest, all the land and contained minerals belonged to William the Conqueror "in right of The Crown" because he was king. Despite centuries of change in law and custom, the underlying ownership of The Crown still exists and there is always a presumption in favour of The Crown unless it can be proved that the land belongs to someone else (that is taken verbatim from the Crown Estate website).

In the 16th century Beavis Bulmer obtained a licence from the King of Scotland to mine gold at Crawfurd Muir near Leadhills in Scotland. This area became known as 'God's Treasure-House in Scotland'. The activity naturally revived interest in gold in Britain, as well as in other metals. The development of armaments, such as cannon and small-arms, increased the demand for all kinds of metals, as well as gold and silver to pay for them and provide for the expanding currency requirements. German miners were employed to prospect and develop copper mining in the Lake District. and inevitably the question of ownership of minerals was raised.

The Case of Mines (R v Earl of Northumberland) in 1568 decided "that by the law all mines of gold and silver within the realm, whether they be in the lands of the Queen, or of subjects, belong to the Queen by prerogative, with liberty to dig and carry away the ores

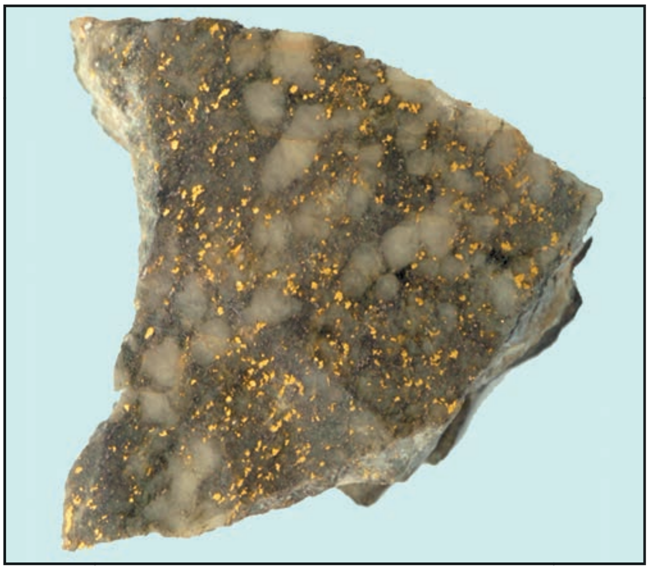

Figure 2. *Gold with quartz from the Clogau deposit.*

thereof, and with other such incidents thereto as are necessary to be used for the getting of the ore."

Since the Royal Mines Act 1688 all naturally occurring gold and silver in Britain has been owned by the Crown, and has been administered by the Crown Estate since 1760, currently through the Crown Mineral Agent. This includes Wales, Northern Ireland and Scotland (apart from Sutherland in northern Scotland where the Duke of Sutherland owns all mineral rights).

The record from the 16th Century until the middle of the 19th is neither voluminous nor clear. There may have been spurious 'gold mines' caused by discovery of pyrite or fool's gold, such as a reported gold discovery near Ampthill in Bedfordshire (Calvert, 1853).

Dolgellau goldfield

In the early 1840s a number of copper and lead mines were working in the Dolgellau area of central Wales. Problems with processing the ore at Cwm-Heisian mine caused the mine manager to call in Arthur Dean as a consultant in 1843 (Hall, 1988). He examined the jigs that were being used to separate the heavier ore from the lighter waste and noticed specks of gold with the galena (lead ore). Dean then published a paper at the 1844 British Association meeting in which he claimed that large numbers of gold veins existed in North Wales. This did not apparently lead to increased interest in the area.

The state of gold mining in Britain was reviewed by John Calvert in 1853. This attracted the derision of some of the professional geological establishment as shown by the following passage Albert Frederick Calvert (1893), possibly a relation of J Calvert: 'Now, in 1853, Mr John Calvert was the subject of fierce attack and insult at the hands of Professor Sedgwick at a British Association meeting in Hull, mainly based on the fact of Mr Calvert not having passed through a college curriculum. But the Professor met his match, and both he and Sir Roderick (Murchison) came off second best in a sharp verbal encounter. John Calvert at once disclaimed the college blinkers, and challenging Sir Roderick's assertion, said that if the speaker's arguments were sound what became of the Silurian system of Wales. Mr. Calvert went on to say "Mr President, although you have written much to prove the identity of the Welsh rocks with those of the Ural, still you have been silent as to their being auriferous". He concluded his speech by asserting that Welsh rocks were extensively auriferous, and offered to meet Sir Roderick and his friends on the Welsh mountains, where he would point out rich veins of quartz. This challenge was duly accepted. They met at Dolgelly and Mr. Calvert took them to Clogau, broke gold from the rocks and turned the tables on his scientific antagonists.'

The two major deposits in the Dolgellau area were Clogau St Davids and Gwynfynydd. They consist of complex mesothermal quartz-sulphide veins hosted in Cambrian carbonaceous shales - the Clogau Formation

Figure 3*. The main lode at Gwynfynydd (photo: BGS).*

(Fig. 2). High-grade ore shoots appear to be concentrated where the shales are intersected by pervasively altered Ordovician dolerite dykes or 'greenstones'. The area is characterised by small bonanza-type deposits separated by relatively barren quartz vein. There were two speculative gold rushes in 1853 and again in 1862 (well documented by Hall, 1988). The highest annual production was by Clogau with 18,714 ounces in 1904 (Hall, 1988). The mines were closed by the early 20th Century after producing about 130,000 ounces of recorded gold. Gwynfynydd reopened in 1981 and was worked intermittently on a small scale, until it finally closed in 1998 after producing around 2000 ounces of gold (Fig. 3). Clogau was briefly worked in 1966-67 and reopened by Caernarvon Mining who raised £2.25 million by floating Clogau Gold Mines plc in 1984. Protracted underground exploration and trial mining to find new oreshoots over the next 30 months yielded only 41 ounces of gold, and the mine was closed at the end of 1987 (Hodgkins, 1988). The mine was then worked intermittently in the 1990s by Welsh Gold, who extracted small amounts of gold for their jewellery business in Dolgellau. Limited investigations by small companies such as Stoic Mining and Cambrian Goldfields are continuing in the area.

The quartz veins in these deposits mainly trend ENE and occur in anastamosing clusters with a strike length that may exceed 5 km. Their width is normally between 1 and 2 m but can vary from thin stringers to large bodies of quartz 10 m in width. They often show multiple phases of deposition implying repeated phases of mineralisation (Mason et al, 2002). The gold-bearing veins are mainly composed of quartz with minor calcite, chlorite, white mica and a variety of sulphide minerals, including pyrite, pyrrhotite, chalcopyrite, galena, sphalerite and arsenopyrite. The sulphide content varies widely. For example, at Clogau, sulphides are relatively minor, while at Gwynfynydd they are more abundant. The veins dip either NNW or SSE. The angle of dip varies with the competence

Stage 1: Cobaltite-arsenopyrite-pyrite
Stage 2: Au-Ag-Bi-Te-Pb-Sb 'bonanza-type' gold-silver; minerals include bismuthinite, galena and tetrahedrite, as well as various tellurides of bismuth, lead and silver.
Stage 3: Pyrrhotite-chalcopyrite
Stage 4: Galena-sphalerite

Table 1*. Dominant phases in the paragenetic sequence for the Dolgellau gold deposits (after Mason et al, 2002).*

of the host rock as veins typically steepen to almost vertical when passing into "greenstone" and flatten out to 60-80º when passing into shale beds. A paragenetic sequence has been deduced (Table 1).

The Dolgellau goldfield drains into the Mawddach estuary and several schemes to recover gold from the estuary have been proposed, including one by the grandly named Mawddach Gold Dredging Syndicate in 1896, but none appears to have been successful (Bennett and Wilkinson, 2007). In the early 1970s RioFinex, an exploration subsidiary of RTZ, carried out some exploration in the estuary during its investigations of the copper deposit at nearby Coed-y-Brenin, but abandoned the area in 1972.

Dolaucothi (Ogofau)

After the Romans left Britain, the Dolaucothi deposit appears to have been left untouched, or at least unrecorded, until 1844, when the Geological Survey recorded gold for the first time. The deposit then had a history of intermittent and minor production (Table 2). Since the 1980s, Cardiff University has used the underground workings for training mining surveyors,

1872	Minor gold production.
1887-97	South Wales Gold Mining Co: 200 t ore.
1905-06	Mitchell mined 381 t ore for 44 oz gold.
1907-09	Ogofau Proprietary Gold Mining Co: 360 t ore for 28 oz gold.
1909-12	Cothi Mines mined 96 t ore for 23 oz gold.
1933-34	Roman Deeps Ltd carried out exploration.
1935-36	Roman Deep Holdings Ltd mined 300 t ore for 260 oz gold, and outlined 150,000 t ore at a grade varying 8.5–17.0 g/t.
1937-38	British Goldfields (No 1) Ltd raised capital of £200,000, but had only £44,000 after buying the lease and equipment; mined 16,862 t ore for 1388 oz gold; funds were exhausted by the end of 1938.
1975-1990	Anglo Canadian Exploration carried out geological, geochemical and geophysical studies (with the Mining Department at Cardiff University) and drilled at least six holes to depths of 250 m; no significant gold mineralisation was found.
1995-2005	Anglesey Mining took over the lease and drilled two holes.

Table 2*. Outline history of gold production at Ogofau (after Annells and Burnham, 1995).*

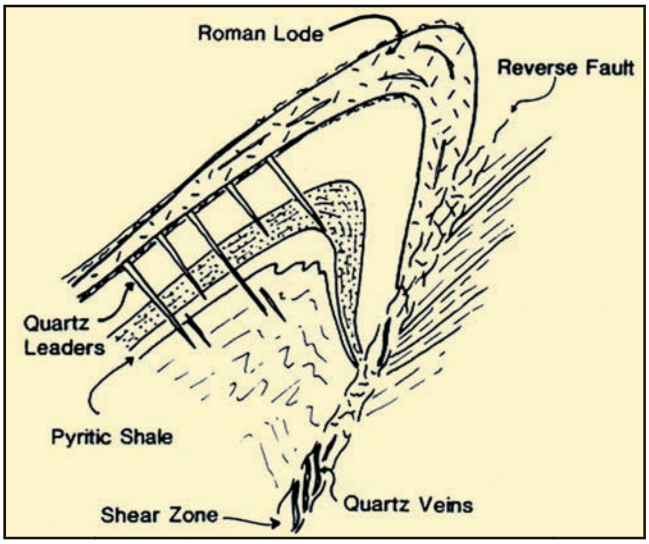

***Figure 4**. The Roman Lode and associated features of the Dolaucothi gold deposit (after Annells and Burnham, 1995).*

and in 2006 the remaining drillcore was moved to BGS Keyworth where Jan Zalaziewicz of Leicester University used it to investigate glaciogenic sediments at the Ordovician/Silurian contact.

The Dolaucothi deposit occurs in tightly folded black pyritic turbiditic shales of Llandovery age. It comprises heavily folded and faulted gold-bearing pyrite and arsenopyrite bands, and also a complex series of quartz veins referred to as the Roman Lode and interpreted by Annells and Roberts (1989) as a classic 'saddle-reef' structure plunging south-west at a shallow angle (Fig. 4). The Roman Lode was the main target for mining at Dolaucothi. Where it is intersected in New Shaft, the Roman Lode is a 1.2 m thick quartz vein with pyrite, arsenopyrite and galena assaying 19.14 g/t (grammes/tonne). The Roman Lode can be traced laterally over several hundred metres and was mined to a depth of about 150 m. The complex structures and sulphide-locked gold made economic development of the mine and treatment of the ores both difficult and expensive, resulting in the ultimately unsuccessful ventures listed in Table 2.

***Figure 5**. Alluvial gold from Helmsdale (photo: BGS).*

Helmsdale

In late 1868 news of a gold strike in the Helmsdale area of Sutherland in northern Scotland was published, and within a few months over 600 men were actively panning for gold in the Kildonan and Suisgill Burns (Fig. 5). In April 1869, the Duke of Sutherland introduced a system of licenses which cost one pound per month for each claim measuring 40 square feet. In addition to this, the prospectors were expected to pay a royalty of 10% on all gold found (Mason, 2007). The alluvial rush was over by the end of 1869 and, as no veins or other sources of hard-rock gold had been discovered, the field was abandoned. A full account of the Helmsdale gold rush is given in Callender and Reeson (2008). Recent investigations by Crummy et al (1997) indicated that the gold might have been sourced from a Devonian volcanic epithermal system similar to that at Rhynie in Aberdeenshire (Rice et al, 1995), though no bedrock gold has been found.

Gold in Britain today

Minor gold mining and prospecting have continued intermittently in the Dolgellau and Pumpsaint area from the cessation of the main mining period in the early 20th century until the present day. However, there was very little interest in gold elsewhere apart from recreational panning, especially around Helmsdale.

The abrupt rise in the gold price in the late 1970s from the previously fixed price of $35 per ounce (Fig. 6), coupled with the development of rapid and relatively cheap methods of analysis with low levels of detection caused a dramatic worldwide upsurge in exploration for gold. In 1983 the Irish company Ennex International (part of the group that had found the Tynagh and Navan lead-zinc deposits in the Republic of Ireland) announced that a potentially economic gold deposit had been found in Dalradian rocks at Curraghinalt near Gortin in County Tyrone (Clifford et al, 1990).

Ennex had been following up reports by the Geological Survey of Northern Ireland of widespread alluvial gold in the Sperrin Mountains (Arthurs, 1976). This was quickly followed by another discovery in similar rocks, also by Ennex, at Cononish, near Tyndrum in western Scotland. A third deposit was found in 1987

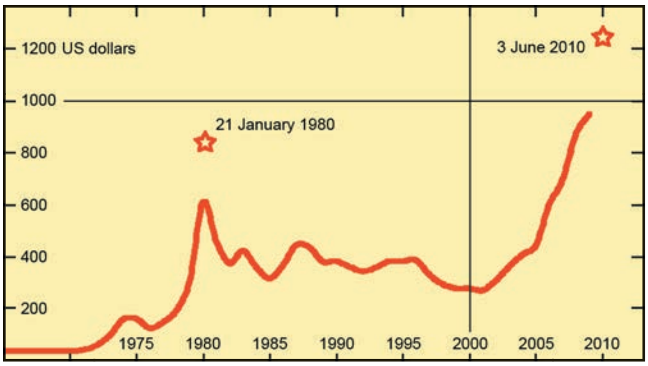

***Figure 6**. Annual average prices for gold (in US dollars) from 1965 to 2010, with spot values at the two notable peaks.*

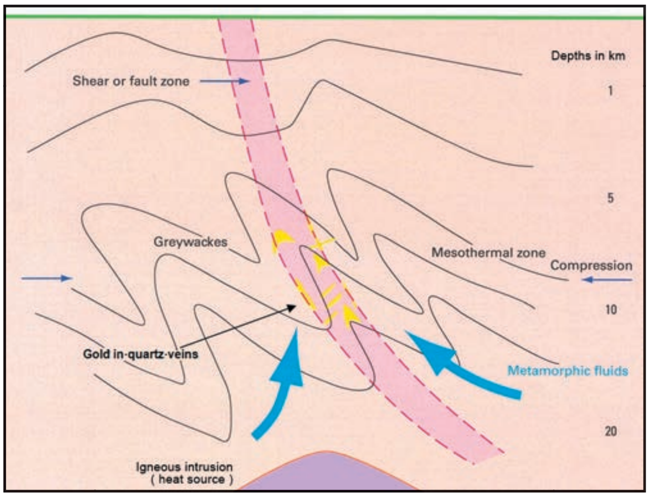

***Figure 7**. Formation of the mesothermal gold deposits.*

by RioFinex at Cavanacaw, again in County Tyrone (Cliff and Wolfenden, 1992). All these deposits were found by conventional prospecting, with panning of stream sediments followed by searches for outcropping quartz veins and associated loose blocks in areas where gold had been panned.

These deposits, and those of the Dolgellau and Ogofau areas, are all variations of the mesothermal, turbidite-hosted class (now usually called orogenic), which are best known from the goldfields of Victoria in Australia (Phillips and Hughes, 1998). The average abundance of gold in the crust is about 4 parts per billion (ppb). Deep seated metamorphic fluids can contain up to 10 ppb Au in chloride and bisulphide complexes as rocks undergo various physical and chemical transformations at depth, often assisted by the presence of igneous intrusions. The fluids rise and migrate to fault zones in areas of lower pressure. As the faults move the pressure is suddenly reduced and the fluids rise to higher levels. This can also cause a drop in temperature, and contained gold can be precipitated when and where the gold complexes become unstable (Fig. 7). Quartz is the most common material in the veins as silica is the most abundant material in the crust. The gold-bearing quartz veins can take up a variety of shapes, including ribbons, breccias and ‘saddle reefs’,

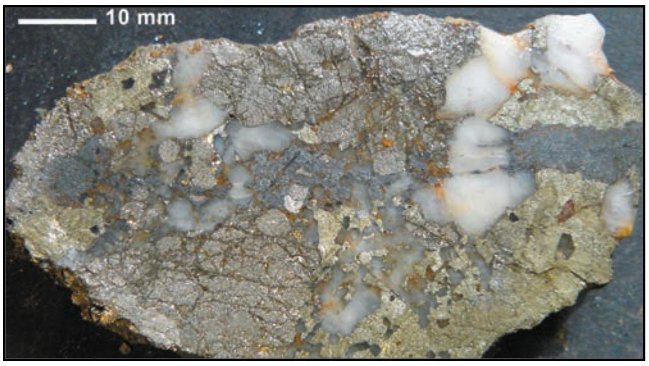

***Figure 9**. Ore from the main vein ar Curraghinault, with quartz, pyrite and chalcopyrite.*

in various orientations and sizes. Economic grades of gold range from one to several tens of parts per million, implying a concentration factor of around 1:1000 from source to deposit.

Curraghinalt

The Curraghinalt gold deposit (Fig. 8) consists of a sub-parallel series of WNW-trending quartz veins up to 2 m wide in Dalradian psammites of greenschist facies. The gold is associated with pyrite, as inclusions, in microfractures and also in quartz (Fig. 9).

Ennex drilled a series of holes to prove the thickness, grade and continuity of the quartz veins which extend over an area of 3 km by 1 km. Then in 1985 they drove an adit 400 m into the hillside below the quartz veining (Fig. 10) to obtain bulk samples for metallurgical testing and resource estimation. A geological resource of 1 million tons at a grade of 0.28 oz/t (280,000 ounces) was announced in 1986. However, due to the continuing low gold price (Fig. 6), mine development did not proceed, and the project passed through a variety of Canadian owners in the following two decades, including Nickleodeon Minerals Inc and Tournigan Gold Corporation; it is now owned by SA Resources Ltd. Following additional drilling by Tournigan the mineral resource has been further defined, and now consists of an Indicated Resource of 570,000 t at a grade of 13.95 g/t (250,000 oz) and an Inferred Resource of 640,000 t at a grade of 17.15 g/t, making a total of

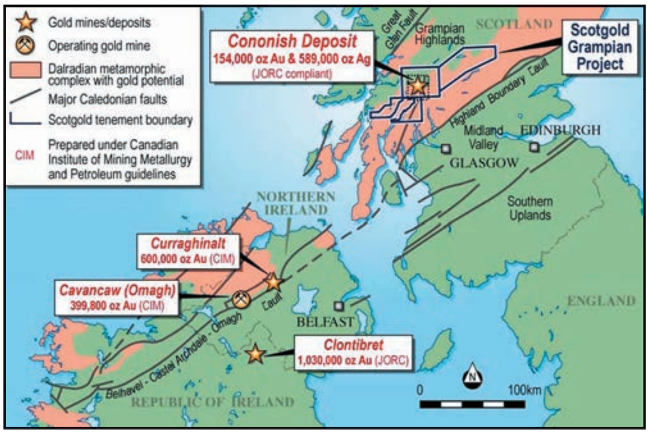

***Figure 8**. Dalradian gold deposits in northern Ireland and Scotland (from Scotgold Resources).*

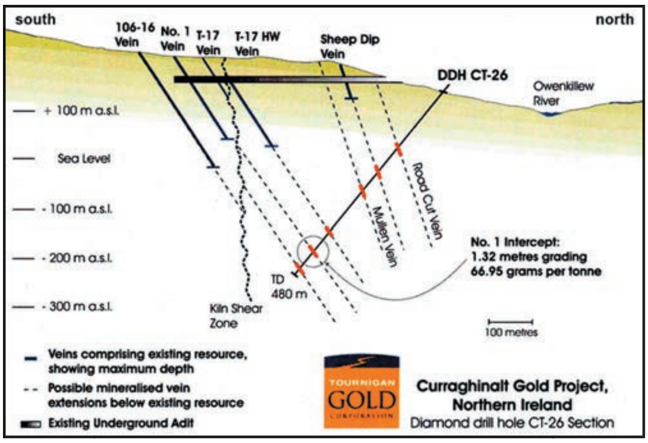

***Figure 10**. Cross section of the veins and the new adit at Curraghinalt (from Tournigan Energy).*

600,000 ounces of gold. The veins have been proved to a depth of up to 400 m (Fig. 10).

Omagh (Cavanacaw)

The Omagh gold deposit (originally called Lack and then Cavanacaw) is about 5 km WSW of Omagh in County Tyrone (Fig. 8). Following the discovery of a gold mineralised quartz vein and high-grade loose blocks assaying up to 156 g/t gold (Cliff and Wolfenden, 1992), soil sampling and shallow drilling of anomalous areas located the north-south trending Kearney Structure. This is up to 20 m wide, and consists of a brecciated quartz vein with pyrite, arsenopyrite and galena up to 5 m wide in a shear zone of altered and brecciated and quartz veined Dalradian metasedimentary and volcanic rocks. Core drilling proved the continuity of the structure over a length of 900 m and to a depth of 300 m. The thick overburden prevented detailed sampling and so a trench was excavated to expose the vein and allow channel sampling across the vein at 1 m intervals over a 200 m length. This indicated a mean grade of 7.6 g/t gold, 19.9 g/t silver and 0.9% lead over a width of 5.1 m. The deposit was then sold to Omagh Minerals Ltd. who were granted planning permission for a mining operation after a protracted public enquiry in 1995. The depressed gold price prevented development until 2007 when a small open pit mine was opened by Galantas Gold Corporation (who currently own Omagh Minerals), and the operation produces a concentrate that is shipped to Canada for treatment. Production in 2009 totalled 5935 ounces gold, 15,120 ounces silver and 187 tonnes of lead.

Cononish

Following the Curraghinalt discovery, Ennex geologists extended their search to the Dalradian rocks of Scotland. Prospecting in the Tyndrum area in 1985 revealed gold-bearing blocks near the old Eas Annie lead vein southwest of Tyndrum (Fig. 8). Follow-up work, including core drilling, outlined a single NE-trending mineralised quartz-sulphide vein (Fig. 11) at the contact of Dalradian mudstones and quartzites. An adit was driven for 400 m into the hillside to provide additional information for resource estimation, and full planning permission for mine development was obtained in 1995. However, as with the other discoveries, the stagnant gold price deterred development and the deposit passed through various operators before Scotgold Resources, an Australian-based company, acquired it in 2007. They have carried out additional drilling and report current resources as in Table 3. The total gold resource of the Cononish Main Vein is estimated to be between 152,000 and 198,000 oz.

Reserves	*Ore*	*Gold*	*Silver*
Measured	53,000 t	17.9 g/t	75.0 g/t
Indicated	63,000 t	10.1 g/t	42.2 g/t
Inferred	285,000 t	11.2 g/t	41.0 g/t

***Table 3**. Reported mineral resources at Cononish.*

***Figure 11**. The Main Vein, dominantly of quartz, inside the Cononish adit (photo: Paul Lusty).*

Scotgold Resources have announced that they intend to start production in 2011 at a rate of 20,000 oz of gold per year. Their exploration has revealed additional prospects in the area, including a zone of mineralised breccias pipes at Beinn Udlaidh 5 km NNW of Cononish. Exploration is continuing (Scotgold, 2008).

Clontibret gold deposit

The Clontibret deposit (Fig. 8) in County Monaghan on the border between Northern Ireland and the Republic of Ireland was long known as a minor antimony-arsenic deposit (Cole, 1922). Gold was first recognised in 1957, and the area was investigated by various companies for the next three decades. Widely-spaced drilling proved a number of NW-trending quartz-sulphide veins with sporadic gold values exceeding 1 g/t. The licence was surrendered in 1992. A few years afterwards the Irish company Conroy Diamonds and Gold plc took up the Irish licences and also extended their interest across the border into County Armagh in Northern Ireland. The area lies in the Longford Down Massif and contains Ordovician and Silurian sedimentary rocks similar to those of the Southern Uplands of Scotland. A major structure, the Orlock Bridge Fault crosses the area from northeast to southwest. Conroy have explored the area over the past fifteen years and have recently announced a Total Resource in the Clontibret licence of 1.03 million ounces of gold made up of an Indicated 11 Million tonnes at a grade of 1.24 g/t for a total of 440,000

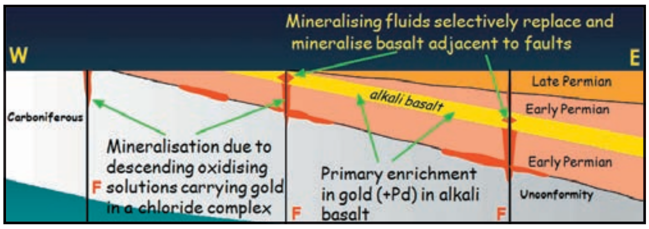

Figure 12. *Concept model for gold mineralisation in the Crediton Trough; the block is about 15km long and 1 km deep (after Leake et al, 1991).*

ounces of gold and an Inferred 14 million tonnes at a grade of 1.32 g/t for a total of 590 000 ounces of gold. They also have found a 30 g nugget at Clay Lake in Co Armagh. This has been followed up by soil sampling and core drilling, with a best intersection of 6.94 m grading 4.14 g/t gold (Conroy, 2008). Exploration is continuing.

Crediton Trough

In the late 1980s the British Geological Survey Mineral Reconnaissance Programme was investigating the Carboniferous and Devonian rocks south of Dartmoor for stratabound, base-metal mineralisation. The extensive occurrence of an unusual style of gold in panned concentrates led to the exploration for a style of gold mineralisation previously unrecognised in Britain (Leake et al, 1988). The gold grains were found to contain palladium and tellurium at percent levels, a very unusual combination that had few parallels elsewhere in the world (Fig. 12). Further exploration showed that the gold appeared to be associated with Permo-Triassic basins, especially where these were affected by alkali-basalt lavas. The Crediton Trough in Devon and the Mauchline and Thornhill Basin in southern Scotland were the most promising in terms of gold grains in streams.

A model for the formation of the mineralisation from which the gold grains were derived was proposed (Fig. 13). Oxidising solutions from the Permo-Triassic sediments leached gold form a dispersed large-volume source by the breakdown of sulphide minerals and moved downwards, carrying the gold in a chloride complex (Leake and others, 1997). Where the concentrated solutions met the underlying reduced Carboniferous they deposited the gold. In 1997 Crediton Minerals, a subsidiary of MinMet, drilled several holes in the Crediton Trough and intersected several thin carbonate veins carrying up to 2–3 g/t gold over narrow widths. No further exploration has been undertaken in these areas.

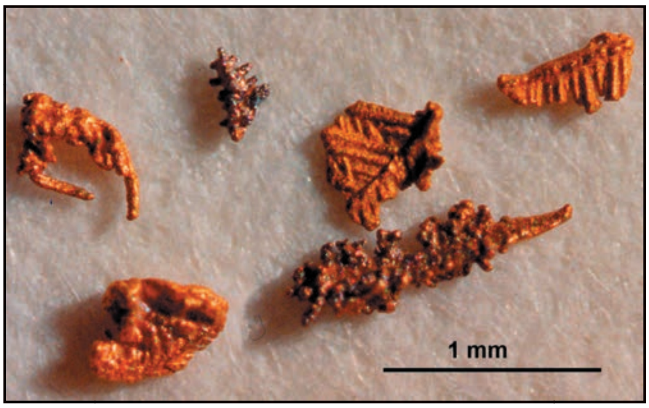

Figure 13. *Tiny dendrites of gold from the Crediton Trough (photo: Don Cameron).*

The future of gold in Britain

There is more gold to be found in Britain. However, any discoveries are unlikely to be of world class, as any really large deposit is unlikely to have remained undetected. Furthermore, the geology of the British Isles does not contain the large Archean greenstone belts, Proterozoic conglomerates or Tertiary-Quaternary destructive plate margins where the giant gold deposits occur. New discoveries will also depend on the amount of exploration effort and money expended; without exploration there will be no discoveries. It is likely that there will be more small discoveries likely in the 100,000 to 1,000,000 ounce range in the Dalradian rocks of Scotland and Northern Ireland. The recent Tellus geochemical and geophysical coverage of the whole of Northern Ireland and the publication and availability of its high-quality datasets has encouraged companies to take out additional mineral exploration licences for gold and base metals that now cover most of the land area (Beamish and Young, 2009). Success at Cononish will generate further interest in the Scottish Dalradian, especially near intrusive complexes that may provide the heat sources to drive mineralising hydrothermal systems. The British Geological Survey has published several reports on exploration models for gold in the Dalradian, such as Plant (1998), and also on the use of Geographic Information Systems (GIS) to assist in the selection of prospective areas (Leake et al, 1996).

There is the possibility of additional discoveries similar to those in the Longford-Down area in the Lower Palaeozoic rocks of Southern Uplands and Northern Ireland. These will be found adjacent to major structures, such as the Southern Uplands Fault and also in association with the abundant minor intrusions. Some small bonanza-type deposits probably remain to be found in the Dolgellau area, but these are less likely to be attractive to companies due to the amount of financial risk involved.

Small-scale panning may locate additional small nuggets of gold in the 1–10 g range, especially around Leadhills, Helmsdale and Dolgellau (Fig. 14). More than 4 tonnes of gold is reported to have been won from the tin streams of Cornwall and Devon (Camm, 1995) but no official records exist of this. The 'tin streamers' who worked the alluvial tin used to carry quills into which they put any grains of gold that they found in their pans. The largest nugget recorded from Cornwall is 59 grammess (almost 2 ounces) from the Carnon Valley, and is in the Royal Institution of Cornwall Museum at Truro (Camm, 1995).

***Figure 14**. Placer gold won from the stream sediments of Helmsdale, panned by an amateur mineralogist on holiday visits in recent years.*

References

Annels, A.E. & Burnham, B.C., 1995. *The Dolaucothi gold mines*. Cardiff: University of Wales.

Arthurs, J.W., 1976. The geology and metalliferous mineral potential of the Sperrin Mountains area. *Special Report of the Geological Survey of Northern Ireland*, 119pp.

Beamish, D. & Young, M.E., 2009. The geophysics of Northern Ireland: the Tellus effect. *First Break*, **27**, 43-49.

Bennett, J. & Wilkinson, J., 2007. Gold in the Mawddach. *British Mining*, 83, 27-46.

Burnham, B.C., 1997. Roman mining at Dolaucothi: the implications of the 1991-3 excavations near Carreg Pumpsaint. *Britannia*, **28**, 323-336.

Callender, R.M. & Reeson, P.F., 2008. The Scottish gold rush of 1869. *British Mining*, 84.

Camm, G.S., 1995. *Gold in the counties of Cornwall and Devon*. St. Austell: Cornish Hillside Publications.

Calvert, A.F., 1893. *The mineral resources of Western Australia*. London: George Phillip.

Calvert, J., 1853. *The gold rocks of Great Britain and Ireland*. London: Chapman and Hall (free download from http://books.google.co.uk/books).

Cliff, D.C. & Wolfenden, M., 1992. The Lack gold deposit, Northern Ireland. 65-73 in Bowden, A. A., Earls, G., O'Connor, P. G. and Pyne, J. F. (Eds), *The Irish Minerals Industry 1980-1990,* Irish Association for Economic Geology.

Clifford, J.A., Meldrum, A.H., Parker, R.T.G. & Earls, G., 1990. 1908-1990: a decade of gold exploration in Northern Ireland and Scotland. *Trans. Inst. Min. Metall*., **99**, B133-B138.

Cole, G.A.J., 1922. Memoir of localities of minerals of economic importance and metalliferous mines in Ireland. *Memoir of the Geological Survey of Ireland* (facsimile edition by Mining Heritage Society of Ireland: Dublin, 1998).

Conroy, 2008. One million plus oz gold resource at Clontibret. www.conroydiamondsandgold.com .

Crummy, J. et al,. 1997. Potential for epithermal gold mineralization in east and central Sutherland, Scotland: indications form River Brora headwaters. *Trans. Inst. Min. Metall*., **106**, B9-B14.

Hall, G.W., 1988. *The Gold Mines of Merioneth*. Knighton: Griffin Publications.

Hodgkins, J., 1988. The reopening of Clogau Gold Mine in 1966. *Rock Bottom*, 5, 2-3.

Leake, R.C., Cameron, D.G., Bland, D.J., Styles, M.T., & Rollin, K.E., 1988. Exploration for gold between the lower valleys of the Erme and Avon in the South Hams district of Devon. *Mineral Reconnaissance Programme Report, British Geological Survey, 98.*

Leake, R.C., Bland, D.J., Styles, M.T. & Cameron, D.G., 1991. Internal structure of Au-Pd-Pt grains from south Devon, England, in relation to low-temperature transport and deposition. *Trans. Inst. Min. Metall.,* **100**, B159-B178.

Leake, R.C, Rollin, K.E., & Shaw, M.H., 1996. Assessment of the potential for gold mineralisation in the Southern Uplands of Scotland using multiple geological, geophysical and geochemical datasets. *Mineral Reconnaissance Programme Report, British Geological Survey*, 141.

Leake, R.C., Cameron, D.G., Bland, D.J., Styles, M.T. & Fortey, N.J., 1997. The potential for gold mineralisation in the British Permian and Triassic red beds and their contacts with underlying rocks. *Mineral Reconnaissance Programme Report, British Geological Survey*, 144.

Mason, D., 2007. The Scottish gold rush. www.helmsdale.org/gold-rush.html

Mason, J.S., Bevins, R.E. & Alderton, D.H.M., 2002. Ore mineralogy of the mesothermal gold lodes of the Dolgellau Gold Belt, North Wales. *Trans. Inst. Min. Metall*., **111**, B203-B214.

Phillips, G N and Hughes, M J. 1998. Victorian gold province. *Australasian Institute of Mining and Metallurgy Monograph*, 22, 493-504.

Plant, J. and 29 others, 1998. Multidataset analysis for the development of gold exploration models in western Europe. *British Geological Survey Research Report*, SF/98/1.

Rice, C.M. and 13 others, 1995. A Devonian auriferous hot spring system, Rhynie, Scotland. *Journal of the Geological Society*, **152**, 229-250.

Scotgold, 2008. Welcome to Scotgold Resources Limited. www.scotgoldresources.com .

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Origin and structure of Devensian depressions at Letton, Herefordshire

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Abstract: Circular to oval enclosed depressions in soft sediments of Pleistocene age are normally interpreted as being either glacial or periglacial in origin. Where these features are developed in glacial sediments, a glacial (and specifically 'kettle hole') genesis is considered most likely. Some have been re-interpreted as periglacial in origin and are thought to be the remains of cryogenic mounds (former pingos or palsas/lithalsas). A group of enclosed depressions in the Letton area of Herefordshire within the Last Glacial Maximum ice limit have been investigated by electrical resistivity tomography and ground probing radar. Their morphology and internal structure, and their existence in glacio-lacustrine sediments of Late Devensian age suggests that they are kettle holes resulting from ice block discharge into shallow lakes. The lack of any ramparts and the fact that they do not overlap also indicate that they are not the remains of cryogenic mounds.

There are numerous groups of circular to oval enclosed depressions situated in soft sediments of Pleistocene age in northwest Europe. In formerly glaciated terrain these have often been interpreted as kettle holes, a form of proglacial feature resulting from the burial of ice blocks and their subsequent melt-out, which causes localised ground subsidence (Maizels, 1977). Since these features are relatively common and merely confirm the role of glaciation in the landscape, they have not generally been investigated in detail. Nevertheless, some Last Glacial age kettle holes in Britain are notable for the organic materials that were preserved within them, such as woolly mammoth (*Mammuthus primigenius* (Blumenbach), Allen *et al*, 2009).

In the 1960s, interest in enclosed depressions increased following the publication of investigations of such features in Belgium and Wales (Pissart, 1956, 1963). The features were interpreted not as kettle holes, but as the remains of former pingos - mounds or small hills that develop in permafrost through the growth of a core of ice (Mackay, 1998). Pissart referred to them as 'relict pingos', and their distribution appeared to provide a means of reconstructing the former distribution of permafrost (Washburn, 1983).

Distinguishing kettle hole depressions from relict pingos became essential. It was determined that a key diagnostic criterion for relict pingos was the existence of a raised rim or rampart around the depressions (Watson, 1971; Watson and Watson, 1974; Sparks *et al*, 1972). At that time, kettle holes were not generally believed to display this attribute (*cf.* Maizels, 1992). The ramparts were believed to have formed by material gradually slipping off the sides of the mound and/or from a displacement of material from the interior of the mound during the growth of the ice core (Mackay, 1988). Modern arctic pingos of the hydraulic type were originally seen as the modern analogue (Gurney, 1998), although more recently a palsa (Gurney, 2001) or lithalsa (Pissart, 2002) analogue has been invoked. At some sites the rampart around the features was incomplete or even completely absent (Gurney, 2000). The rampart may have originally existed but had been lost through subsequent land use (ploughing, drainage operations etc). Such rampart-less features require information on the sub-surface to enable correct interpretation.

Although research has tended to focus on either glacial or periglacial origins, it must be remembered that there are many other explanations for such

***Figure 1**. Feature #30; this depression has been dug out so that it now forms a perennial pond; it does however indicate the typical size and shape of the depressions at Letton; see Figure 2 for its exact location.*

enclosed depressions. These include dissolution (to form dolines), nivation, subsidence, mineral workings (e.g. collapsed flint mines, marl pits etc) and bomb craters. Detailed discussions of the possible origins for the enclosed depressions of Norfolk are given by Prince (1961, 1964) and West (1987).

Until recently the investigations of these features primarily involved mapping and the excavation of trenches through the features. A more sophisticated and less invasive approach could now include the use of geophysical techniques to determine the sub-surface structure of the depressions in combination with mapping. To date only a few sites in west Wales have been subject to such an approach, at Cledlyn (Harris, 2001) and at Llanio Fawr (Ross *et al*, 2007). The investigations at the latter site favoured a glaciofluvial origin.

The Letton site

This site lies about 15 km northwest of Hereford. It has low relative relief and is situated to the north and just above the level of the floodplain of the River Wye. Upstream of Hereford, the Wye is underlain by the Raglan Mudstone Formation of the Devonian Lower Old Red Sandstone (Brandon, 1989). Herefordshire may have been glaciated in several of the Pleistocene cold stages, but only two left evidence, namely the Anglian cold stage and the Late Devensian (Brandon, 1989). Within the relatively well-defined end moraines, Late Devensian glacial deposits are characterised by sizeable areas of irregular relief containing hummocks and kettle holes (Luckman, 1970) along with glaciofluvial and glaciolacustrine sediments (Richards, 2005). The study site is over 7 km inside the Devensian limit and the surficial sediments are believed to be glaciolacustrine in origin, according to the mapping provided by the 'BritIce' project (Clark *et al*, 2004), although these may be underlain by glacial till.

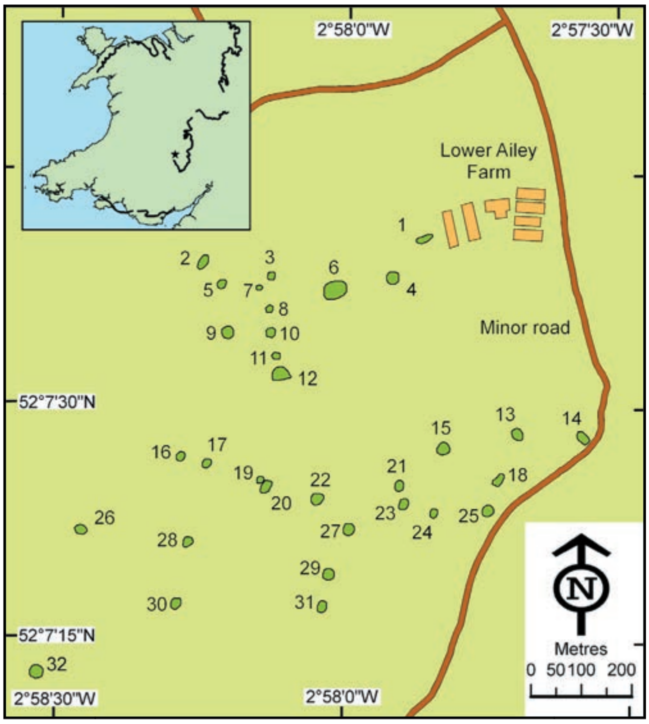

Figure 2*. Distribution of enclosed depressions at Letton; the inset map indicates the site location (black star) and the Devensian ice limits (bold black line); the depression investigated using geophysics was Feature #21.*

In order to determine the origin of the depressions (Fig. 1), detailed geomorphological mapping and geophysical investigations were undertaken. The mapping was based upon field survey using a base of 1:10,000. The resultant mapping (Fig. 2) was digitised and incorporated into a Geographical Information System (GIS, using ESRIs ArcGIS).

Thirty-two depressions were mapped, and these were circular to oval in plan, although some of their shapes have been modified by the creation of a hedge-line or through some other agricultural development. The depressions range from 10 to 55 m across and are from 0.2 to 0.8 m deep. Some of them are occupied by perennial ponds (Fig. 1) where they have been artificially deepened to provide a source of water for livestock; others have a pool of water only during wet periods.

The ground surrounding and between the depressions is generally of low gradient and is without any specific micro-topography; specifically it cannot be described as 'hummocky'. The spatial pattern of the depressions is not unlike that of kettles holes elsewhere in the Welsh borders (Worsley, 2005). None of the depressions mapped has a convincing rampart and none appears to be 'mutually interfering' (i.e. overlapping), which are both characteristics of relict cryogenic mounds (Gurney & Worsley, 1996).

Internal structure of Feature #21

In order to determine the distribution and structure of the sediments at depth, two geophysical methods were used to investigate the 2D structure of one of the depressions (Feature #21 on Figure 2). This depression is about 30 m across, and 0.65 - 0.75 m deep. Electrical resistance tomography (ERT) profiles were acquired on two lines (Figs. 3 & 4) at right angles to each other, using a Campus Geopulse multi-channel switching unit and making measurements using a Wenner-Schlumberger array. The two arrays had 25 and 32 electrodes, on a spacing of 3 m. Ground probing radar (GPR) was also employed with GSSI equipment over the same profiles using both 400 MHz and 100 MHz bistatic antennae. The two profiles were oriented northwest to southeast and at right angles to that, and crossed each other in the centre of the depression.

The ERT profiles of Feature #21 confirm the lack of an obvious rampart at the surface or at depth. The sub-surface materials appear to have a three-layered structure (Fig. 4). The surface layer is about 4 m thick, with a resistivity in the range 45-75 Ωm. This overlies a low resistivity layer (25-40 Ωm), whose thickness is

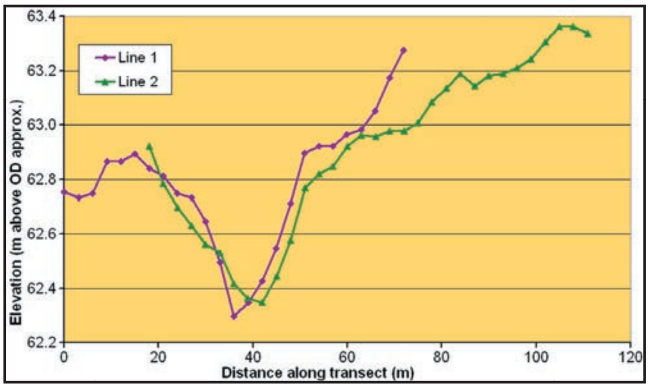

Figure 3. Topographic profiles across the depression; the two lines intersect at right angles at the 39 m point.

not well constrained, but is tentatively interpreted as about 6 m. It overlies material of higher resistance (40-50 Ωm).

Augering down to about 1 m in the depression indicated that the upper layer beneath the topsoil is made of brown silts, locally containing small nodules of iron oxide. Comparison with a recent borehole located about 200 m to the south, suggests that the middle layer is composed of blue-grey clay to silt, with the upper layer being of oxidised clay and silt. Both these layers are inferred to be lake deposits (glacio-lacustrine) from the Late Devensian. The increased and laterally variable resistivity of the upper layer reflects the partial de-saturation and consequent oxidation, of the lacustrine silt/clay. The increase in resistance at depth may reflect the influence of Devonian bedrock, or older Pleistocene deposits (probably glacial till) beneath the lacustrine sequence. The lateral variation in resistance in the upper layer does not show any obvious relationship to the position of the surface depression.

The GPR profiles obtained with the 400 MHz antenna show that the ground absorbs the radar wave and generally has little internal contrast, so that reflections are weak to absent. The 100 MHz antenna shows some additional reflections down to about 75 ns (about 2 m deep) and 50 ns associated with the depression. The deepest reflector is overlain by layers that thicken to the centre of the depression; this has been interpreted as a deformed near-surface layer overlain by accumulated sediment. Data from the GPR suggest that the depression has been formed, and was perhaps enhanced by, local subsidence of the ground, thereby deforming a near-surface soil layer. The accumulation of up to 2 m of sediment within this depression, implies enhancement of the feature over a significant period of time.

Origins of the depressions

The geophysical imaging provides evidence for understanding the origin of depression #21, and by inference for the other depressions as well. Taken with the results of the nearby borehole, the ERT and GPR results are consistent with a thick sequence (the ERT implying at least 10 m) of fine-grained sediments being present. The ERT further suggests that partial to total de-saturation and oxidation of these sediments has taken place to about 4 m depth (which may represent the water table depth at this site, with its potential link to the River Wye to the south). The GPR profiles are consistent with the perpetuation of the investigated depression by a positive feed-back mechanism. The sediment of the infill provides an additional sediment load which has caused continued slow subsidence of the underlying material, presumably accommodated at depth by compaction of the soft, saturated, lacustrine, silty clays.

The lack of ramparts at the surface or at depth, combined with the fact that none of the depressions displays any so-called 'mutual interference' (*cf.* Gurney, 2000 and Pissart, 2002), suggests that a hypothesis of periglacial and specifically cryogenic mound development is untenable. The presence of the depressions in soft glacio-lacustrine sediments points strongly toward a glacial origin. Other areas with numerous depressions in Herefordshire are associated with hummocky moraines and are clearly glacial in origin. All the evidence leads us to conclude that these depressions are almost certainly glacial in origin and represent the remains of kettles holes.

The glacio-lacustrine origin of the sediments within which the depressions are formed indicates that ice blocks were discharged into a lake or lakes (Theakstone, 1989). The blocks then became grounded in the shallow water, and remnants of them become buried in the lake sediments. Following drainage of the lake, the buried blocks of glacier ice thawed slowly over time, creating the depressions within the surficial sediments. This environment of deposition led to a landscape with kettle holes but no intervening micro-relief, which is in contrast to other sites with kettle holes in Herefordshire (e.g. on the Kington-Orleton moraine). The assumption that 'kettled' topography is always formed by the passive decay of blocks of glacier ice derived from the *in situ* decay of ice at a stagnant margin may not always apply. Observations following

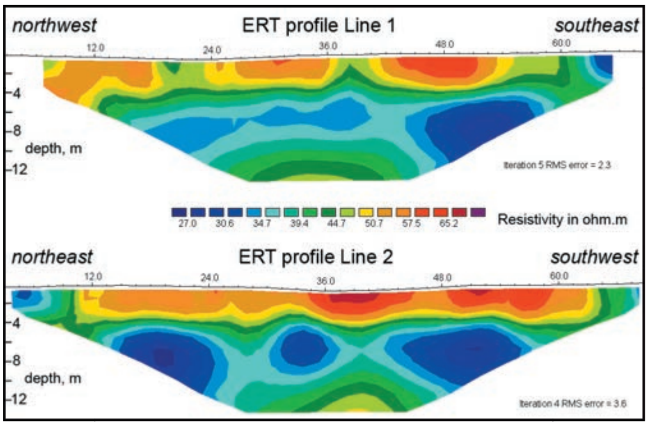

Figure 4. Electrical resistance tomography (ERT) profiles across the depression that is Feature #21.

the 1996 jökulhlaup in southern Iceland has suggested that such outburst floods provide for the release and burial of ice blocks by a mechanism that is far from passive (Fay, 2002).

The thirty-two enclosed depressions at Letton are concluded to be glacial in origin and are likely related to the thaw of ice blocks buried in glacio-lacustrine sediments during the Late Glacial period (*cf.* Ross et al, 2007). Unlike other kettle holes within the glacial sediments of Herefordshire, they are not associated with 'hummocky moraine' (Luckman, 1970).

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References

Allen, J.R.M., Scourse, J.D., Hall, A.R. and Coope, G.R., 2009. Palaeoenvironmental context of the Late-glacial woolly mammoth (*Mammuthus primigenius*) discoveries at Condover, Shropshire, UK. *Geological Journal* **44**, 414-446.

Brandon, A., 1989. *Geology of the country between Hereford and Leominster (Memoir for 1:50,000 geological sheet 198 England and Wales)*. HMSO: London, 62pp.

Clark, C.D., Evans, D.J.A, Khatwa, A., Bradwell, T., Jordan, C.J., Marsh, S.H., Mitchell, W.A. and Bateman, M.D., 2004. Map and GIS database of landforms and features related to the last British Ice Sheet. *Boreas* **33**, 359-375

Fay, H., 2002. Formation of kettle holes following a glacial outburst flood (jökulhlaup), Skeiðarársandur, southern Iceland. In: *The extremes of the extremes: Extraordinary Floods*. IAHS Publication 271, 205-210.

Gurney, S.D., 1998. Aspects of the genesis and geomorphology of pingos: perennial permafrost mounds. *Progress in Physical Geography* **22**, 307-324.

Gurney, S.D., 2000. Relict cryogenic mounds in the UK as evidence of climate change. In: McClaren, S.J. and Kniveton, D.R. (eds.), *Linking climate change to land surface change,* Kluwer: Dordrecht, 209-229.

Gurney, S.D., 2001. Aspects of the genesis, geomorphology and terminology of palsas: perennial cryogenic mounds. *Progress in Physical Geography* **25**, 249-260.

Gurney, S.D. and Worsley, P., 1996. Relict cryogenic mounds at Owlbury, near Bishop's Castle, Shropshire. *Mercian Geologist* **14**, 14-21

Harris, C., 2001. Ground ice depressions, Cledlyn Valley. In: Walker, M.J.C. and McCarroll, D., *The Quaternary of west Wales: Field Guide,* Quaternary Research Association, 67-70.

Luckman, B.H., 1970. The Hereford basin. In: Lewis, C.A. (ed.), *The glaciations of Wales and adjoining regions,* Longman: London, 175-196.

Mackay, J.R., 1988. Pingo collapse and palaeoclimatic reconstruction. *Canadian Journal of Earth Sciences* **25**, 495-511.

Mackay, J.R., 1998. Pingo growth and collapse, Tuktoyaktuk Peninsula area, western Arctic cost, Canada: a long-term field study. *Géographie physique et Quaternaire* **52**, 271-323.

Maizels, J.K., 1977. Experiments on the origin of kettle-holes. *Journal of Glaciology* **18**, 291-303.

Maizels, J.K., 1992. Boulder ring structures produced during jökulhlaup flows: origin and hydraulic significance. *Geografiska Annaler* **74A**, 21-33.

Pissart, A., 1956. L'origine périglaciaire des viviers des Hautes Fagnes. *Annales de la Société Géologique de Belgique* **79**, 119-131.

Pissart, A., 1963. Les traces de pingos du Pays de Galles (Grande Bretagne) et du Plateau des Hautes Fagnes (Belgique). *Zeitschrift für Geomorphologie* **7**, 381-392

Pissart, A., 2002. Palsas, lithalsas and remnants of these periglacial mounds: a progress report. *Progress in Physical Geography* **26**, 605-621.

Prince, H.C., 1961. Some reflections on the origin of hollows in Norfolk compared with those in the Paris region. *Revue de Géomorphologie Dynamique* **12**, 110-117.

Prince, H.C., 1964. The origin of pits and depressions in Norfolk. *Geography* 49, 15-32.

Richards, A.E., 2005. Herefordshire. In: Lewis, C.A. and Richards, A.E. (eds.), *The glaciations of Wales and adjacent areas,* Logaston Press: Hereford, 129-144.

Ross, N., Harris, C. and Brabham, P.J., 2007. Internal structure and origin of Late Devensian 'ramparted depressions' Llanio Fawr, Ceredigion. *Quaternary Newsletter* 112, 6-21.

Sparks, B.W., Williams, R.B.G. and Bell, F.G., 1972. Presumed ground-ice depressions in East Anglia. *Proceedings of the Royal Society of London* **A327**, 329-343.

Theakstone, W.H., 1989. Further catastrophic break-up of a calving glacier: observations at Austerdalsisen, Svartisen, Norway, 1983-87. *Geografiska Annaler* **71A**, 245-253.

Washburn, A.L., 1983. Permafrost features as evidence of climatic change. *Earth Science Reviews* **15**, 327-402.

Watson, E., 1971. The remains of pingos in Wales and the Isle of Man. *Geological Journal* **7**, 381-392.

Watson, E. and Watson, S., 1974. Remains of pingo in the Cletwr basin, south-west Wales. *Geografiska Annaler* **56A**, 213-225.

West, R.G., 1987. Origin of small hollows in Norfolk. In: Boardman, J. (ed.), *Periglacial processes and landforms in Britain and Ireland,* Cambridge University Press, 191-194.

Worsley, P., 2005. Glacial geology of the Condover area, south Shropshire. *Mercian Geologist* **16**, 107-114.

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Building stones of St Mary's Church at Colston Bassett, Nottinghamshire

Albert Horton

The ruins of St Mary's Church stand on a low rise nearly a kilometre northwest of the village of Colston Bassett (at SK695338). They provide an opportunity to study 1000 years of change in architectural style, including construction, extension, modification and repair. The church a also offers an opportunity for geological study of the lithology of rocks that are now poorly exposed.

The early history of the church was investigated by Mr John Severn and colleague villagers as part of a campaign to preserve the ruin. The village is not recorded on the Domesday Book, of 1086, but the church was definitely in existence by 1135; King Henry 1 (1100-1135) acknowledged the gift of Richard Bassett (Chief Justice of England) of several lands and many churches, among which is the church of Coleston, *to the church of Lourd, in Leicestershire, which has been founded for the son of King William, his father*. This is confirmed by evidence of a Norman church, while the discovery of a Saxon carved stone during recent conservation work would indicate the existence of an even earlier building, either here or nearby.

Records show that in 1284 Ralph Bassett was granted a charter by King Edward 1 to hold a market and fair in the town. The large size of the church and the preservation of traces of medieval architecture (in Norman, Early English, Decorated and Perpendicular styles) suggest a long period of occupation and a significant number of parishioners. No evidence has been found of a village close to the church (the present village, southeast of The Hall, later became the main centre). If it existed, it must have been abandoned before 1600. Village depopulation is commonly attributed to the initial Black Death plague (1349-50) and subsequent outbreaks. This could have been compounded by people dying of starvation, due to a series of harvest failures recorded during the early years of the 14th century. A further factor could have been the change from mixed arable farming to sheep grazing with the consequent reduction in the need for labour; several villages in the Wolds were abandoned. St Mary's church, like many local churches, was most affluent during the 14th and 15th centuries, at the peak of the wool trade with Europe. This period was characterised by the Perpendicular style of architecture.

By 1744, the local population had declined, the buildings were in disrepair and permission was granted to demolish the North Arcade and Transept. The arches of the North Arcade were infilled, and windows in the Classical style were inserted. The South Porch was removed and a window in the South Aisle was replaced by a door. Major structural problems led to a partial rebuild of the Nave in the 19th century. Stabilisation work to preserve the remaining structure, and make it safe for public access, have recently been carried out by English Heritage. The church was built on weak mudstones of the Cotham Member of the Lilstock Formation, in the Triassic Penarth Group that was formerly known as Rhaetic.

Figure 1. *The surviving remnants of the walls and stonework at St Mary's Church, seen from the west, on its low hill northwest of the village of Colston Bassett.*

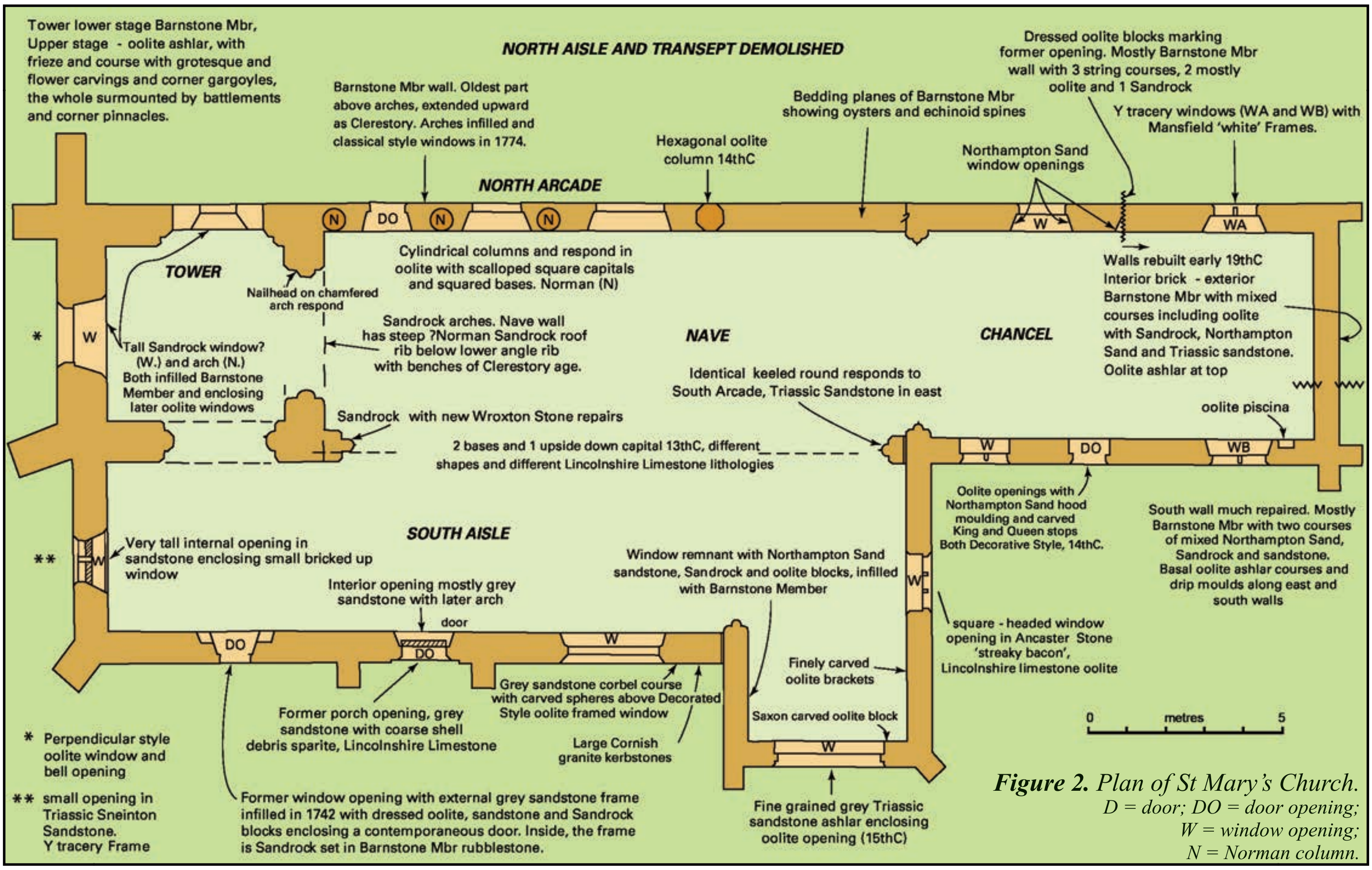


Figure 2. *Plan of St Mary's Church. D = door; DO = door opening; W = window opening; N = Norman column.*

Building stone lithologies

Colston Bassett lies within a region of gently dipping sedimentary rocks ranging in age from Permian to Jurassic. Building stone acquired locally was the cheapest, as transport was difficult and hence expensive. Medieval churches tend to be built of one or two local stones, and the distribution of such churches is closely related to the outcrop of the dominant source rock. However the 15th century was an affluent period, and Perpendicular buildings of this time show a massive increase in the use of freestone brought in from non-local sites.

Building stones can be divided into freestones and rubblestones. Freestone is a rock that can be freely worked with a chisel; it can be cut in all directions, but is best laid with the original bedding horizontal. When precisely cut with squared faces it can be laid in regular courses; this style, known as ashlar, reached its peak in the Classical period and used minimal amounts of mortar. In earlier times, using stone of poorer quality, the blocks may have been only face-dressed and had varying vertical dimensions. Rubblestone comprises roughly cut stones with even faces, the thickness of the finished stone often reflecting the original bed thickness of the sedimentary rock.

All the building stones in St Mary's Church are of sedimentary origin. They occur at ten different stratigraphical horizons (see table on right), and are described in order of decreasing geological age.

	GROUP	Formation	Member	nearest source
JURASSIC	INFERIOR OOLITE GROUP	Lincolnshire Limestone		Lincoln, Ancaster, Stamford, Waltham on the Wold, Ketton
		Grantham		-
		Northampton Sand		Oakham - Corby
	LIAS GROUP	Whitby Mudstone		-
		Marlstone		-
		Dyrham Silt	Sandrock	Local; Ab Kettleby, Holwell, Branston, etc.
		Charmouth Mudstone		-
		Scunthorpe Mudstone	Barnstone	Local; Cropwell Bishop Langar; Barnstone, etc.
TRIASSIC	PENARTH GROUP	Lilstock	Langport Cotham	-
		Westbury		-
	MERCIA MUDSTONE GROUP	Blue Anchor		-
		Cropwell Bishop		-
		Edwalton		-
		Gunthorpe		-
		Ratcliffe		-
		Sneinton		Sneinton, Gedling, Lowdham, etc.
	SHERWOOD SANDSTONE GROUP	Bromsgrove Sandstone		Castle Donnington, Repton Kingsmill, etc.
		Nottingham Castle Sandstone		-
-?-		Lenton Sandstone		-
PERMIAN		Brotherton		-
		Edwalton		-
		Cadeby		Bulwell, Linby, Mansfield area
		Permian Basal Breccia		-

Millstone Grit

Course-grained, medium to pale grey sandstone. The nearest quarries are Melbourne and north of Derby, and only small quantities were used in the church.

Cadeby Formation

Formerly known as the Lower Magnesium Limestone, of Permian Age. Two distinct types are recognised, Bulwell Stone and Mansfield Stone. The former is represented by a single stone in the southwest diagonal buttress of the South Aisle; it can more easily be examined as the large gravestone against the wall beside the nearby South Doorway. This buff coloured dolomite has a saccharoidal texture with small rhombic dolomite crystals. The rock was originally deposited as limestone at the hot arid margin of the Permian sea. Subsequently, magnesium-rich groundwaters replaced the calcite ($CaCO_3$) with dolomite ($CaMg(CO_3)_2$); the latter has a smaller volume, and so developed idiomorphic rhombic crystals, faces of which reflect the light and so can be seen easily with a hand lens.

Another broken gravestone occurs on the floor of the South Transept. The pale brown, fine, micaceous dolomitic sandstone used in the Y tracery windows in the Chancel is thought to be Mansfield Stone. The characteristic thin green clay wisps can be traced in the vertical mullions. These surfaces were probably bedding plane partings, but their present slightly uneven character may result from stylolitic recrystallisation. The windows although characteristic of the start of the Decorative Period (c1300) are thought to have been inserted during the early 19th century rebuilding.

Triassic sandstones

Two freestones are present. One is slightly harder, pale grey with a darker surface weathering; this occurs as hood moulds and scattered blocks. Its source is uncertain, but it may have been obtained from the Bromsgrove Sandstone Formation in the Castle Donnington area. The second lithology is a slightly greenish-tinted grey sandstone, some with pink patches and in one case a pale red clay parting. This is derived from the Sneinton Formation, at the base of the Mercia Mudstone Group. It resembles the building stone of churches north of the Trent, such as Lowdham and Lambley, but lacks the reddish tinge and deformation structures typical of that area. Some specimens show the characteristic small spherical concretions ('pimples') and others small surface depressions.

Barnstone Member

This is the basal member of the Scunthorpe Formation at the base of the Lias Group. The traditional name Blue Lias (blue layers) aptly describes its characteristic alternation of limestone and mudstone, and is retained here to describe the building stone. In boreholes some limestones have clearly defined boundaries, but others pass into calcareous mudstones. The limestones yield rubblestone, which is the dominant building stone of the church. Bed thickness varies, mostly under 10 cm.

Figure 3. *Southeast corner of the Chancel with Blue Lias rubblestone enclosing a piscina carved from a block of oolite adjacent to a C19th window.*

The colour of exposed surfaces varies from pale grey to dark grey, depending on the lime content; these are surfaces created by wedge and hammer fracturing of larger slabs. Natural joint surfaces are often tinted pale brown by weathering, with oxidation of the finely disseminated pyrite that gives the original grey colour. Rarely, blocks have been fractured along ultra-thin calcite-pyrite veins and produce darker brown colours. The structureless dark stones have a high clay content and are more susceptible to weathering by surface exfoliation, thereby revealing fresh rock.

In contrast, the harder limestones contain an abundance of calcareous laminae; these weather to shallow ridge and extremely shallow wedge structures with rare erosional surfaces. The laminae are generally only millimetres in thickness. They probably represented current-sorted isolated ripple and sheet accumulations of microscopic shell detritus and possibly immature shells. The bedding planes sometimes contain *Liostrea* valves and very thin echinoid spines (<0.5 mm in diameter and up to 12 mm long) with lengthwise ridge ornamentations. Other bivalve shells can be seen in cross-section.

The Barnstone Member rests concordantly on the Triassic sediments. It was probably deposited at shallow depths in an anoxic marine environment. The early Jurrasic sea transgressed across a featureless coastal plain that provided only fine-grained detrital sediments. The laterally persistent alternation of calcareous mudstone and laminated limestones suggests a moderately shallow environment alternating from quiet water to periods of winnowing current activity. The Barnstone Member crops out within several hundred metres of the church. Differences in stone thickness and colour allow one to distinguish the different stages of building.

Figure 4. *Southwest door of the South Aisle, with its contrasting exterior and interior designs.*

Sandrock

Along with the overlying ironstone, the Sandrock was formerly included in the Marlstone Rock Bed (now Marlstone Formation), but is now included as a bed at the top of the Dyrham Silt Formation. It is an ochreous, limonitic, fine-grained sandstone freestone. Unoxidised, it is a slightly greenish grey sandy limestone with siderite (iron carbonate) and berthierine (chamosite, iron silicate), but surface weathering oxidises the iron minerals to limonite and goethite (hydrated ferric oxides) and leaches the calcite. Thick shelled brachiopods (terebratulids and rhynchonellids), belemnites and bivalves are scattered throughout. Small burrows are marked by paler cylindrical tubes 2.5 mm in diameter, and bioturbation has generally destroyed original bedding structures. The base of the Sandrock is commonly marked by an erosion surface, which is locally overlain by a pebbly sandstone. The Sandrock accumulated in a shallow marine environment under reducing conditions. It forms the distant escarpment, that limits the Vale of Belvoir to the southeast, where there are numerous quarries around Holwell and Ab Kettleby, but it has not been worked for at least a century.

Northampton Sand

This freestone is a dull purplish brown, leached and oxidised, calcareous and ferruginous sandstone. Reddish brown specimens with dark berthierine (chamosite) grains, are more fossiliferous with coarser shell debris than in the Sandrock. The lack of bedding may indicate intense bioturbation, and reddish brown cylinders up to 9 mm in diameter, are probably parts of U-shaped burrows. The fauna includes bivalves with corrugated shells, oysters and rhynchonellids. Thick fawn calcareous tubes with upstanding longitudinal ridges and growth crenulations are serpulid worms; these may be confused with large pentacrinoid ossicles. Small round crinoid ossicles are more common; these calcite plates show a distinct pentagonal symmetry marked by small voids. Small dumbbell-like features are infilled with coarse clear calcite; one specimen, with an ovoid micrite-filled trace enclosing one end of the dumbbell could be an ammonite.

The Northampton Sand accumulated in a shallow marine environment similar to that of the Sandrock. This freestone is far travelled, as the nearest outcrop and quarries are in the Rockingham and Corby area, and east and south of Oakham.

Lincolnshire Limestone

This Middle Jurassic Formation comprises a variety of pale cream to buff, oolitic, pelletal and shell-debris limestones. It can be difficult to distinguish between concentric oolith grains and structureless micrite pellets. The bed yields a variety of excellent freestones, all of which have a sparry calcite cement. These are usually well-sorted with rounded shell debris and are often cross-bedded. They accumulated in a relatively warm, high-energy, shallow-water marine environment. The formation also contains matrix-supported grainstones, but these are unsuitable for building stone, as the calcareous mud (micrite) matrix readily absorbs moisture causing the rock to fracture under frost action.

The nearest source is the outlier at Waltham on the Wolds. Major quarries lie along the main outcrop from Lincoln to east of Grantham and Oakham and thence south of Rockingham. The stone has been used in the

Figure 5. *The Northern Aspect of the Nave and Tower.*

church possibly since Saxon times. It is impossible to match these ancient building stones to specific quarries that have been long abandoned. They form excellent freestones and have been used as columns, capitals, dressed stone, monuments, statuary, carved features, gargoyles and window frames. A characteristic type, seen in the post-17th century structures, comprises alternations of pale cream, well-cemented oolite, and slightly darker, less well-cemented, more porous oolite. This 'streaky-bacon' texture is thought to be typical of Ancaster Stone. Limestones rich in shell debris are harder and more resistant to weathering, and were used for dripstone courses, hood moulds and sills. Despite its high cost, the quality and durability of this stone has led to its extensive use throughout the history of the church.

Tour of the Church

North Elevation

This comprises the Chancel (left), Nave and Tower. The dominant stone is Blue Lias. Variations in thickness of the rubblestone, the colour and rock types help distinguish stages of construction and repair. The remaining Nave wall contains traces of three pointed arches; the eastern arch is taller and may be slightly later in age. This was the North Arcade until the associated North Aisle and North Transept were removed in 1774. The arches were infilled with Blue Lias, which enclosed Classical (Georgian) style windows with alternating long and short blocks of Lincolnshire Limestone. These show bands of well-cemented and darker poorly cemented oolite, a texture typical of Ancaster Stone. The present North Door opening is framed with grey Triassic sandstone and oolite. It is much older (C 14th) than the wall and was probably transferred from the North Aisle in 1744.

This aspect shows that the Tower was built in two stages; the lower part was constructed about 1350 using Blue Lias, but was heightened in the early 1400s. There was an almost round-headed Sandrock arch in the north wall. Originally the North Aisle continued in front of the Tower, and this arch was also infilled in 1744. A string of Sandrock lies above the inserted window and there is an oolite rib higher up; both may relate to ancient roof lines visible on the east wall of the Tower. The Sandrock and oolite quoin above the lower string belongs to the oldest part of the Tower. The higher rib is related to the raising of the North Arcade wall, to create a Clerestory, with its Perpendicular style window.

Before entering the Nave through the North Door, note the misalignment of the Nave and Chancel wall. The slight northward inclination of the Chancel is thought by some to reflect the tilt of Christ's head on the Cross, as depicted in many paintings.

The Nave

Internally, the north wall reveals three round columns that rest on square bases and support square capitals with deeply carved flutes (Figs. 7 and 8). These are typical

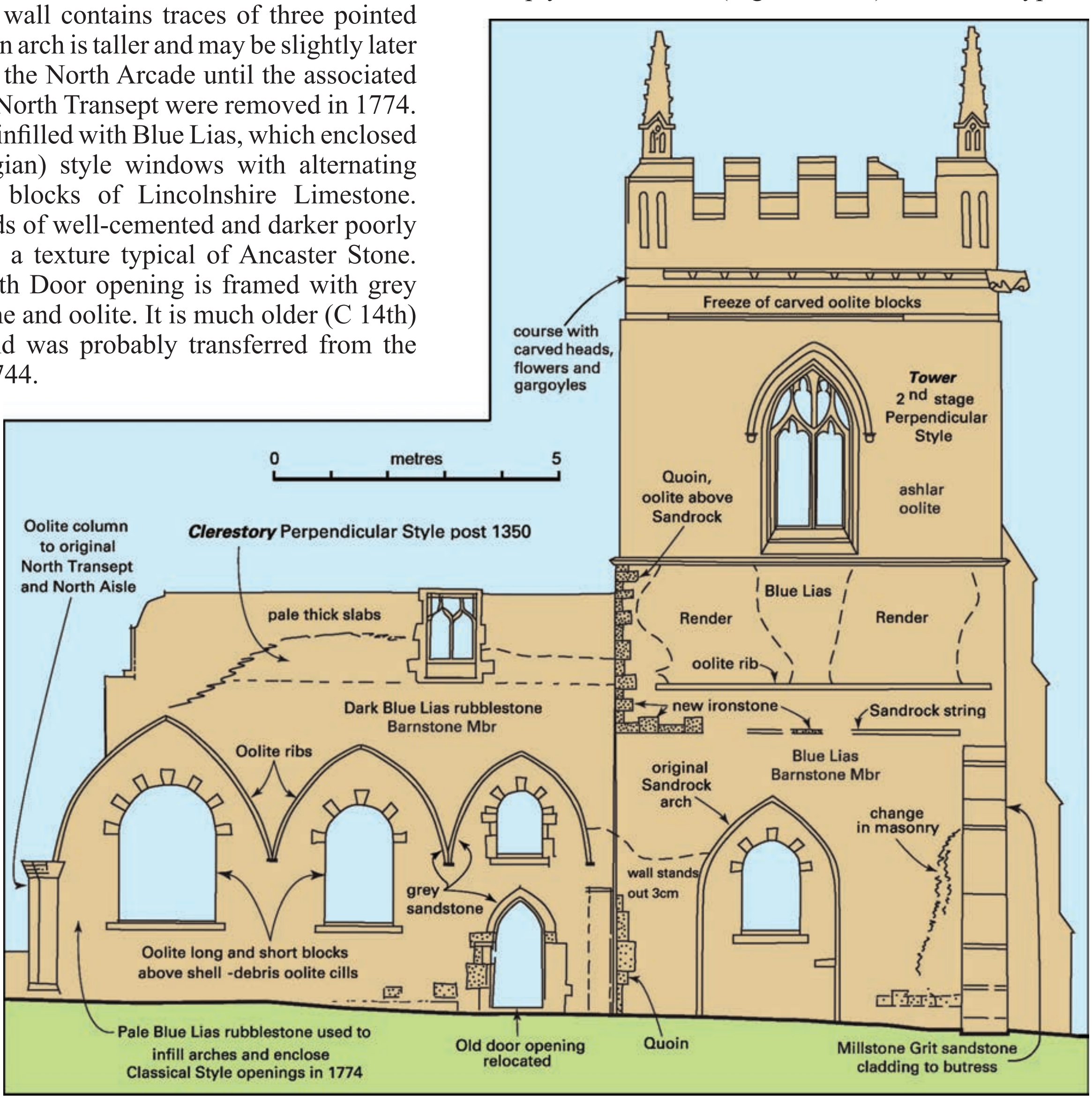
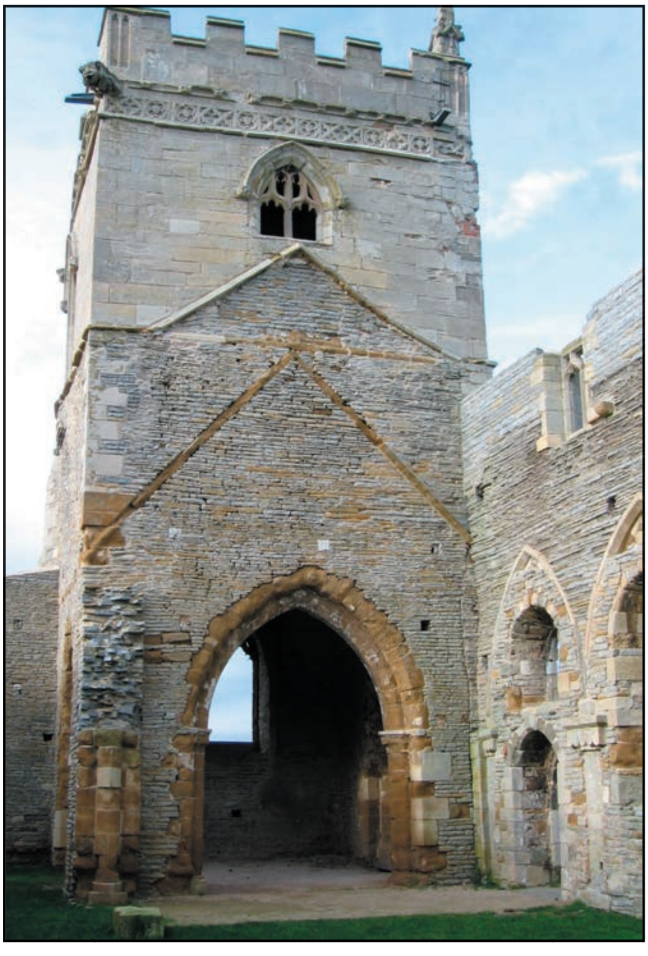


***Figure 6**. North aspect of Tower and infilled North Arcade, now the wall of the Nave. The apex of the arch within the Tower is more rounded than on those of the younger arcade.*

Figure 7. *North Arcade Nave Wall. The two and a half rounded columns with scalloped capitals, all Lincolnshire Limestone, are typically Norman. Subsequently the North Isle was raised with the insertion of ribbed pointed arches mostly oolite with some sandstone. The first two are set below the ironstone roof rib of the tower, but the third is taller and wider. Georgian style windows were inserted when the arcade became the Nave Wall.*

Figure 9. *East Face of Tower with five faceted arch built of Sandrock (Early English style, C 13). The two ribs relate to original roof lines. The lower Sandrock rib ends just above the North Aisle Arches. The higher hipped rib consists of Lincolnshire Limestone and marks the building of the Clerestory and reconstruction of the Tower in the Perpendicular style (C 14).*



of Norman style (c1130), and are made of Lincolnshire Limestone oolite. The fourth, most easterly, column is octagonal (C 13th-14th), also of oolite, as are the pointed and chamfered arches above. The east face of the tower shows evidence of two roof structures (Fig. 9). The lower, Sandrock roof rib is steeply inclined suggesting an older reed or thatched roof; it intersects the Nave wall just above the points of the first and second arches but below the taller third arch. One can conjecture that the round pillars once carried typical semicircular Norman arches, which were subsequently replaced by the present arches. The higher oolite roof rib is less steeply inclined, with shoulders, and is clearly related to construction of the Clerestory.

The Tower

The lower part of the tower's inner walls are built of Blue Lias. Originally there were three arches and associated responds (half column supports), all chamfered (five-sided) and built of Sandrock. The capital above the northeast respond has a band of nailhead (small pyramid) decoration (Fig. 10) that is typical of Early English style (mid C 13th). The others are similar in shape, but undecorated. The capital of the southeast arch respond has a slightly different moulding and a thin oolite plate at the top. The north arch was infilled with Blue Lias, with a Classical style window inserted in 1774. Internally, the original opening on the west wall is very high, almost round-headed and built of Sandrock. This was probably a window, but the insertion of a smaller early Perpendicular window with oolite frame enclosed in Blue Lias destroyed the evidence.

Figure 8. *Scalloped Norman capital and rounded column.*

***Figure 10**. Nailhead decoration on the capitals of a column supporting the Tower's arches, with traces of old whitewash.*

Externally the two-stage construction is clearly visible (Figs. 6 and 11). The Blue Lias of the lower stage shows outward bulging; there are remaining traces of render applied to improve the appearance. The upper stage is built with Lincolnshire Limestone ashlar blocks, with bell openings in Perpendicular style (Fig. 12). There is a frieze course of decoratively carved compound blocks, each with a central shield enclosed within four intersecting circles and diagonal crosses with ogee protrusions, the whole enclosed in an upstanding rim. It is succeeded by a course of ashlar and then a corbel table, a protrusion with superbly carved heads and flowers, and monster-headed gargoyles at the corners (Fig. 13). This is succeeded by an embattled parapet with twin tall niches (with ogee mouldings at the top) at the corners of the tower. The final embellishment comprises four crocketed (leaf knob decoration) pinnacles each with a basal square column and additional twin niches. This extravaganza bears witness to the superb quality of Lincolnshire Limestone freestones, the ability of the Medieval masons, the affluence of the parish in the late 14th and early 15th centuries, and the durability of this freestone.

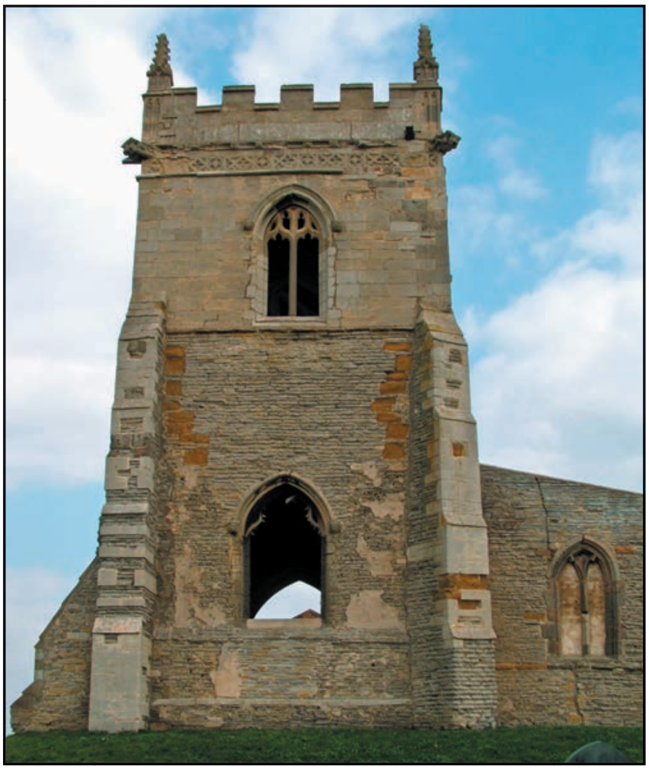


***Figure 12.** West aspect of the Tower. The Blue Lias rubblestone contrasts with the oolite ashlar of the upper stage of the Tower. The windows illustrate three architectural styles: the oldest, in the South Aisle, is Early English; the preserved Tracery of the lower window of the Tower suggests Decorative style (both windows are enclosed internally within older larger Sandrock frames); the flamboyant architecture of the upper stage is typically Perpendicular.*

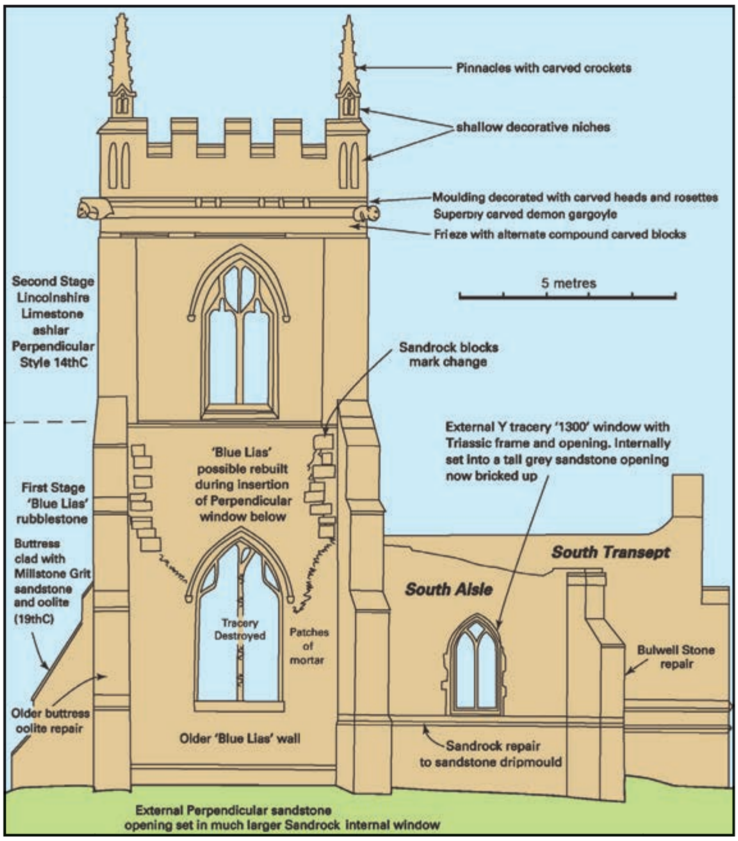


***Figure 11.** The Western Aspect.*

***Figure 13.** Gargoyle at SW corner of Tower, set above a carved frieze, both in Lincolnshire Limestone.*

Three buttresses support the west end of the tower. The two angle (perpendicular) buttresses at the north end are probably 14th century, and the lower buttress has a later cladding of Millstone Grit sandstone. At the other end, the 15th century buttress and the proximal buttress of the south aisle have been extensively repaired with oolite, sandstone and Sandrock.

South Aisle

This extends across the south face of the tower and consists of Blue Lias rubblestone. The west window has the Y tracery typical of the early Decorative Style (c1300). It is built of Sneinton sandstone that is grey with pale red patches; this rock is fine-grained, has small weathering pits, is cross-bedded and shows compactional distortion. Although the head of the window is pointed, the matching internal opening is larger and more round-headed and comprises chamfered grey sandstone blocks, with two Sandrock ends and one oolite replacement. It is infilled with mixed stones above an arch of bricks similar to those used in the Chancel (early C 19).

A similar tall opening occurs opposite the tower on the internal south wall (Fig. 4). It has a grey sandstone arch above a Sandrock frame, including two oolite and one sandstone replacement blocks. Externally it has a pointed arch which almost reaches to the top of the wall. The frame is grey Triassic sandstone. Possibly originally a window, it was replaced by a small door of Classical style, the infill comprising salvaged blocks of oolite, Triassic sandstone and Sandrock.

The original South Door to the east was enclosed by a porch, the remnants of which have been used as buttresses (Fig. 14). Externally it has a pointed arch with a hoodmould and chamfered frame, composed mostly of Triassic sandstone at the top and oolite below. On the right side, there is a block of coarse shell-debris-pellet spar-cemented limestone. Internally the door has an almost rounded arch (now fractured) composed of grey Triassic sandstone blocks with oolite and Sandrock below. This encloses a smaller pointed arch set above a wooden beam with a door below.

To the east there is a large square-headed window with an original sandstone frame, replaced at the top by oolite, and remnants of Decorated style tracery. Above the window, a corbel of mostly red-tinted grey Triassic sandstone, has badly weathered carved 'spheres' (ballflowers) overlain by a sandstone plinth. A similar sandstone dripstone lies in the lower part of the wall.

South Arcade

Return inside the church where traces of the South Arcade remain. Only the responds, the half columns that supported the outermost arches, remain intact. The west respond against the Tower is cylindrical with a narrow keel (protrusion) and is mostly made of Sandrock. This has weathered badly in the 112 years since the roof was removed, and the conservators replaced several blocks with Marlstone Formation ferruginous limestone from the Banbury district. The respond against the Chancel and South Transept wall is identical in shape, but has a Triassic Sneinton sandstone column with oolite capital and base. All that remains of the arcade are two column pedestals and an inverted capital, all lying on the ground; they comprise three different Lincolnshire Limestone lithologies. Their complex shapes suggest Decorative Style and confirm the 14th century age of the South Aisle. Carved slots on the Chancel respond and the nearest plinth indicate the former existence of a wooden screen.

South Transept

The internal walls are of Blue Lias. The southern end of the west wall contains the trace of a window infilled with Blue Lias rubblestone. The window has a pointed arch consisting of two thin slabs of Triassic sandstone. Only the right upright remains and comprises Northampton Sand, Sandrock and oolite blocks above a Sandrock sill. This must have been sealed off prior to the insertion of the adjacent south window (Perpendicular style, c1370-1530). The small piscina beneath the infilled window has been reconstructed to include an oolite block with Saxon carved-knot tracery, which was discovered in a wall during the conservation (Figure 15). This is the oldest stone in the church. In contrast the back of the

Figure 14. *Part of the South Aisle with original porch door.*

piscina comprises a slab of grey sandstone beneath a piece of Swithland Slate, possibly a fragment of an abandoned gravestone.

The east wall has two delicately carved pale grey oolite brackets; sadly they have been defaced, possibly during the Reformation. It also contains a square headed window with oolite frame, probably early Perpendicular Style (c1360-80).

Figure 15. Reconstructed piscina with Saxon carving.

Externally the walls are almost entirely of Blue Lias. The east wall has a high level string course of Triassic sandstone with two isolated blocks of Northampton Sand. A drip course of grey sandstone extends around the transept, except at the northern end of the west wall where it is replaced by oolite. The huge south window has an oolite frame and is set in a mixed ashlar wall, mostly oolite with some blocks of sandstone, Sandrock and Blue Lias. The insertion of the window destabilised the adjacent walls, which now lean outwards. The diagonal southeast buttress is built of Blue Lias below the drip course and then ashlar oolite and Sneinton sandstone above. The adjacent east wall for 50 cm comprises mixed stones suggesting rebuilding. In contrast, the south western buttress is perpendicular to the wall; it consists of Blue Lias below the drip course, a course of shell-debris oolite with coarse crystalline cement, then oolite succeeded upward by Triassic sandstone, then an oolite quoin. The masonry is contiguous with the adjacent wall suggesting that it was contemporaneous with the insertion of the window.

The Chancel

This was the most unstable part of the church, so two steel tie bars restrain the north and south walls. Externally the south wall is mostly Blue Lias but contains two string courses with diverse blocks (Fig. 16). The lower string is Northampton Sand sandstone with several Sandrock and two grey sandstone blocks. The upper also starts at the eastern window but dies out at a possible repair joint before the west window; it includes Sandrock and a new block of Banbury Marlstone Formation. The western window is unweathered oolite in the Decorative style, with a hood mould terminating in uncarved cubic blocks. It is enclosed in Blue Lias except for the blocks of Northampton Sand. The south

Figure 16. The south wall of Chancel with its repeated repairs.

Figure 17. The east wall, rebuilt without a window.

(priest's) door is typical Decorative style, with multiple roll mouldings built with shell debris oolite except for the stops; these are extremely weathered Northampton Sand, but the original king and queen heads can still be recognised. There is a roughly vertical join in the wall masonry between the door and eastern window on this south wall. The area enclosing this window appears to be an original wall of Blue Lias. Repaired areas with dressed stone courses occur above the window and also west of the vertical join. The second window has early Decorated Y tracery, and the mullions are fine-grained, thinly bedded dolomitic sandstone, Mansfield Stone. Although the style dates from c1300, this and the identical window on the north wall are early 19th century. The wall has two drip courses separated by two ashlar courses, the upper of oolite and Sandrock.

The two drip courses continue on the external east wall, but the intermediate ashlar courses are oolite (Fig. 17). Surprisingly, the church lacks an east window. The southern masonry is almost entirely of Blue Lias. North of an irregular join, the wall above the drip course is Blue Lias, with three decorative strings made in a random selection of dressed oolite, Northampton Sand, Sandrock and Triassic sandstone. Three courses of mostly oolite occur above the buttresses. The triangular gable is of oolite with a few Sandrock blocks, and its basal course contains a rounded columnar block of oolite. The greater part of this wall has been rebuilt.

Externally the north wall is mostly Blue Lias. It can be divided into two parts by a line of vertical blocks, which may be the trace of a window opening; this coincides with the blocked off window seen on the internal wall. To the east, the wall contains three courses, the lower mostly of oolitic, with Sandrock dominant above; it was rebuilt in the 19th century. It includes a second contemporary Y tracery window. The westerly window has been partly destroyed; its opening is defined by shaped blocks of purplish Northampton Sand, shelly calcareous ferruginous bioturbated sandstone. Internally, only the left side and part of the arch of the blocked off window survive; the blocks are five of Northampton Sand, two of Sandrock, two of oolite and one of grey sandstone. An early 19th century brick wall extends from this window frame to the recently infilled, 10 cm gap in the east wall (Fig. 3). And from there, the internal wall is built of Blue Lias.

Acknowledgements

Credit is primarily due to the parishioners of Colston Bassett who set up a committee to raise funds to preserve the ruin. The late John Severn FRIBA, Emma and John Alcock and many others raised £32,000. The remaining £393,000 represented grants from English Heritage, Heritage Lottery Fund, The Pigrims Trust, WREN, The Jonathan Vickers Trust, The Chetwode Foundation, The Frognall Trust and both the Nottingham County Council and Rushcliffe Borough Council. The local committee prepared an undated pamphlet, and there is an excellent unpublished report 'Structural Interpretation and Archaeological Assessment, St Mary's Church, Colston Bassett', dated 1995 by Peter F Ryder of Broomhaugh, Northumberland. I thank the architects, The Howitt Partnership, Nottingham, for permission to use their drawings, and Jane Smalley for preparing the diagrams. Photographs are by John Barnett and the author.

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William W. Watts, pioneer Midlands geologist

Helen Boynton and Trevor Ford

Abstract: W. W. Watts lived from 1860 to 1947, during which time he was a leader in geological thinking and played many roles in the early development of the geological sciences. He is best known for his geological mapping and interpretation of the ancient rocks of Charnwood Forest. This biography is presented as a review of his life as a geologist closely associated with Charnwood Forest, as featured in his book *Geology of the Ancient Rocks of Charnwood Forest, Leicestershire*, which was posthumously published in late 1947.

William Whitehead Watts was born at Broseley, Shropshire, on 7th June 1860; thus 2010 is the 150th anniversary of his birth. He died on 30th July 1947.

Watts' father was a music master and his mother (née Whitehead) was a farmer's daughter. Watts' education started at Bitterley School, near Ludlow, from 1869-1870 and was continued at Shifnal Grammar School 1871-3, before he went to Denstone College, near Uttoxeter, Staffordshire; this had only just opened as one of the Woodard Schools, with a leaning towards science and mathematics. As a bright scholar, he gained an Exhibition worth £40 to Sidney Sussex College, Cambridge, where he studied Chemistry under J.F.Walker, who persuaded him to take up geology as part of the Science Tripos. Watts soon made geology his main subject and in due course he gained a First Class Honours degree. While at Cambridge, Watts was active in the formation of the students' society known as the Sedgwick Club.

After graduation Watts gained valuable experience as an Extension Course Lecturer for the many adult education classes put on by Cambridge University throughout the Midlands. He taught courses in geology, physical geography and archaeology in no less than 36 towns from 1881 onwards, i.e. from the age of 21. Somehow he fitted in the post of part-time science master at Denstone College, Uttoxeter. He also took on the duties of deputy professor at Yorkshire College, Leeds, (later the University of Leeds) and taught at Mason College, Birmingham (later the University of Birmingham), covering for Professor Lapworth during his illness. He taught one-term courses at both Oxford and Cambridge Universities and gave two highly popular courses in Leicester. During this busy period he continued mapping the geology of his native Shropshire, where he had already found the graptolite *Dictyonema* (now *Rhabdopleura*) *flabelliforme*, so confirming the presence of late Cambrian strata (Tremadocian, now regarded as early Ordovician).

From 1891 onwards, Watts became involved with several leading geological institutions. Firstly, he was petrographer to the Geological Survey when they were mapping in Ireland; later he had the equivalent post at the Geological Survey's London headquarters. He then returned to academic life as assistant to Professor Charles Lapworth at Birmingham University from 1897 to 1906. Lapworth was Professor of Geology and Physiography (broadly equivalent to geomorphology today). Lapworth and Watts jointly contributed much to knowledge of the geology of the Midlands, particularly Shropshire. In 1906 Watts succeeded J.W.Judd as Professor in the Royal College of Science and Royal School of Mines (later Imperial College, part of the University of London), where he remained until his retirement in 1931, being instrumental in developing the College's courses in mining, petroleum and engineering geology, with specialist assistants in each of those fields. During World War I, Watts was an adviser to several Government Departments, ranging from Munitions and Aeronautics to Water Supplies. He reported on the future of coal-mining, and recognized that concealed reserves lay beneath the Trias between the known coalfields of the Midlands. He noted the possibility of the exhaustion of coal reserves sometime in the future.

At various stages Watts served on the Councils of the Geological Society, Geologists' Association, Mineralogical Society, Royal Geographical Society and the British Association. He was elected President of the Geological Society of London (1912), and later was

W.W.Watts (Photo: BGS archives).

Lapworth (left) and Watts (right) on the Corndon intrusion, Shropshire (Photo: Lapworth Museum, University of Birmingham).

Below: Rothenstein's 1931 portrait of Watts that hangs in Imperial College, London (Photo: Imperial College).

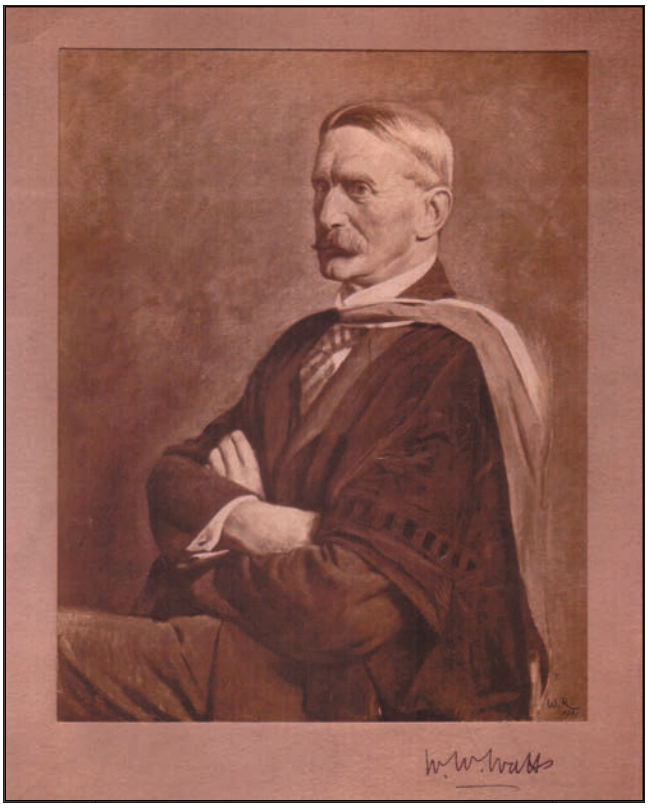
elected a Fellow of the Royal Society. He was awarded the Wollaston Medal by the Geological Society and was twice President of the Geologists' Association (1908-1910 and 1930-32), the Mineralogical Society and Section C (Geology) of the British Association (1903 and 1924). He was particularly keen on promoting the field excursions of the Geologists Association as an essential part of the enjoyment of geology (Sweeting, 1958). Watts received Honorary Degrees and other accolades from several universities. A complimentary dinner was held in his honour by the Geologists Association in 1937. On his retirement the Watts Medal was established for the best graduate student at Imperial College each year, and a portrait of Watts (c.1931) by Sir William Rothenstein still hangs in the College.

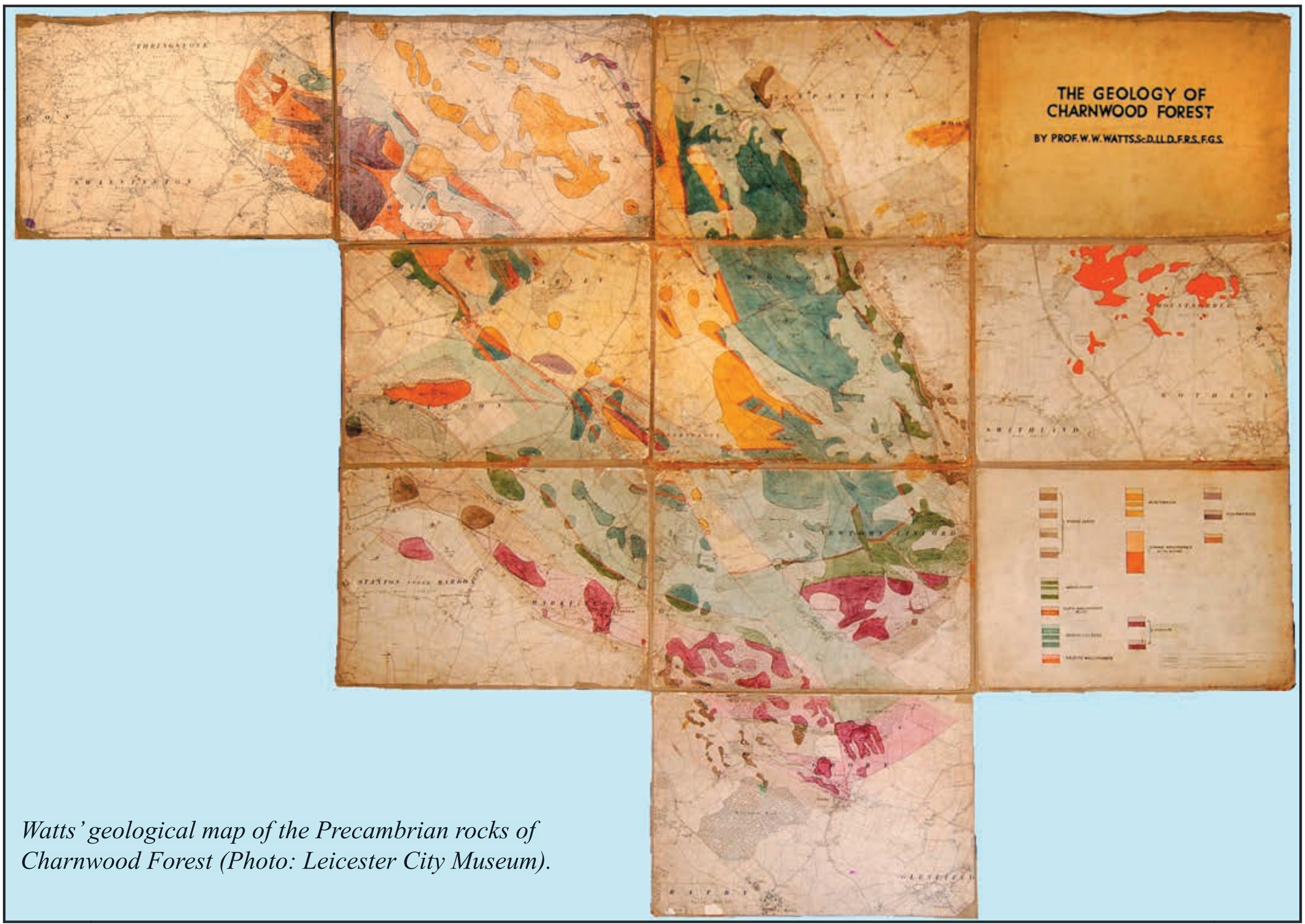
Watts was married twice, first to Louisa Adelaide Aitchison in 1889 but she died in childbirth only two years later. The daughter, Beatrice Mary Adelaide Watts, later married Professor W.G.Fearnsides, who established the Geology Department at Sheffield University (Fearnsides' daughter carried on the geological hierarchy by marrying Professor O.M.B.Bulman of Cambridge University). In 1894 Watts married Rachel Turnour, and their daughter Marjorie Lilian married and later moved to Australia. In his later years, Watts lived at Sutton, Surrey, and commuted to London daily.

Watts' Contribution to Geology

Watts' first original work was on the Breidden Hills near Welshpool, where he mapped the largely shaly succession and found *Trinucleus concentricus* in Caradocian strata and *Pentamerus oblongus* in the overlying Silurian, thereby demonstrating that there was a hiatus between the Ordovician and Silurian. He also studied the graptolites and was able to determine the distinctive faunas of the Wenlock and Lower Ludlow Series. While Watts was at Birmingham he learned much from Lapworth, who had solved the controversy of the relationship of Sedgwick's Upper Cambrian and Murchison's Lower Silurian by establishing the Ordovician system as it is known today. Though Lapworth did little research in Charnwood Forest, in 1898 he and Watts introduced the term Charnian for the ancient rocks there. Lapworth was also much involved in the recognition of the thrust structures in the Northwest Highlands of Scotland and this may have influenced Watts' early interpretation of the structure of Charnwood Forest as having overfolds and thrusts along its flanks.

In the late 1890s, as petrographer to the Geological Survey, Watts worked on the deformed Ordovician rocks of the Isle of Man when the island was being surveyed by G.W.Lamplugh (1897-1903). Watts supported Lamplugh's concept that the so-called "crush-conglomerates" were the effects of considerable tectonic deformation, though modern research has indicated that they are the results of submarine slumping on a large scale, with later cleavage superimposed.





Watts' geological map of the Precambrian rocks of Charnwood Forest (Photo: Leicester City Museum).

Charnwood Forest

Watts' best known contribution to geology was his mapping of Charnwood Forest which he began in 1896. The original of his 6 inches to 1 mile map is in Leicester Museum and copies are lodged in the British Geological Survey's archives and in the Geology Department of Leicester University. His work was incorporated into Fox-Strangways' maps and memoirs for the Leicester area (Fox-Strangways, 1900, 1903 and 1905). As early as 1896 Watts published an outline account of Charnwood Forest and drew attention to the weathered surfaces of the pre-Triassic rocks. Though Watts published further short accounts of the Charnian in 1907 and 1910, he did not complete his Charnwood book until long after retirement and it was published posthumously in 1947. In these publications he linked together the stratigraphy of the isolated outcrops to construct a map which depicted both the outcrops and inferred sub-Triassic subcrops. Together they make up the striking scenery of Charnwood Forest (see Ambrose *et al*., 2007). Watts found that there were no reliable fossils to help correlation, though his 1947 book recorded a few "worm burrows" which F.W.Bennett had found in Deer Barn Spinney in Bradgate Park. Watts failed to notice the abundant worm burrows in the Swithland Slate, best seen in tombstones in Leicestershire churchyards, and later identified as the trace fossil *Teichichnus* (Bland & Goldring, 1995; McIlroy *et al*., 1998) which has indicated that this slate, the highest unit of the Charnian succession, could now be regarded as of early Cambrian age.

In a review of the Leicester Literary & Philosophical Society's Geology Section activities, published posthumously in 1935, Dr F.W.Bennett paid particular tribute to Watts' inspiration: "his delightful descriptions clothed the story of Charnwood Forest with a garb of romance and made this small area a source of never-failing delight". Watts led numerous excursions into Charnwood Forest, particularly for that Society's Geology Section.

Watts was rather dismissive of the ring-shaped trace fossils in the North Quarry of Charnwood Golf Course, now known to be important components of the late Precambrian (Ediacaran) fossil assemblage (Boynton & Ford, 1995). Apparently he never saw the frond-shaped fossils though they were exposed in the same quarry.

Following encouragement from his colleague Lapworth, Watts established the succession of three series, namely the Blackbrook (hornstones and grits), Maplewell (agglomerates, tuffs, grits and hornstones) and Brand Series (conglomerates, grits, quartzites and slates). (Hornstones were very fine-grained siliceous rocks, occasionally used as hone-stones for sharpening tools). While Watts' stratigraphic sequence has stood the

The "Bomb Rocks" in Charnwood Forest (Photo: BGS).

test of time, it was revised and formalized by Moseley & Ford (1985 & 1989). Further revisions were made by the British Geological Survey (Worssam & Old, 1988; Carney *et al*., 2001, 2002, 2009; Ambrose *et al*., 2007; Carney & Ambrose, 2007). Correlation between the scattered outcrops is complicated by differences in the thickness and the relationships of units on either side of the Forest. On the west, the succession seemed to be less complete as it was interrupted by outcrops of igneous rocks, which Watts determined as lavas, "bomb-rocks", intrusive porphyroids (porphyritic micro-diorites) and "syenites" (actually diorites). However, there has long been some difference of opinion as to which rocks were extrusive lavas and which were intrusive sills (e.g. Bonney, 1915). The "Bomb Rocks" are now thought to be due to abrasive rounding in a volcanic vent, not to explosive eruption. The enigmatic andesite breccia of Bardon Hill is now regarded as having solidified in the shallow subsurface of a volcanic vent (Ambrose et al. 2007).

Regarding the structure of Charnwood Forest, Watts recognized that the Charnian sequence had been folded into an anticline oriented NW-SE and plunging southeast, and that slaty cleavage denoting compression with a similar orientation had been imposed. Later studies revealed that the orientation of the cleavage is variable and not quite parallel to the fold axis. The poor development of this cleavage in the nearby Cambrian rocks of Nuneaton led him to regard the compression as of pre-Cambrian age, though more recent research has argued that the cleavage is Caledonian (i.e. late Silurian) and that the adjacent Cambrian rocks were too shallow to be affected to the same extent.

Watts introduced the term "ripple cleavage" to define the refraction effect as cleavage passed through beds of different grain size a few centimetres thick. In his 1947 book Watts paid tribute to the pioneer work of Hill & Bonney (1877-1880) who had recognized the volcanic origin of what they called "the pre-Carboniferous Rocks of Charnwood Forest" by their petrographic studies; however, they did not deduce a stratigraphic sequence nor did they describe the anticlinal structure. Watts' papers included a diagrammatic section across Charnwood Forest with overfolds on each flank directed towards the centre and carried on low angle reverse faults (thrusts) dipping outwards, though this interpretation is not easy to deduce from his field map. Watts showed these alleged structures in a diagrammatic section in his 1907 review and it was repeated in his 1947 book (p. 96). However, the overfolds are shown by dotted extrapolations above the ground profile, and the thrust faults are not clearly identified on his map. The repetition of outcrops can be explained by normal faulting. The nature of recumbent folds above thrusts was not well understood at the beginning of the 20th century and he may have been influenced by Lapworth's recognition of thrust masses in NW Scotland: however Watts' misconception was an advance in structural geology. He realized that Charnwood Forest is a plunging anticline but apparently continued to believe in his idea of overfolds and thrusts until his death as the diagram was repeated in 1947. Subsequent re-mapping has discarded the concept. The Charnian strata were re-mapped in the 1920s with a few differences from Watts' map (Bennett *et al*., 1928). Charnwood Forest has been mapped again by John Moseley (Moseley & Ford, 1985, 1989), by Carney *et al*. (2001; 2002), by Ambrose *et al*. (2007) by Carney & Ambrose (2007) and by Carney *et al*. (2009). With modifications to fit modern rules of stratigraphic nomenclature Watts' stratigraphic divisions have generally been adopted by later authors.

The Mount Sorrel granite mass is close to the eastern margin of Charnwood Forest and has pre-Triassic erosion features similar to those of Charnwood Forest,

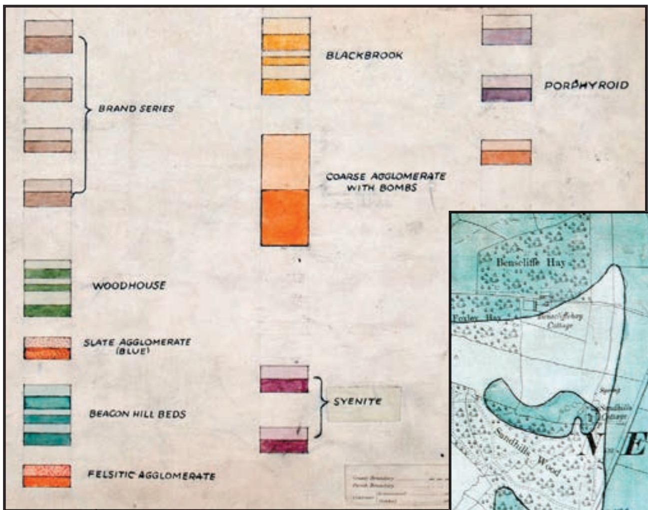
Beacon Hill tuffs exposed high on Charnwood Forest, with Loughborough in the distance (Photo: BGS).

but Watts recognized that it was a separate intrusion and that it was much younger, Watts noted the basic varieties of granite on its western flank. Later described by Lowe (1926), the intrusion is now regarded as of late Ordovician age (Carney *et al*., 2007, 2009). Watts noted that thermally metamorphosed slates along the western shore of Swithland Reservoir were relics of a former sedimentary cover of possible Cambrian age.

Watts and Lapworth introduced the term Charnian System as early as 1898; however the Charnian is now regarded as a local representative of the Ediacaran Period (Knoll *et al*., 2004), within the Neoproterozoic III, the youngest subdivision of Precambrian time. Neither Watts nor subsequent investigators have found any evidence of a pre-Charnian basement. In his 1947 book, Watts discussed possible correlations with various rocks in Wales and the Borders, in particular the Longmynd. However, although absolute dating of rocks by isotopic ratios was available by the 1930s, this method was not applied to the Charnian rocks until long after Watts' death and he made no comment on their absolute age in his book. Several isotope dates for the intrusive rocks, some of uncertain validity, were summarized by Boynton & Ford (1995); later, a series of dates for the volcaniclastic sediments ranging from 559-566 million years was reported by Compston *et al*. (2002) and further dates were discussed by Carney *et al*. (2009).

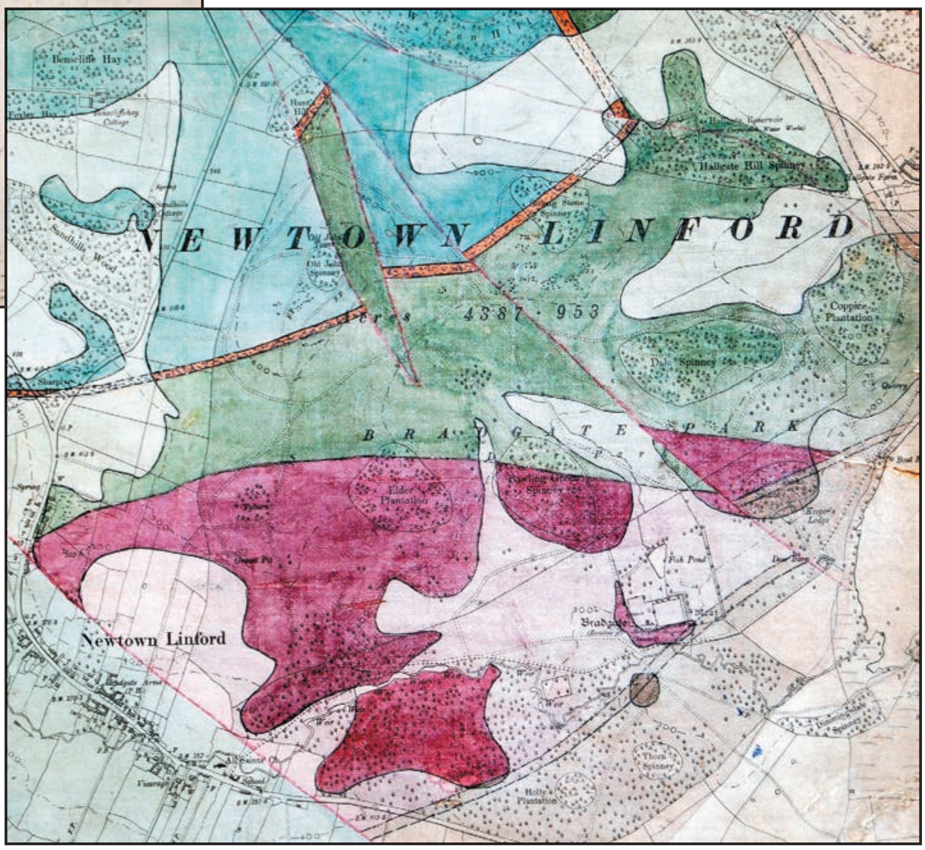
Though Watts did not discuss the probable extension of the Charnian beneath the younger Triassic and Jurassic of the East Midlands, it is likely that he was well aware of the possibility of a buried mountain chain (Pharaoh et al. 1987).

Watts had recognized that the landscape of Charnwood Forest was a group of hills in an ancient Triassic landscape by 1896, and this theme was expanded in detail by Bosworth in 1912 and by Raw in 1934. Watts argued that the landscape had been deeply eroded by Old Red Sandstone times, forming an island or archipelago on the margin of the later Carboniferous basin of the South Pennines, finally buried by Triassic deposits, from which the Charnian rocks were now being exhumed. Watts commented that the area could be compared to the Arizona desert though no record that he ever visited Arizona has been found. Firstly, the rocks were compacted, cleaved, folded and faulted to form mountains. Secondly, there was intense erosion and thirdly came the arid conditions of the Triassic period, when a sequence of thick red mudstones (the Keuper Marl, now known as Mercia Mudstones) lapped up against and finally covered the eroded mountains. The rounded forms of some of the "tors" of ancient rocks buried by Triassic sediments were attributed to desert weathering with sand-blasting. Watts realized that there had once been a cover of marine strata in Jurassic and Cretaceous times, as their escarpments

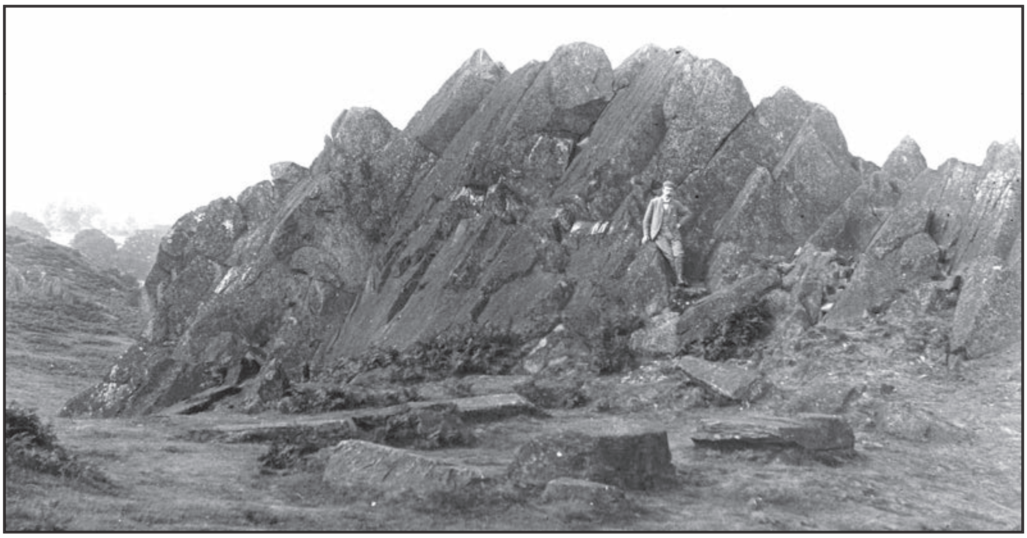


The key to Watts' map of Charnwood Forest.

(Photos: Leicester City Museum)



Detail of the Bradgate Park area on Watts' geological map of Charnwood Forest.



Watts on the Hanging Rocks, which are now within Charnwood Golf Course (Photo: BGS archives).

had only retreated a few kilometres to the east but little could be deduced of the nature of the former cover. The final stage in the evolution of Charnwood Forest scenery was the progressive removal of the Triassic deposits during late Cenozoic and Pleistocene times, the latter being enhanced by glacial scouring in the Ice Age. Watts also noted the radial drainage pattern of the streams in Charnwood Forest, which he regarded as flowing off a domed cover of Trias and gradually being superimposed on to the old rocks, creating the gorge-like features where the streams had been incised into the Charnian rocks. An alternative concept is that the superimposition was from the later Quaternary cover (Bridger, 1978).

Beyond Charnwood Forest

Between his busy life of lectures Watts led many field excursions – in 1909 he took Geologists' Association parties to Paris, Tenby, Frome, Stroud and North Wales. He published around 80 geological papers and his obituarist P.G.H.Boswell provided a list of 77 of these.

Watts conducted many field excursions in Charnwood Forest, the last in 1936, when he was aged 76. He occasionally showed foreign visitors round: one such was Johannes Walther (1860-1937), a German professor well known for his research on both modern and fossil desert weathering processes. Walther pointed out to Watts that the basal Triassic sediments formed infills to buried channels visible as sections cut in several quarries in the Charnian rocks and that these could be compared to the "wadis" of North Africa. Watts took up his idea and was subsequently nicknamed "Wady Watts".

Several contemporary Leicestershire geologists doubtless influenced Watts' geological thinking on Charnwood Forest: these included W.J. Harrison, J.D. Paul, C. Fox-Strangways, M. Browne, F.W. Bennett, E.E. Lowe, F. Jones, H.H. Gregory, and A.K. Coomaraswamy (see Appendix).

Watts enthusiastically took up the use of a motor car to get him to his many engagements and for field work, and he was an early member of the RAC. However, he disliked other modern inventions such as the telephone and refused to have a secretary, typing his own correspondence and reports on an ancient typewriter.

The long obituary of 16 pages prepared by P.G.H.Boswell, one of his colleagues on the Geological Survey and later Professor of Geology at the University of Liverpool, described Watts as an eloquent lecturer and pioneer in geological teaching methods, and as one who took great interest in his students, being proud of the many who made their way into senior positions as Professors or as Directors of Geological Surveys. Watts was staunchly conservative in his political views, and had strong likes and dislikes. His favourite author was Kipling, and he liked parodies and nonsense verse, both sometimes adapted for geological audiences. He was a heavy pipe-smoker throughout his life. He was active to a ripe old age and gave an address at the age of 85 to the Geological Society's first William Smith meeting in 1945 on "The Geological Society; its work and workers", though his research on Charnwood Forest had only a brief mention therein.

Though Watts set the scene for subsequent research in Charnwood Forest, he would have been amazed at the progress made since he died in 1947, especially in the palaeontology of the Ediacaran fossils found there, the assignment of the Swithland Slate to the Lower Cambrian on the basis of the trace fossil *Teichichnus*, in the isotope dating of the rocks and in the discovery of plate tectonics with its relationship of the Charnian to the former continent of Gondwanaland.

Acknowledgements

Thanks are due to Mark Evans of Leicester City Museum, Leicester Literary and Philosophical Society, John Carney and Mike Howe of the British Geological Survey, Roy Clements of the University of Leicester, Sir David Attenborough, Professor Patrick Boylan, Professor Paul Smith and John Clatworthy of the Lapworth Museum of Geology in the University of Birmingham, Anne Barrett of Imperial College and Richard Taylor of Welford Road Cemetery for their help in compiling this review.

Watts' Associates and Collaborators

This list is of geologists who were contemporaries of Watts and with whom he discussed many aspects of his research.

William Jerome **Harrison** (1845-1908) came to Leicester as Chief Curator of Leicester Museum in 1872 before moving to Birmingham in 1880. He was very active in local geology and was also a keen photographer, so he illustrated his book on the Geology of Leicestershire and Rutland, published in 1877, with his own photographs; many of the photographs in the Lapworth archive in Birmingham are thought to be by Jerome Harrison. He was a leading member of several photographic societies and published books and articles on photography. He was especially interested in Pleistocene geology, and recorded exposures no longer available. In 1953 Professor F.W.Shotton named the glacial lake that had covered much of the Midlands Lake Harrison after him.

Charles **Lapworth** (1842-1920) was the first Professor of Geology and Physiography (broadly the same as geomorphology) at Mason College, later the University of Birmingham. He was a pioneer in unravelling the geology of Shropshire, the Southern Uplands and, later, the Northwest Highlands. He was Watts' mentor and collaborator in working out the geology of Shropshire, particularly the area around the Longmynd, and he steered Watts to Charnwood Forest, where he mistakenly tried to interpret some of the structures as overfolds and thrusts. Watts wrote extensive obituaries of Lapworth, whose son Herbert Lapworth was an engineering geologist based at Imperial College.

Thomas George **Bonney** (1833-1923) was professor at University College, London. He and Edwin Hill were both Fellows of St Johns College, Cambridge, and co-operated in petrographical studies of the pre-Carboniferous rocks of Charnwood Forest, so setting the scene for Watts' research.

Harry Edward **Armstrong**, F.R.S. (1848-1937) was a contemporary of Watts as a lecturer in chemistry at Imperial College. He recorded desert weathering on granite blocks at Mount Sorrel.

Thomas Owen **Bosworth** (died 1929) was a local geologist who followed Watts' lead in a study of the relationship of the basal Trias to the Charnian inliers. He later joined the Geological Survey in Scotland, and finally became an oil geologist working in various parts of the world.

Frank **Raw** (c.1875-1961) was a lecturer at Birmingham University in the 1930s, whose research included a re-interpretation of Watts' concept of pre-Triassic weathering of the Charnwood and Mountsorrel rocks.

Percy George Hamnall **Boswell** (1886-1960) was a colleague of Watts at Imperial College. He worked with the Geological Survey in East Anglia before moving to the Chair of Geology at Liverpool University, and wrote an extensive obituary of Watts for the Royal Society.

John D. **Paul** was Honorary Curator of Leicester Museum from 1882 to 1890 and an active member of the Geology Section of the Leicester Literary and Philosophical Society. While he took part in many excursions to Charnwood Forest, his main interest was in the superficial (glacial) deposits of the Soar Valley.

Edwin E. **Lowe** became Director of Leicester Museum in 1907, retiring in 1940. His research was mainly on the Mountsorrel granite intrusion, which gained him a Ph.D., and he was President of the Leicester Literary and Philosophical Society 1922-23.

Hubert Harold **Gregory** (1891-1950, M.A.Oxon.) was born at Foots Cray, Kent. After service with the RNVR in World War I, he served as Assistant Curator of Leicester Museum from 1923 until the late 1940s, with responsibilities for geology. Apart from leading many excursions in Charnwood Forest, he was the organizer of the Museum's Saturday Club for children. One of these children was David Attenborough who attributed his early interest in geology to Gregory and often helped with classifying fossils in the Museum stores. Sir David's father, Frederick L. Attenborough, was Principal of University College, Leicester, where Gregory was a part-time lecturer in Adult Education.

Montagu **Browne** (1839-1903) was Curator of Leicester Museum 1881-1903 and contributed numerous notes on local geology as well as a manual on taxidermy.

Charles E. **Fox-Strangeways** (1844-1910) was a colleague of Watts at the Geological Survey and a lecturer at the Royal School of Mines (Imperial College). He mapped much of the geology of Leicestershire, and incorporated Watts' work on Charnwood Forest into the Geological Survey Memoirs.

Frederick William **Bennett** (died 1930) was a leading Leicester physician with a hobby of geology, particularly that of Charnwood Forest. Bennett warmly thanked Watts for his inspiring guidance, as recorded in his posthumous history of the Geological Section of the Leicester Literary and Philosophical Society in their Anniversary volume of 1935. Together with Lowe, Gregory and Jones, Bennett mapped the Charnian rocks, and their map of 1928 shows some differences from Watts' map.

Francis **Jones** was a Leicester man who became a lecturer at Imperial College. He collaborated with Bennett, Lowe and Gregory in Charnwood Forest in the 1920s, with particular emphasis on the joint pattern in the igneous rocks and on the cleavage. In 1926 he published early accounts of the petrology and structure of Bardon Hill and of the joints and dykes of Groby.

Ananda Kentish **Coomaraswamy** (1877-1947) took many of Watts' photographs. He was a Tamil who studied at Imperial College and met Watts there. He later became Director of the Geological Survey of Ceylon (now Sri Lanka) and finally moved to America.

Left: Professor Charles Lapworth (photo: Lapworth Museum).
Centre: Charles E. Fox-Strangways (photo: Leicester Lit. & Phil. Soc, and Leicester Museum).
Right: Dr. F. W. Bennett (photo: British Geological Survey).

Watts' publications on Charnwood Forest

1895. Notes on some specimens collected in the Trench, Brazil Wood, Charnwood Forest. In J.D.Paul: "Cutting in the Swithland Reservoir". *Transactions of the Leicester Literary & Philosophical Society,* **4**, 12-13.

1896. Notes on the Ancient Rocks of Charnwood Forest. *Geological Magazine,* Decade IV, **3**, 485-487.

1896. Notes on the Ancient Rocks of Charnwood Forest. *Report of the British Association,* 795-797.

1896. (with G.E.Coke & J.W.Carr). Excursion to Nottingham and Leicester. *Proc. Geologists' Association,* **14**, 430-433.

1898. (with C. Lapworth).A Sketch of the Geology of the Birmingham District. *Proceedings of the Geologists' Association,* **15**, 313-428 (Charnwood pp. 323-335 & 417-418).

1898. (with G.J.Binns & C. Fox-Strangways) Notes on some rock specimens from borings at Netherseal. *Transactions of the Federated Institution of Mining Engineers,* **13**, 599-601.

1898-1909. Annual reports to the British Association on photographs of geological interest (the photographs are now archived at the British Geological Survey, Keyworth).

1899. Excursion to Charnwood Forest. *Transactions of the Leicester Literary & Philosophical Society,* **5**, 309.

1899. Notes on the surface of the Mount Sorrel Granite. *Report of the British Association,* 747 (also in *Geological Magazine*, Decade 4, **6**, 508).

1901. Professor Charles Lapworth. *Geological Magazine,* Decade IV, **8**, 289-303.

1901. Excursion to Charnwood Forest. *Transactions of the Leicester Literary & Philosophical Society,* **6**, 514-517.

1902 (with C. Fox-Strangways). Excursion to Charnwood Forest. *Proceedings of the Geologists Association,* **17**, 373-381.

1903. Charnwood Forest: a buried Triassic landscape. *Geographical Journal,* **21**, 623-633.

1907. Geology of Charnwood Forest, pp. 251-275 in *British Association Handbook for Leicester and Neighbourhood.*

1909. The Jubilee of the Geologists Association, *Proceedings of the Geologists Association,* **21**, 119 & 146-7.

1910. The Geology of Charnwood Forest, 770-785 in *Geology in the Field* (Geologists' Association Jubilee Volume).

1910. Fifty Years Work of the Geologists Association. *Proceedings of the Geologists Association,* **21**, 401 et seq.

1916. Pre-Cambrian, Cambrian and Ordovician rocks of Great Britain. *Handbuch Regionalen Geologie,* 27-34, 45-78 & 331-333.

1920. Charles Lapworth. *Nature,* **105**, 110-111.

1926. Thomas George Bonney. *Proceedings of the Royal Society,* **B107**, xvii-xxvii.

1926. Notes sur la geologie de la Forêt de Charnwood, Angleterre. *Livre Jubilaire de la Societé Geologique de Belgique,* 279-286.

1937. (with H.H.Gregory). Report of Field Meeting in Charnwood Forest. *Proceedings of the Geologists' Association,* **48**, 1-12.

1945. Leicestershire Climate in Triassic times. *Geological Magazine,* **82**, 34-36.

1947. *Geology of the Ancient Rocks of Charnwood Forest, Leicestershire.* Leicester Literary & Philosophical Society, 160 pp.

A bibliographic list of 77 Watts' publications on Charnwood, Shropshire etc is in Boswell's Obituary of Watts (1948). An archive of Watts' field notebooks is at Imperial College.

References

Ambrose, K., Carney, J.N., Lott, G.K., Weightman, G.K. & McGrath, A., 2007. *Exploring the landscape of Charnwood Forest and Mountsorrel.* British Geological Survey, Keyworth, 52 pp. (with 1:25000 geological map).

Bennett, F.W., 1935. Section C (Geology) 223-251 in F.B.Lott (ed.) *The Centenary Book of the Leicester Literary & Philosophical Society.*

Bennett, F.W., Lowe, E.E., Gregory, H.H. & Jones, F., 1928. The Geology of Charnwood Forest. *Proceedings of the Geologists' Association,* **39**, 241-298 (excursion report 486-491).

Bland, B. & Goldring, R., 1995. *Teichichnus* Seilacher 1955 and other trace fossils (Cambrian) from the Charnian of Central England. *Neues Jahrbuch Palaontol. Abh.,* **195**(1-3), 5-23.

Bonney, T.G., 1915. The northwest region of Charnwood Forest. *Geological Magazine,* Decade VI, **2**, 545-554.

Boswell P.G.H., 1948. William Whitehead Watts (1860-1947), *Obituary Notices of Fellows of the Royal Society,* **6**(17), 262-279.

Bosworth, T.O., 1912. *The Keuper Marls around Charnwood.* Leicester Literary & Philosophical Society, 129pp.

Boynton, H.E.& Ford, T.D., 1995. Ediacaran fossils of the Precambrian Charnian Supergroup, Charnwood Forest, Leicestershire. *Mercian Geologist,* **13**, 165-182.

Bridger, J.F.D., 1978. The problem of discordant drainage in Charnwood Forest, Leicestershire. *Mercian Geologist,* **8**, 214-223.

Carney, J., Ambrose, K. & Brandon, A., 2001. *Geology of the Country between Loughborough, Burton and Derby.* Memoir of the Geological Survey.

Carney, J., Ambrose, K. & Brandon, A., 2002. *Geology of the Loughborough District.* Explanation of Sheet 141, British Geological Survey, Keyworth.

Carney, J. & Ambrose, K., 2007. *Geology of the Leicester District* (explanatory booklet of 1:50,000 map), British Geological Survey, Keyworth, 34pp.

Carney, J.N., Ambrose, K., Cheney, C.S. & Hobbs, P.R.N., 2009. *Geology of the Leicester District.* Sheet Description, British Geological Survey, Keyworth, 110pp.

Compston, W., Wright, A.E. & Toghill, P., 2002. Dating the Late Precambrian volcanicity of England and Wales. *Journal of the Geological Society,* **159**, 323-339.

Ford, T.D., 1974. The place of Charnwood Forest in the History of Geological Science. *Transactions of the Leicester Literary & Philosophical Society,* **68**, 23-31.

Ford, T.D., King, R.J., & Snowball, G., 1973. Bibliography of the Geology of Leicestershire up to 1970. *Mercian Geologist,* **4**, 247-347.

Fox-Strangways, C. & Watts, W.W., 1900. *The Geology of the Country between Atherstone and Charnwood Forest.* Memoir of the Geological Survey, 102pp.

Fox-Strangways, C. & Watts, W.W., 1903. *The Geology of the Country near Leicester.* Memoir of the Geological Survey, 122pp.

Fox-Strangways, C. & Watts, W.W., 1905. *The Geology of the Country between Derby, Burton, Ashby and Loughborough.* Memoir of the Geological Survey, 83pp.

Harrison, W.J., 1877. *A Sketch of the Geology of Leicestershire and Rutland.* Reprinted from White's History, Gazetteer and Directory of the County, Sheffield. 67pp (revised edition 1904).

Hill, E. & Bonney, T.G., 1878-1880. The pre-Carboniferous Rocks of Charnwood Forest. *Quarterly Journal of the Geological Society,* **33**, 754-789; **34**, 199-239; **36**, 337-350.

Jones, F., 1926. The petrology sand structure of the igneous rocks of the Charnian at Bardon Hill. *Geological Magazine,* **63**, 241-255.

Jones, F., 1926. A preliminary enquiry intyo the directions of joints, faults and dykes in the igneous rocks of Groby. *Transactions of the Leicester Literary & Philosophical Society,* **27**, 23-31.

Knoll. A.H., Walter, M.R., Narbonne, G. & Christie-Blick, N., 2004. A new period for the Geologic Time Scale. *Science,* **305**, 621-622.

Lamplugh, G.W., 1903. *The Geology of the Isle of Man.* Memoir of the Geological Survey.

Lowe, E.E., 1926. *The igneous rocks of the Mountsorrel District.* Leicester Literary & Philosophical Society, 49pp.

McIlroy, D., Brasier, M. & Moseley, J. M., 1998. The Proterozoic-Cambrian transition within the Charnian Supergroup of Central England and the antiquity of the Ediacaran fauna. *Journal of the Geological Society,* **155**, 401-413.

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

Moseley, J. & Ford, T.D., 1989. The sedimentology of the Charnian Supergroup. *Mercian Geologist,* **11**, 251-274.

Pharaoh, T.C., Merriman, R.J., Webb, P.C. & Beckinsale, A., 1987. The concealed Caledonides of Eastern England: preliminary results of a multidisciplinary study. *Proceedings of the Yorkshire Geological Society,* **46**, 355-369.

Sweeting, G.S., 1958. *The Geologists Association, 1858-1958.* London, 165pp.

Watts, W.W., 1921. Obituary Notice of Charles Lapworth, 1842-1920. *Proceedings of the Royal Society,* **B92**, xxxi-xl.

Watts, W.W., 1921. The geological work of Charles Lapworth. *Proceedings of the Birmingham Natural History and Philosophical Society,* **14**, Special Supplement, 51 pp.

Worssam, B. & Old, R., 1988. *Geology of the Country around Coalville.* Memoir of the Geological Survey.

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MEMBERS' EVENING 2010

The fourth Members' Evening was held on 13th March 2010. Once again, the instructions to the presenters were simple: *show us your interests and infect us with your enthusiasm*. It is hoped that other members, especially those who are amateur, will offer short presentations to continue the Members' Evenings into future years.

Spotlight on Shetland

John Aram

When geologists mention Shetland they are normally talking about oil; but since this lies in rocks deep beneath some of the world's stormiest ocean, and is difficult to photograph, the onshore geology forms the basis of this presentation.

Because of its outstanding geological heritage, Geopark Shetland became a full member of the European Geoparks Network on 15 September 2009. This gave it the triple aims of: 1) conserving the geological heritage and demonstrating links with the natural and cultural heritage of the islands, 2) raising awareness and increasing the understanding of this geological heritage, and 3) enhancing the image of Shetland, while promoting sustainable development linked to its geological heritage and geo-tourism.

The Shetland Isles consist of over 100 islands that lie between 60º and 61º north, in the same latitude as Southern Alaska, and they are closer to Norway than to

Devonian flagstones used to build an Iron Age broch on the isle of Moussa, off the east coast of southern Mainland.

Folded and sheared schist formed as a part of the Caledonian mountain building when granite and other rocks were intruded in northern Unst.

England. Blessed by the warm North Atlantic Drift that springs from the Gulf Stream, they enjoy a relatively mild climate, while the surrounding seas are rich in life that for many centuries has provided food both for the local people and also for massive colonies of sea birds.

The bedrock of the Shetlands accumulated when quite different terrains came together over long periods of geological time, along continuations of the Moine and Great Glen Faults of the Scottish Mainland. In Shetland, the oldest rocks occur in the Hebridean terrain west of the Walls Boundary Fault, where an inlier of Lewisian Gneisses, of >2900 Ma, is surrounded by garnet mica schists.

Frost sorted, patterned-ground mainly in serpentinite at Keen of Hamar, on Unst. Note the purple-blotch colouring of healthy leaves, due to high chromium content in the soil.

Post-Caledonian granites forming reddened cliffs, arches and stacks along the west coast of northern Mainland, as seen looking southeast from the Eshaness peninsula.

Much of the remainder of Shetland's southern Mainland, including the Walls peninsula, consists of Devonian conglomerates and breccias overlain by sandstones and flagstones. These were deposited in alluvial fans and along braided rivers that derived from an active volcanic highland area towards the end of the Devonian and ended in the northern margin of the Orcadian Basin. In western Eshaness, the Devonian volcanic suite, including rhyolite and andesite lavas, vent agglomerates and ignimbrites dates from around 365 Ma. The distinctive pink granites that form Shetland's highest hill (Ronas Hill, at just 450 m), and extend through the eastern part of the Eshaness peninsula, are dated later, at 350 Ma.

Dalradian rocks forming the central part of Mainland east of the Walls Boundary Fault, consist of steeply dipping metamorphic rocks. These include the quartzite and schistose grit extracted at the Scord Quarry near Scalloway for roadstone. Four thick beds of marble have now been linked to 'Cap Carbonates' that formed during the melting phase of a Snowball Earth around 635 Ma. Close to Whiteness these beds have provided a source of lime, while the soil on them has a distinctive flora and fauna and also a higher value for agricultural development.

A north-south fault zone separates these Dalradian rocks from Grampian rocks that form eastern Mainland, where they are partly overlain by Devonian sediments dipping gently east. Carboniferous faulting then controlled mineral veins containing copper that was being worked more than 2000 years ago (on the evidence of excavations of an Iron Age broch at Scatness). Dalradian rocks continue northwards beyond the faulting around Yell, into the northern isles of Fetlar and Unst. Here they include a serpentinised slice of ocean floor and mantle material that was worked near Keen of Hamar for metallic ores, notably its chromite. Until the middle of last century these were exported for pigments from the end of Chrome Lane in Lerwick. This ophiolite sequence also provided soapstone (a form of talc schist) that was carved by the Vikings settlers into lamps and cooking vessels; small quantities of talc are still extracted in the area for industrial use.

Shetland's Quaternary history includes the formation of an ice-cap on Ronas Hill and an invasion by Scandinavian ice-sheets that brought distinctive Norwegian erratics. Stone stripes and polygons, turf-banked terraces and block-fields form patterned ground features that are still active on the most exposed uplands. During glaciations, global sea levels were around 100 metres lower than at the present day, when the Shetland Isles therefore had a very different geography. The subsequent progressive rise in sea-level formed the deep sheltered inlets known locally as 'voes', and has given the islands a spectacular assemblage of coastal erosion and depositional features including massive cliffs, stacks, arches, blow-holes, bay-head bars and single and double tombolos.

The whole suite of Shetland's geological delights is good reason for any 'sooth-mooth' geologist to make the trip north, especially during the 'Simmer Dim' when the sun hardly dips below the horizon.

St Ninian's tombolo, a single sand ridge joining St. Ninian's Isle to the west coast of southern Mainland. Sand extraction for local building material at the mainland end has now ceased.

The Golconda Mine Orebody

John Jones

Golconda Mine lies a kilometre north of the village of Carsington, and 2 km east of Brassington. Although very little is known about the early history of the mine, there are various names and dates left by the miners of long ago. One, very prominent in a post-mineralisation cavern reached through the mine, reads "I. Rawlinson, September 29, 1796".

Golconda closed in 1913, when it is recorded that only two men were working undergound (Burt et al, 1981). It was then reopened in 1915 by the Hopton Mining Company to extract baryte, with galena as a insignificant by-product. It is estimated that during the following 30 years more than 75,000 tonnes of baryte were produced.

Country rock at Golconda is the Carboniferous limestone, but this has been subjected to dolomitization that cuts through the horizontal stratigraphy, by as much as 35 metres. Some of the ore zones follow this, which gave rise to winch-hauled inclines throughout the mine. Within the dolomitized limestone the beds are, in places, separated by green clay wayboards; these are thought to be have been formed by volcanic dust, and are generally 40-200 mm thick. Orebodies have also developed on the upper surfaces of some of the wayboards. Silica sands have been washed down fissures into the cavernous limestone; of possible Tertiary age, these are mainly composed of material derived from a former Triassic cover and are now preserved as Pocket Deposits in surface solution hollows, some as much as 58 metres deep (Yorke, 1954).

Aurichalcite and hemimorphite, 50 mm high.

Photographs on the back cover

Upper left: Cluster of secondary acicular baryte crystals about 20 mm long.
Upper right: Hemimorphite crystals encrusting nodular baryte; 110 mm across.
Middle left: Scalenohedron of calcite 30 mm long, on baryte.
Middle right: Botryoidal form of aurichalcite, 50 mm across.
Lower left: Crystals of hemimorphite and cerussite encrusting galena, 60 mm across.
Lower right: Octahedral crystals of galena with a patina of iron oxides, 80 mm across.

Eight categories of mineral associations have been recognised within the Golconda orebodies (Ford and King, 1965):

1. Undisturbed Layered Ores are horizontal alternating layers of barite, galena, dolomite sand and crystalline calcite. Some of these exhibit ten layers within 150 mm, between a green clay below and a dolomite roof.

2. Cavity Linings are common and consist of barite 25-50 mm thick, locally carrying small galena values.

3. Collapsed Cavity Linings are common, especially in the deep 70 Fathom (126 m) levels. Excessively thick and heavy baryte cavity linings have fallen from the roof and walls into the cavities, where they have been cemented by a later deposit of calcite.

4. Late Cavity Linings. Any spaces left between the top of the collapses and the roof of the cavity have been infilled with a final deposition of large calcite scalenohedron crystals.

5. Vertical Scrins. Only one scrin has been seen cutting through a fill of detrital baryte fragments within limonite-cemented sand layers within a solution cavity; it continues into the unaltered limestone below, indicating a mechanism of solution and infill that was a continuous process. There are several scrin-type features that are mineralised joints in the roof of the cavities, but these only extend upwards into the dolomite.

6. Metasomatic Replacement of the dolomite by baryte is uncertain. It is now thought that the baryte has infilled small cavities in the dolomite that were caused by the disaggregation of the limestone, thereby giving a false appearance of metasomatism.

7. Secondary Oxidation Products are numerous and very complex.

8. Placer Deposits occur in post-mineralization solution cavities, many of which are filled with sand that has migrated down from the overlying Tertiary Pocket Deposits. These sand fills locally carry small amounts of galena, although some sites have yielded large blocks of galena, one of which weighed nearly 70 kg (Ford and King, 1965).

It is postulated that mineral emplacement was by precipitation from downward or laterally migrating solutions, and, although the original sulphides are syngenetic, the orebodies are better classified as epigenetic (Ford and King, 1965).

The Secondary Minerals

The primary galena crystallised in the octahedral and cubo-octahedral forms. It is usually encrusted with the oxidation products of the zinc sulphide, sphalerite, which has been completely oxidised, and is not seen anywhere in the orebody. The surfaces of the galena crystals commonly exhibit a patina of orange-brown iron oxide that is a result of the oxidation of the iron component within the sphalerite. The lead carbonate and sulphate, cerussite and anglesite, are relatively rare oxidation minerals, although cerussite pseudomorphs after anglesite crystals have been recorded (Ford and Jones 2007).

Zinc is now only represented by its silicate and carbonate, hemimorphite and smithsonite. Hemimorphite is the dominant secondary mineral within the orebody; groups of sheaf-life crystals form drusy surfaces in cavities, and locally form botryoidal surfaces. Colour varies from highly lustrous transparent crystals, through to yellow, green and dark brown. Smithsonite forms small botryoidal, pale green crusts coating galena crystals; it is a rare mineral in the orebody, usually seen only within an undisturbed layered ore sequence.

Aurichalcite, a carbonate-hydroxide of zinc and copper, is locally common in areas of the mine where small deposits of the copper sulphide, chalcopyrite, are seen in a partially oxidised state. Commonly the colour varies from pale to dark green, in crusts with a velvety texture. It also occurs as delicate acicular crystals forming tufts of feathery incrustations. A mammilary form, pale blue with a pearly texture, has been found in the area known to the miners as "Bonsall Man's Roof". In the same area a small quantity of secondary baryte occurs, forming as white ribbons down the mine walls, and locally coating sand grains in shallow water on the floors to form cave pearls.

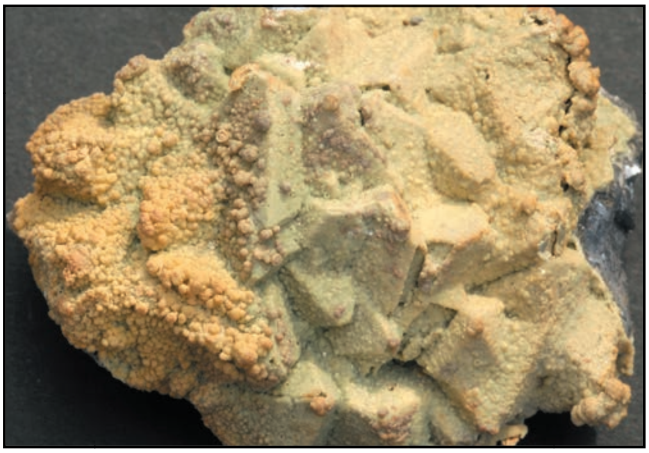
References

Burt, R., Waite, P., Atkinson, M., and Burnley, R., 1981. *The Derbyshire Mineral Statistics, 1845-1913*. University of Exeter and Peak District Mines Historical Society.

Ford, T.D. and Jones, J.A., 2007. The geological setting of the mineral deposits of Brassington and Carsington. *Mining History*, **16** (5), 1-23.

Ford, T.D. and King, R.J., 1965. Layered epigenetic galena-barite deposits in the Golconda Mine, Brassington, Derbyshire, England. *Economic Geology*, **60**, 1686-1701.

Yorke, C., 1954. *The Pocket Deposits of Derbyshire*. Private Publication: Birkenhead (revised with supplements 1961).



Very pale green smithsonite encrusting galena crystals, 50 mm across.

Fine crystals of hemimorphite overlying the patina of iron oxide, derived from original sphalerite, that coats larger crystals of galena, forming a block 100 mm across.

In the steps of a master: following James Hutton around Scotland

Gerard Slavin, Gerry Shaw and Brenda Slavin

James Hutton is regarded in Britain as a founder of modern geological thought. We visited sites in Scotland which were important to him, some well known, but others less so. Many of these may be visited from the English Midlands in a pleasant series of weekend cross-border raids, or more leisurely and sensibly on a touring holiday.

After medical school in Leiden in 1750, Hutton never practiced medicine, but farmed at Slighhouses near Duns, Berwickshire, which is only a slight diversion from the A1 on the way north. In pursuing agriculture, he travelled extensively through England and the continent, and during these travels studied geology. Insight into his life at this time can be obtained by visiting the recently established exhibition (www.james-hutton.org.uk).

Hutton was supported by colleagues and friends, who accompanied and provided him with specimens and information that stimulated and guided his journeys. In 1764, he toured the Highlands with Sir George Clerk. It may have been a seminal moment when he saw the basaltic dyke near Drummond Castle, Crieff, thrusting aside the country rocks (Fig. 1) and which he thought might be traced to Campsie Linn near Perth.

He returned to Edinburgh in 1767, devoting his time thereafter to study of the Earth and agriculture. In the Midland Valley there are many basaltic volcanoes and intrusions. He described dykes in the Water of Leith, in drainage trenches in Edinburgh New Town and on the Clyde coast at Skelmorlie. He recognised Salisbury Crags as intrusive, and concluded that its rock was molten when it pushed aside sedimentary strata (see photo on page ////////////). These and other locations were illustrated by Sir John Clerk (Craig et al, 1978).

In 1785 he lectured the Royal Society of Edinburgh on a "System of the Earth", concluding that the Earth operated as a "machine fired by heat", and he promulgated the idea of uniformitarianism (Hutton, 1785). The fusion of granite was not mentioned in the abstract, but stimulated by a specimen of graphic granite from Portsoy, given to him by Sir John Clerk in 1779, he concluded "It is not possible to conceive any other way in which ..... quartz and feldspar could be thus concreted except by congelation from a fluid state in which they had been mixed. ..... evidence that this body having been consolidated by fusion and by no other manner".

Figure 2. *Veins of pink granite intrude metasedimentary rocks at Glen Tilt.*

From 1785 to 1788, Hutton sought evidence for the fusion of granite and its intrusion into sedimentary rocks. A visit to Glen Tilt was stimulated by Sir John Clerk, who in 1779 had seen granite dykes cutting metasediments at Dalnacardoch in the River Garry (McIntyre, 2008). At the Dail-en-eas bridge over the Tilt, a tributary of the Garry, Hutton found many veins of "red granite .... traversing the black micaceous schistus" (Fig. 2). His exuberant response was such that his guides "were convinced that it must be nothing less than silver or gold that could call forth such joy and exultation" (Playfair, 1802).

In 1786 he went with Clerk to Galloway "to see the junction of the granite country with the schistus strata of the south of Scotland" (Hutton, 1794) and at

Figure 1. *Dolerite dyke left as a wall after erosion of weaker country rocks, near Drummond Castle, Crieff; the rib of rock is about 300m long, 15m high and 10m thick*

__Figure 3__. Silurian greywackes are intruded by red granodiorite from the Dalbeattie pluton, at Needles Eye, on the North Solway coast.

Cairnsmuir they found granitoids cutting greywackes (now obscured). Further east, at Needles Eye on the Solway coast (Fig. 3), similar intrusions are seen, though they are less convincing than those at Glen Tilt. Indeed, Jameson, a Neptunist and one of Hutton`s arch-critics, concluded that the evidence here was in favour of precipitation out of solution (Jameson, 1814; Brookfield, 1999).

__Figure 4__. Hutton`s angular unconformity at Lochranza, on Arran, with the Carboniferous cover dipping steeply left nearer the sea, over the Dalradian rocks dipping right where the person is standing.

Hutton went to Arran with John Clerk Junior, in 1787 and found contacts between the northern granite and Dalradian schists in North Sannox Burn, and also in the Glen Shant stream above Brodick and in Glen Rosa. At North Sannox, Hutton described "... the schistus ... broken and invaded by the granite ... (which) enters and traverses the schistus in little veins terminating in capillaries" and concluded that the granite had been "in a state of fusion by ... subterranean heat". On Arran, Hutton observed the number and complexity of basalt dykes, some of which are largely glass and which he compared to glassmaking in Leith by fusion of sand and other minerals. At Lochranza, he described an angular unconformity between Dalradian schists and overlying Carboniferous sandstones (Fig. 4). He was clearly perplexed: "Here the schistus and the sandstone both rise at about 45º, but ..... inclined in almost opposite directions ..... like the rigging of a house", and "were it not for the little overlapping of the strata on the schistus it would have been impossible to have said which one of these two bodies of strata ... was superincumbent on the other".

Later in 1787, Hutton visited Jedburgh where he described the unconformity with horizontal Old Red Sandstone above near-vertical Silurian beds separated by a conglomerate (Fig. 5). Again he was perplexed by the process of deposition, uncertain whether the vertical strata had been broken or erected beneath overlying horizontal strata, or whether the older strata had been rendered vertical and broken prior to deposition of the younger rocks. Disappointingly, the unconformity is now obscured by trees and access is restricted, but Jedburgh is worth a visit to see the splendid memorial to Hutton in the form of a wall that represents an artist`s concept of the unconformity (Fig. 6).

Hutton sought for other unconformities, and with Sir James Hall set out to explore the East Lothian cliffs by boat from Dunglass Burn. At Siccar Point, the junction between the Silurian greywackes and overlying Old Red Sandstone was obvious (Fig. 7). It clarified previous problems: "the sandstone strata are

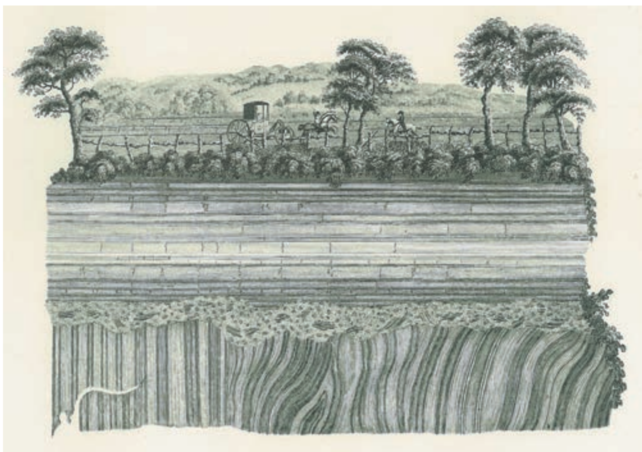


__Figure 5__. Engraving of a drawing by John Clerk of the classic unconformity at Jedburgh, as it was before being lost behind a screen of trees.

Figure 6. *James Hutton`s memorial wall at Jedburgh, with sandstone above and greywacke below.*

partly washed away and partly remaining upon the ends of the vertical schistus; and in many places points of the schistus strata are seen standing up through among the sandstone".

Hutton published his *Theory of the Earth* (parts I & II) in 1795. It was not a success due to its prolixity and obscurity, and his opinions were challenged by Neptunists. But, with an explanatory text by Playfair (1802) and continued input from his supporters over the next 40 years, his views were gradually accepted. A further volume was published posthumously, edited by Geikie in 1899.

Figure 7. *Siccar Point, with horizontal Old Red Sandstone overlying the nearly vertical Silurian greywackes (photo: British Geological Survey).*

The usual view of Hutton is coloured by Raeburn`s rather priggish portrait in the Scottish National Gallery which R. L. Stevenson dubbed as a Quaker without a hat. He was far from that. His letters show a man who was humorous, bawdy, blasphemous and occasionally drunk. He wrote a doggerel latin toast to concubines, and had a particular fancy for married women (Jones et al, 1994, 1995).

He died in 1797, and was buried in an unmarked grave in Greyfriars Kirkyard next to his great friend, Joseph Black, discoverer of carbon dioxide. The Kirkyard is worth a visit, for in 1947 the Royal Society of Edinburgh and the Geological Society put up a plaque to commemorate him, 150 years after his death. After leaving the Kirkyard, stop at Greyfriars Bobby or Sandy Bells – two well-remembered pubs from medical student days - before proceeding to a last stop at St John`s Hill where Hutton lived, just beyond where the Pleasance meets the Cowgate. There in 1997, to mark the bicentenary of his death a memorial garden was erected. Boulders placed in it include schists infiltrated by granite veins, from Glen Tilt, and appropriately one bears an inscription which earned him opprobrium in his lifetime but which is his everlasting legacy: "We find no evidence of a beginning, no prospect of an end. James Hutton, 1788".

References

Brookfield, M.E., 1999. Hutton, Hall & Jameson in Dumfries & Galloway. *Transactions of the Dumfries and Galloway Natural History Society*, **73**, 1-8.

Craig, G.Y., McIntyre, D.B. & Waterston, C.D., 1978. *James Hutton`s Theory of the Earth: The Lost Drawings*. Scottish Academic Press: Edinburgh.

Hutton, J., 1785. Abstract of a dissertation concerning the system of the Earth. *Transactions of Royal Society of Edinburgh*, 31-32.

Hutton, J., 1794. Observations on granite. *Transactions of Royal Society of Edinburgh*, **3** (2), 77-81.

Hutton, J. (posthumous: ed. Geikie, A.), 1899. *Theory of the Earth in book form: Volume III*. Geological Society: London.

Jameson, R., 1814. Notes on the geognosy of the Cri-Fell, Kirkbean and the Needle`s Eye in Galloway. *Memoirs of the Wernerian Natural History Society*, **4**, 541-547.

Jones, J., Torrens, H.S. & Robinson, E., 1994 and 1995. The correspondence between James Hutton and James Watt with two letters from Hutton to George Clerk-Maxwell. *Annals of Science*, **51**, 637-653, and **52**, 357-382.

McIntyre, D.B., 2008. The Royal Society of Edinburgh, James Hutton, the Clerks of Penecuick and the igneous origin of granite. *Transactions of the Royal Society of Edinburgh: Earth Sciences*, **97** (Suppl.), 1-15.

Playfair, J, 1802. *Illustrations of the Huttonian Theory of the Earth.* Cadell & Davies: London, and William Creech: Edinburgh. Facsimile reproduction (1956), Dover: New York.

Playfair, J, 1805. *Biographical account of the late James Hutton, F.R.S.Edin*. Republished (1997) from Vol. V of Transactions of Royal Socety of Edinburgh. RSE Scotland Foundation: Edinburgh.

REPORT

Charnian Fossils in the Outwoods

The Outwoods, near Loughborough, present a unique fauna of Precambrian fossils of Ediacaran age in the Charnwood Forest inlier. The fossils consist of multi-ringed ovoid discs of varied sizes and a number of rings, set in clusters of small bead-like microbial matting.

In the mid 1960s Bob King, accompanied by Trevor Ford, found a loose block containing a large multi-ringed ovoid disc (Fig. 1). This featured in *The Geology of the East Midlands* (1968) and is now in the Geology Department, University of Leicester (item 58115). It was named *Cyclomedusa davidi*. Trevor Ford then found three more discs on a nearby bedding plane, which has since been moulded and cast by BGS for their collection. Another large multi-ringed disc on a loose block was then found (Fig. 2), and is also in University of Leicester (item 96877/8/9). In 2007, Grazhdankin and Gerdes described similiar multi-ringed discs as microbial colonies 1-3mm thick, from the Yorga Formation, near the White Sea, NW Russia. Comparing these images with those of The Outwoods, it seems possible that the latter may be similar microbial colonies and not medusoids as was originally thought.

Figure 1. Cyclomedusa davidi.

Figure 2. *Ovoid multi-ringed disc.*

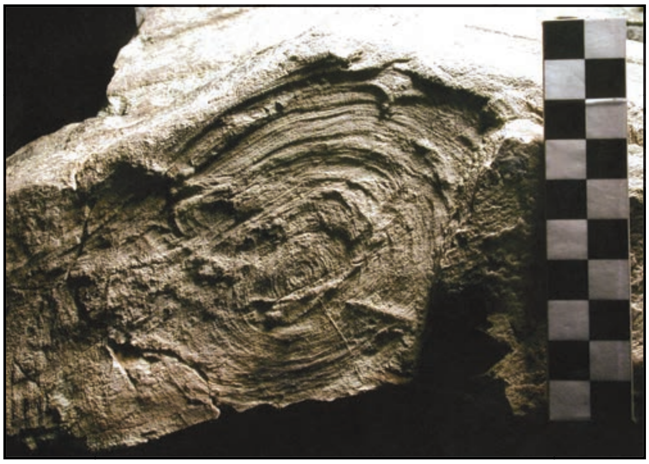


Figure 3. Pseudovendia charnwoodensis *from The Outwoods, with possible fronds to the left and a stem at the base,suggesting it is probably a frondose fossil, rather than an arthropod.*

Figure 4. *The newly found frond, stem and disc.*

In 1978 the author found another fossil on a loose block near to Bob King's original find (Fig. 3). This was named *Pseudovendia charnwoodensis* (Boynton and Ford, 1979) as it was thought to be a primitive arthropod showing similarities to *Vendia* in Northern Russia (Keller and Fedonkin, 1976). After discussion between members of the Charnia Resaerch Group,, it is now considered more likely to be part of a frond.

In March 2009 Phil Wilby, of the British Geological Survey, found a new fossil in The Outwoods very near to the main fossiliferous bedding plane. This was first thought to be another *Pseudovendia*, but, on close examination under oblique lighting and after computer enhancement, it appears to have a stem emerging on its left side, which was supported by a disc (Fig. 4). It could be a new *Charniodiscus* species, and awaits moulding and casting by BGS. This is the first specimen of this nature found in The Outwoods, which could yield some more important finds in the future; research continues.

Acknowledgements

Grateful thanks for discussion and photographs go to John Carney, Mike Howe, Phil Wilby, Trevor Ford, Mark Evans, Bob King, Kay Hawking, Richard Callow and Alex Lui.

Bibliography

Boynton, H.E. & Ford, T.D., 1979. *Pseudovendia charnwoodensis* – a new Precambrian arthropod from Charnwood Forest, Leicestershire. *Mercian Geologist*, **7**, 175-177.

Grazhdankin, D. & Gerdes, G., 2007. Ediacaran microbial colonies. *Lethaia*, **40**, 201-210.

Keller, B.M. & Fedonkin, M.A., 1976. New Organic Fossil Finds in the Precambrian Vendian Series along the Suyzina River. *Izvest Akad. Nauk Surv* No. 3, 38-44 (in Russian).

Sylvester-Bradley, P.C. and Ford, T.D., 1968. *The Geology of the East Midlands*. Leicester University Press, 400pp.

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HOLIDAY GEOLOGY

Wave Rock, Australia

Most of Western Australia is underlain by an assemblage of very old granites and metamorphic rocks that collectively form the West Australian Craton. These rocks where formed in stages by successive continental collisions dating from 3700 to 450 Ma. The break-up of Gondwanaland from 135 Ma then separated India and Antarctica from Australia, which then moved northward from its location near the South Pole while undergoing stages of subsidence, uplift and erosion.

Today, granite outcrops break the surface at many locations in an otherwise largely flat landscape. Many of these sites pull in local visitors and foreign tourists alike. Wave Rock, near Hyden in the Midland Wheat Belt is four hours drive east of Perth and attracts 100,000 visitors a year.

From the surrounding bush the rock emerges with a profile shaped like a perfect wave. It is just the skirt of an extensive granite dome. The Wave itself is over 100 m long and about 12 m high. The granite, which dates from 2600 Ma, shows flow banding and has contemporary pegmatite dykes. Although this part of Western Australia is fairly dry there is sufficient rainwater run-off for algae to grow on the rock face, and it is this that forms the vertical stripes on the wave. The dark stains are living algae that change colour to rust brown when the water supply diminishes. When the algae die, the crust peals off to reveal the clean pale granite. The catchment area above the Wave is sufficiently extensive, and productive in the wet season, to justify the low walls built along the rim of the Wave to direct run-off water into a reservoir at the east end.

On the dome above Wave Rock, large granite boulders are core-stones left from deep sub-soil weathering in the past.

The pale pink porphyritic granite from which Wave Rock has been carved.

The wave shape was created by underground weathering beneath a moist soil. Subsequently, the soil was eroded away to exposing the Wave and the adjacent rock pavement. On the dome above the Wave, a barren granite plain has depressions filled with lush vegetation and a scatter of large granite boulders. At first sight these could be taken to be erratics that remain from the extensive glaciations prior to 135 Ma, but they are actually core-stones left by deep weathering of the granite during the Tertiary and Quaternary.

Alan Filmer

View along Wave Rock, with the dark streaks formed by algae that grows along drip lines.

HOLIDAY GEOLOGY

Wadi Ghul, Oman

Oman is an up-and-coming holiday destination, taking a slice of the Gulf States' visitors and also now easily accessible by a short drive from Dubai. For geologists, one of the key destinations has to be the Jabal Akhdar, the mountain range across the north of the country, where a breached anticline of Cretaceous limestone rises above the jagged lowland of the well-known ophiolite outcrops. The mountain summit is Jabal Shams, and just below lies the huge canyon of Wadi Ghul. Often called the Grand Canyon of Oman, it has the layered walls of its Arizona namesake, but everything is tipped up at a dip of about 15º. It is hundreds of metres deep, barren and wild, and truly spectacular. It is also very accessible, with a tarred road that rises from Al Hamra, near Nizwa, before turning into a dirt road that is perfectly drivable in a 2WD car. This climbs the flanks of Jabal Shams until it emerges on the rim of Wadi Ghul at a series of stunning viewpoints.

The highlight of the site is the village of Sap Bani Khamis, lying almost directly below the first viewpoint (so only visible from promontories to the right). This incredible village stands on ledges of thinly bedded limestone, between vertical cliffs of massive limestone both above and below. Some of the ruined stone houses can be seen from the canyon rim, but they are 100 m down, below a vertical cliff. So the keen visitor will walk round to the village - along a very airy path that traverses the canyon wall, with vertical cliffs both above and below; this starts 4 km south in a gully where the upper limestone has been largely removed by erosion, and the views from this path are unforgettable.

Perched, almost literally, on its canyon wall ledge, Sap Bani Khamis was the ultimate defensive site, established when there was almost perpetual fighting between neighbouring village tribes. It once held about 15 families, and the last moved out just 30 years ago, in favour of a more relaxing environment. Survival of the village depended on the very small perennial stream that emerges from a bedding plane at the foot of the upper cliff (directly above the houses in this view). The stream flows for less than 100 metres, cascades over small ledges, and then drops over the main overhang into the depths of Wadi Ghul. Next to the stream channel, carefully crafted field terraces stand directly above 500 m of open space that undercuts the one strong bed of limestone spanning the void. The hardy folks who once lived at this amazing site must have had an unusual understanding of what geology is all about.

Tony Waltham

The limestone ramparts of Wadi Ghul, with key features indicated below.

<< upper cliff, with another 30 m up to the canyon rim

<< spring from bedding plane at foot of upper cliff

<< Sap Bani Khamis village in dark shade beneath a small overhang left of the stream, and the terraced fields right of the stream

<< main limestone overhang

<< another 400 vertical metres of the lower cliff extending off this photograph

HOLIDAY GEOLOGY

Hutton, Hall and Darwin: a Tale of Two Cities

Many cities have little to offer the visiting geologist, except perhaps the interest of their building stones and their museums. How lucky then to visit cities where the geology dominates the environment wherever one turns and even a business trip can turn into a mini-holiday. This year we have been to two such cities, Edinburgh and Cape Town, where the geology is not only spectacular, but is also linked by field observations in the 18th and 19th centuries that were important in the debate between Neptunists and Plutonists. These critical features are still easily seen today.

Edinburgh

The centre of Edinburgh is dominated by early Carboniferous Visean basaltic volcanics that were extruded over the Inverclyde and Strathclyde Groups of sediments. Castle Rock, a volcanic plug, overlooks the old city centre. To the east, Arthur`s Seat volcanics, forming Calton Hill, Whinney Hill and the vents of Arthur`s Seat itself, are largely within Holyrood Park. Perhaps the most striking feature is the analcime dolerite (teschenite) sill of Salisbury Crags intruded in the late Carboniferous, largely concordant with, but cropping out through, Inverclyde sandstones and marls. It extends 900 m from the north, where it is about 40 m high, with prominent vertical jointing and layering parallel to the top and base of the sill, before it thins to the south, ending close to the Lion’s Head vent on Arthur`s Seat. Contact with the overlying sediments is only seen to the north of the sill, but the lower contact is observed at several points adjacent to the Radical Road along the base of the crags; the most famous of these is Hutton`s section, close to the southern end of the sill, which formed part of the evidence in the controversy with the Neptunists.

James Hutton and Salisbury Crags

We were Edinburgh medical students in the early/mid 1950`s and rushed to Salisbury Crags on Sunday mornings to climb in the Little Quarry before the park keepers came on duty. Geologically ignorant, we passed Hutton`s section without a thought and it was nearly 35 years later before we became aware of its significance. Now, whenever we return to Edinburgh we take a slower walk round the Radical Road to reverentially revisit the section, a few metres in front of the crag face (Fig. 1). At two places, the lower margin of the dolerite sill is seen with a chilled edge transgressing the subjacent laminated marls and sandstones, distorting and wedging them upwards, indicating a forcible intrusion by a hot molten magma into the country rocks. A slab of sedimentary rock has been torn away and the broken ends of the sedimentary strata were rotated upwards by the intrusion. Towards the top of the sill, a little way to the south-east, inclusions of sedimentary rock within the dolerite are seen. Hutton’s section provided conclusive field evidence that the Salisbury Crags sill was formed from a magma that intruded into older layers of sedimentary rock - but this was initially disputed.

Neptunists, Vulcanists and Plutonists

A bitter dispute began in the 18th century when Italian geologists challenged the traditional (Neptunist) view that all rocks including basalts and granite originated as aqueous precipitates or sediments. Following the discovery of the ancient volcanoes in Auvergne, Demarest of France suggested that basalt was of volcanic origin and this started the battle between Neptunists and Vulcanists. Neither Hutton nor Professor Werner of Saxony, later the leading protagonist of Neptunism, was involved in the initial skirmishes. Hutton`s interest in geology began about 1753 when farming in Norfolk. But not until 1785, when he read the *Theory of the Earth* to the Royal Society of Edinburgh, published in the *Transactions of the Royal Society of Edinburgh* in 1785 and in book form 10 years later, did he established his position as a Plutonist - developing the view that granites and not only basalts are of igneous origin. He positively sought out places where granite veined the country rock, in Glen Tilt, on Arran and in Galloway, confirming his theory that some granites might not only have been molten but also “been made to flow in the bowels of the earth, in like manner as these great masses of our whinstone and porphyry which may be considered as subterranean lavas”.

Hutton was notoriously obscure in his writings. He was unpopular as an alleged atheist and free thinker and after his death his views were opposed by Neptunists, led in Europe by Werner, in Ireland by Professor Kirwan (subsequently President of the Royal Irish Academy) and even in Edinburgh by Professor Robert Jameson. His work was defended and reinterpreted by his friend John Playfair, Professor of Mathematics, in *Illustrations of the Huttonian Theory* and later by Charles Lyell author of the epoch making *Principles of Geology*.

Figure 1. *Hutton`s section on Salisbury Crags, with distortion of the marls and sandstones by the overlying intrusive dolerite.*

Figure 2. Table Mountain from the Waterfront, showing the steep cliffs formed by the Table Mountain Group Sandstones.

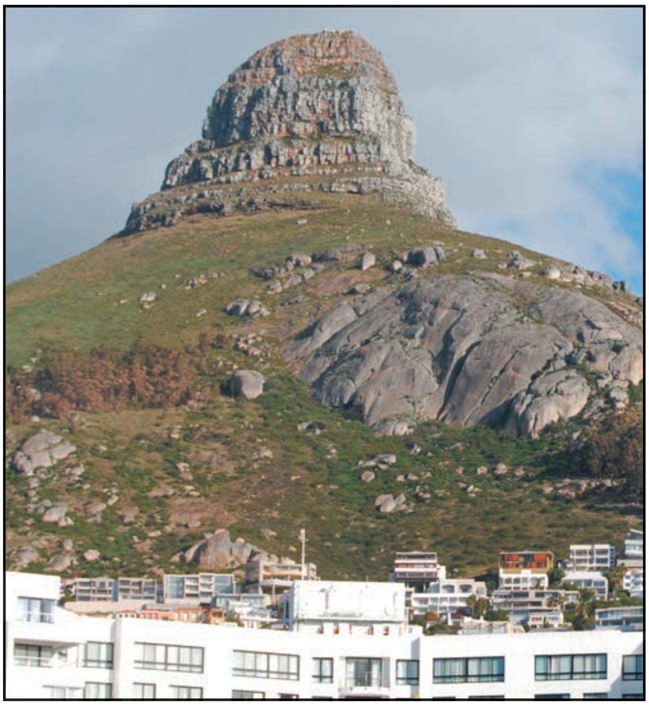


Figure 3. The Lion`s Head above Sea Point, with Table Mountain sandstones overlying the rounded, pale granite intrusion.

Charles Darwin at Edinburgh and Cambridge

Darwin went to Edinburgh in 1825 to study medicine, and attended the official university lectures, but complained that most were stupid and boring. He was disgusted by the dull and outdated anatomy lectures of Professor Alexander Munro Tertius who, appointed in 1798, was content to read to his students his grandfather`s lectures, a century old, and although he had never been to Leyden still included the remark "When I was a student in Leyden in 1719...."! Darwin was sensitive to the sight of blood. He regularly attended clinical wards and was greatly distressed; he went to surgical operations only twice, rushing away before they were completed, upset by the brutality of surgery without anaesthetics.

The chemistry lectures of Thomas Hope, a friend of Hutton, were an exception to the general dullness, and he taught Huttonian views opposing those of Werner. Darwin also took the natural history course of Professor Robert Jameson, which included stratigraphic geology, mineralogy and some field geology. Jameson, a pupil of Werner, forcefully taught that strata were precipitated crystallised from molten crust. Darwin left Edinburgh in 1827, without qualifying and with the determination "never as long as I lived to read a book on geology or in any way study the science".

He entered Cambridge in 1828 to prepare for the Anglican clergy and found the tutorial system more to his liking than didactic Scots lectures. He passed his exams in 1831, but, with two terms before graduation, was crammed in geology by Henslow, his tutor. He probably attended lectures by Adam Sedgwick, and accompanied him for geological field studies in North Wales. After Edinburgh and Cambridge, Darwin was well aware of the Neptunist v Plutonist dispute and of the significance of Huttons`s observations on Salisbury Crags. He was aware of Sedgwick`s view that the evidence of the igneous formation for Northumberland trap rock was complete, and was able to contrast it with Jameson lecturing on a trap dyke in Salisbury Crags and ascribing it to sediments filled in from above but "adding with a sneer that there were men who maintained that it had been injected from beneath in a molten condition".

In September 1831 he was offered the post of geologist, naturalist and gentlemanly companion to Captain FitzRoy of H.M.S. Beagle and sailed from Plymouth in December, 1831. He landed in Cape Town in 1836 on the voyage back to England.

Cape Town

Table Mountain presents an iconic image (Fig. 2) and is the northern end of a sandstone mountain range forming the spine of the Cape Peninsula. Its main feature is a level plateau 1085 m high and about 3 km wide, surrounded by steep cliffs. The plateau, flanked by Devil`s Peak to the east and by Lion`s Head to the west, together with Signal Hill (or Lion's Rump), forms a natural amphitheatre about central Cape Town and Table Bay harbour. To the south of the main plateau, along the Atlantic coast the range continues as the Twelve Apostles, a series of buttresses divided by faults, with resort towns at the foot, and then onwards to Cape Point.

The oldest rocks forming much of the lower ground are Precambrian sediments, the Malmesbury group of greywackes and shales, deposited as turbidites on the continental slope of the Adamastor ocean and subsequently distorted in the Saldanian orogeny with folding best seen between the Waterfront and Sea Point or on Robbens Island. The sediments were intruded by the Peninsula granite during the Ordovician (540 Ma) and contacts can clearly be seen on the Lion`s Head and Rump (Fig. 3) as well as on the sea shore at Sea Point. Table Mountain Group sandstones, of fluvial, deltaic, tidal flat and shallow marine origin, were deposited on the eroded basement of Malmesbury sediments and granite. The basal Graafwater Formation, composed of 50 m of thinly bedded, pale brown sandstones and maroon shales, is distinctive, and along Chapman`s Peak Drive is seen lying directly on the granite (Fig. 4). Above, about 500 m of more thickly bedded pale grey sandstones of the Peninsula Formation form the ramparts of Table Mountain and extend southwards as far as Cape Point. Small remnants of diamictites related to Ordovician glaciation are found near Maclear`s beacon on the plateau summit.

Captain Basil Hall at Cape Town

Basil Hall R.N. was the second son of Sir James Hall of Haddington, a companion and friend of Hutton and a protagonist of the igneous origin of granite. Basil visited Cape Town in 1812, and his observations of Table Mountain, in a letter to his father, were presented to the Royal Society of Edinburgh by Playfair in 1813. He described vertical beds of "Schistus or Killas" (Malmesbury greywackes) on the lower slopes of Table Mountain penetrated by veins from the main granite and similar features on the Lion`s Head and Rump: "the contact was the finest thing of the kind I ever saw..... The number of veins that we could distinctly trace to the main body of the granite was truly astonishing; and the ramifications which extended on every side, were of all sizes from the breadth of two yards to the hundredth of an inch. Masses of killas cut off entirely from the main body of that rock floated in the granite without numbers, especially near the line of contact and the strata there appeared broken, disordered, and twisted in a most remarkable degree." Higher up the mountain, he noted a line where the granite ceased to be succeeded by strata of horizontal and undisturbed sandstone (Table Mountain Group Sandstones). Playfair concluded that the granite younger than the greywacke "has come up from below.... and is not one of which the materials have been deposited by the sea in any shape either mechanical or chemical. It is a species, therefore, of subterraneous lava.... (that) has always existed in the bowels of the earth..... and is highly favourable to the opinion that granite does not derive its origin from aqueous deposition".

Figure 4. *Contact between pale granite and overlying pink Graafwater Formation is clearly seen in the view, from Hout`s Bay, of Chapman`s Peak road, which runs horizontally for several kilometers along the contact.*

Figure 5. *On the shore at Sea Point, pale granite, on the right, infiltrates sub-vertical beds of the Malmsbury Group with melting and migmatisation.*

Charles Darwin at Cape Town

Darwin visited Cape Town in 1836 on the return journey of the Beagle to England. There he went to the granite/sedimentary contacts on the Lion`s Head and Rump recorded by Hall, and gives Hall precedence in his notebook. He also visited Sea Point shore where granite infiltrates the Malmsbury Group sediments (Fig. 5), producing a spotty hornfels with andalusite and cordierite crystals and a narrow zone of migmatisation that extends up towards Lion`s Head. Large xenoliths of country rock are contained within the granite and he wrote to Lyell concerning his findings, and their significance in the genesis of igneous rocks. A memorial plaque existed at Sea Point to commemorate Darwin`s visit and observations. Alas, in modern South Africa scrap metal is worth more than sentiment, and the plaque has been vandalised, leaving the seashore exposure to speak for itself, as ever.

Bibliography

Clarkson, E. & Upton, B., 2006. *Edinburgh Rock: the Geology of Lothian*. Dunedin Academic Press: Edinburgh.

Herbert, S., 2005. *Charles Darwin, Geologist*. Cornell University Press: Ithaca.

Guthrie, D., 1958. *A History of Medicine*. Thomas Nelson: Edinburgh.

MacPhee, D. & de Wit, M., 2003. *How the Cape got its Shape*. Map Studio: Cape Town.

Norman, N. & Whitfield, G., 2006. *Geological Journeys*. Struik: Cape Town.

Playfair, J. & Hall, B., 1815. Account of the Structure of the Table Mountain and other Parts of the Peninsula of the Cape. *Transactions of the Royal Society of Edinburgh*, **7**, 269-278.

Van Wyhe, J., 2009. *The complete works of Charles Darwin online*. http://darwin-online.org.uk/darwin.html

Various, 1950. James Hutton, 1726-1797: commemoration of the 150th anniversary of his death. *Proceedings of the Royal Society of Edinburgh*, **63**, 351-400.

Gerard and Brenda Slavin

REPORT

Creswell Crags

In the summer of 2009, the opening of a big new visitor centre marked a welcome step forward for Creswell Crags, on the Nottinghamshire-Derbyshire border close to Worksop. The recent discovery of cave art at Creswell hugely raised its profile, and the whole site has now been greatly improved as befits an important archaeological location. The road that ran through the crags has been diverted away, the old sewage works is long gone, and the landscaped parkland now offers a lovely walk, with or without a visit into the caves.

Creswell Crags lie within the Permian Cadeby Formation (once the Magnesian Limestone), where a wide ravine cuts through a low wooded ridge east of a small fault scarp. Its stream never ran underground, but restricted dissolution of the dolomitic rock has merely etched out fissures and rifts along joints that lie near the surface, and especially in those that open into gorge walls. So the Creswell Crags are liberally punctured by caves along the walls on both sides of the stream; and all are short caverns, sealed by mud at the back, with dry floors and arched roofs. They made ideal dwelling caves for man or animal.

Following Anglian ice retreat, the Creswell caves were occupied mostly by hyenas - scavengers who would drag large chunks of carcasses back to their cave dens. Discarded bones survived inside the caves, thereby creating a collection of the remains of almost all the large animals that had been there in the Pleistocene. There were mammoths, woolly rhinoceros and reindeer from the colder periods, when glaciers occupied valleys not far to the north, while hippopotamus, horse and lion were left from times of warmer climates. Bone-rich sediments were metres deep in some of the caves, and made quite decent "cave earth" floors for subsequent human occupations.

The raised walkway inside Church Hole at about the level of the original cave floor, prior to the Victorian excavations; it was installed recently to take visitors up to where the cave art can be seen.

During warmer interludes in the early Devensian, itinerant hunters periodically took shelter in the Creswell caves, leaving behind crude stone tools. Then, about 12,500 years ago, after the main Devensian cold stage was over, cave dwellers returned to Creswell's rock shelters, especially those along the north side of the gorge where they could catch more of the warm sunshine. These were more sophisticated people; they were even into producing art. A fragment of rib bone, just 7 cm long and beautifully engraved with a horse's head, is perhaps the most famous of the many artefacts that have led to the distinctive post-glacial culture being named the Creswellian. It was found in 1876 among the floor debris in the fancifully named Robin Hood's Cave, which lies in the southern wall of the Creswell Crags, and is therefore likely to have been one of the occupied caves in Creswellian times.

Evening light reaches the limestone crags along the southern side of Creswell Crags; Boat House Cave lies at water level at the near end of the crags, and Church Hole is out of sight among the trees near the far end.

Modest indentations on the wall of Church Hole, which required skilled interpretation to identify as the work of Creswellian cave artists (photo: English Heritage).

Next people into the caves were the Victorian antiquarians, who relished sites where they could excavate huge quantities of well-preserved bones from what had been simple hyena dens. In the southern wall of Creswell Crags, Church Hole was excavated in the 1870s. Removal of huge amounts of bones and debris lowered the entire cave floor by more than two metres, though still did not reach a rock floor. The cave walls of Creswellian times were therefore left out of reach up near the ceiling. The Victorians had seen nothing of interest on those walls, and later visitors could not get close to them.

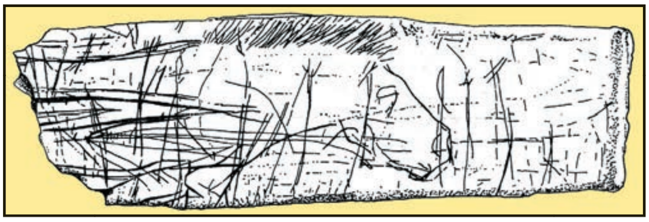
The efforts of Creswellian artists were not seen or appreciated until 2003. Only then did a small group of specialists (Paul Bahn, Paul Pettitt and Sergio Ripoll) visit Church Hole during their nationwide search for cave art. They had a lucky break when one of them

The head and beak of the ibis that are clearly recognisable on the wall of Church Hole (photo: English Heritage).

looked at just the right angle at a piece of wall that was side-lit by daylight from the entrance. Shadows picked out a few lines etched into the rock, which they recognised as the work of a bygone artist. They looked further, and found the remnants of more than a dozen artworks in that one entrance chamber. A bison and a stag, each two metres long, appear only as engraved outlines, while the distinctive beak of an ibis is cut deeper into a fine bas relief. But the relatively soft and friable dolomitic limestone has weathered badly in a cave chamber long open to the weather. Perhaps once the engraved lines were the outlines of paintings, but no colour survives. In Church Hole you have to be shown the right spots and then need to look very carefully to see the cave art.

Dating of a thin stalagmite coating that covers some of the engraved lines, and of associated charcoal, both indicate ages of about 12,000 years, so this is definitely Creswellian art, and it is the most northerly cave art yet found. Already significant, Creswell Crags is now a site of even greater note, and a landmark within the East Midlands.

Tony Waltham



The horse's head that was engraved onto a piece of bone by a Creswellian artist before being lost among the debris on the floor of Robin Hood's Cave (drawing: English Heritage).

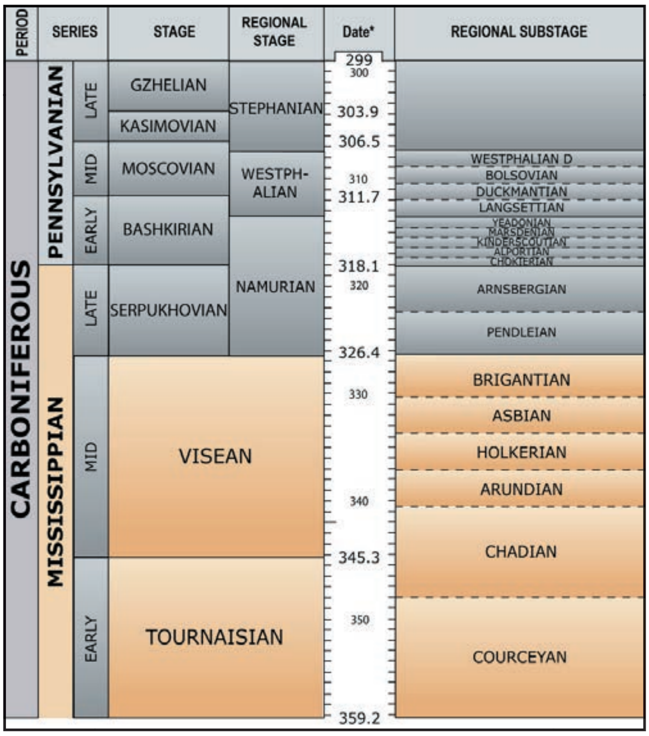
REPORT

BGS OpenGeoscience

The British Geological Survey has recently launched a website that offers a mass of information, maps and photographs as free downloads. This is a great step forward within our modern digital age, and many Society members will find interesting and useful geological material here. The site openly encourages non-commercial use of the material, so personal research, school projects and private presentations are going to find it invaluable (there are also access programmes for commercial, institutional and educational use).

There are many routes around and branches within the website, and they are likely to evolve through usage and experience. But the home page offers four notable routes that are great starters.

Data: includes a lexicon of stratigraphic terms, links to various publications on mineral statistics, and also an excellent suite of rock classifications that are comprehensive and hugely detailed reports available as pdf downloads. It also has a splendid Geological Timechart that can be followed into individual tables with considerable detail, such as that for the Carboniferous as reproduced here.



The Carboniferous page of the stratigraphic chart; resolution of the file copied off the website is adequate to print at twice this size, thereby making the smallest text more legible.

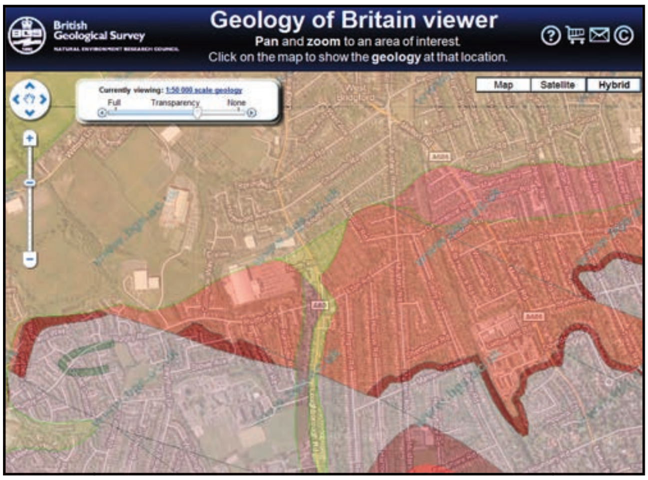
Maps: has a wonderful "Geology of Britain viewer" where you can zoom in to see bedrock and superficial geology down to the level of 1:50,000 detail superimposed on a satellite image, a street map or a hybrid. A slider allows transparency of the geology layer to vary over the satellite or map view; the halfway stage is very good where there are roads to identify through the geology, but open country is a little difficult to see in a single view. Map images can only be saved as a screen-grab.

Pictures: profers a huge selection of geological photographs, mainly but not exclusively of Britain, in a searchable archive. There are some excellent images of so many of the classic sites, though many are in black-and-white because they are the original BGS records photos. Though presented as free downloads of 1000x1000 pixel images, they only download at a smaller size just 800 pixels on their maximum dimension. A little frustrating, but still a marvellous resource.

Reports: includes a route into the searchable NERC Open Research Archive, where hundreds of reports are available as pdf downloads. So much material, so useful on so many projects.

Go to http://www.bgs.ac.uk/opengeoscience/ and have a browse when you are next on-line. Commercial awareness means that a lot of geological material cannot be reached through this website, but the missing bits are the maps and major publications that are available in paper form at reasonable prices. This website is a welcome resource that should be held and used in parallel with the BGS publications on paper.

Tony Waltham



A screen grab from the map viewer showing the geology of West Bridgford superimposed with about midway transparency on the hybrid satellite image and street map.

REVIEWS

Geology of the Nottingham District by A.S. Howard, G. Warrington, J.N. Carney, K. Ambrose, S.R. Young, T.C. Pharaoh and C.S. Cheney, 2009. Memoir of the British Geological Survey (Sheet 126). 212 pages, 48 figures, 22 photos, 21 tables, 978-0-85272-579-5, £24.

At last; it's out. The new sheet memoir for Nottingham has been published. Fourteen years after its companion map, and exactly 100 years after its predecessor. Ripples of applause across the East Midlands. So good to see this in print – and such a close thing when it may be one of the last of the 1:50,000 sheet memoirs to be produced in paper form.

It is excellent to have available this invaluable geological resource for the Nottingham area, another splendid BGS example of serious, competent, authoritative and detailed geology in the finest tradition. But after that bald statement, it is perhaps rather difficult to warm to such a tome. Easy reading it is not. But for raw geological data it is magnificent, because it's all there: 26 pages on the applied geology, 46 pages on the Carboniferous and older rocks, 58 pages on the Permo-Triassic, 14 pages on our little corner of Jurassic, 22 pages on the Quaternary, 25 pages on the structure and concealed basement, and the usual end pages. Some would dismiss the long chapters on bedrock geology as boring, old-style, stratigraphic geology, but these are presentations of the solid facts that must lie at the heart of any real geological research.

Perhaps the part nearest to easy reading is that on the applied geology, with overviews of mineral resources, water resources, flooding, engineering properties of the ground and the various human activities that have left their mark. Also welcome is the Quaternary chapter on unconsolidated sediments and landscape evolution, which now receives full and proper coverage, in contrast to the old days when anything above the Pliocene (or should we now say Neogene) was almost dismissed as mere soil by the geological purist.

Inevitably, one must make comparisons between this new volume and the earlier BGS offering on the Nottingham geology (*Nottingham: a geological background for planning and development*, published in 1990 as Technical Report WA/90/1). They even have the same cover photograph of Castle Rock, though prior to the recent removal of its sylvan screen. The 2009 Memoir covers a much larger area, as the 1990 Report covers only the southwestern corner of Sheet 126. And only the Memoir has the wealth of stratigraphic detail on both the solid and the drift geology. There is of course overlap, where the 2009 section on applied geology is largely a condensed and updated version of the 1990 material. The 1990 Report has its 16 large fold-out derivative maps with various aspects of the geology, mostly at 1:25,000, while the 2009 Memoir has 130 more pages (and should be accompanied by the 1:50,000 map). The new memoir is an affordable £24 (though the map will cost another £12), while the earlier report is a rather daunting £90. So some similarities, but very different; each to his own choice; but any local geologists, amateur or professional, will want to have their own Memoir, and many will gain from having both.

Like it or not, we are in transition to the electronic age. And the new memoir reflects this, as it is produced by short-run, on-demand, digital printing that avoids the high costs of litho preparation. This is recognisable by the text being a fraction less crisp than that in a litho print, but this is no great problem, and it does have the advantage of allowing full colour reproduction on all the maps and photos scattered through the pages. The presentation is excellent.

Few members of the Society will feel the urge to read this memoir, but many will feel the need to have it as an essential reference – it is after all very good value for a huge amount of local information. Essential for anyone doing serious geology around Nottingham, and a key reference for years to come.

Tony Waltham

Darwin's Lost World: the Hidden History of Animal Life by Martin Brasier, 2009. Oxford University Press. 304 pages, 37 photos and figures, 978-0-19-954897-2, £16.99 in hardback.

In the famous book *The Origin of Species by Means of Natural Selection* published 150 years ago, Charles Darwin expressed his concern that the fossil record showed evidence that the animal phyla we know so well today appeared suddenly in the Cambrian (then regarded as a lower part of the Silurian system) with no antecedents in Precambrian rocks, then regarded as Azoic (without life). This new book is a welcome addition to the numerous tomes about Darwin, and Martin Brasier has concerned himself with the same problem – the so-called Cambrian explosion and the poor record of previous fossil life, in particular with what is now known of the array of Precambrian fossils found since Darwin's day.

Martin Brasier's book is a personal, broadly autobiographical account of how his thinking has evolved since he started his professional career as the naturalist on a Royal Navy survey ship, as did Darwin. Moving to a lectureship at the University of Hull, and later to a Chair of Palaeobiology at Oxford University, the author has taken part in expeditions to many parts of the world, seeking the evidence provided by strata deposited across the Precambrian-Cambrian boundary, particularly in Newfoundland, Russia, Siberia, China, Mongolia, Oman and Australia, and of course the more accessible Charnwood Forest. His account is at times light-hearted, providing us with an entertaining description of the logistics of reaching these far-flung localities and the problems of doing field work there. The results of his investigations can be summarized as saying that the Cambrian explosion was a more drawn-out affair than usually seen with a variety of fossil organisms, some known as Small Shelly Fossils, of uncertain nature, appearing before the earliest Cambrian trilobites. He describes the now-well-known Ediacaran biota of mainly frondose and disc-shaped organisms preserved either in shallow-water sandy sediments or in volcani-clastic deposits as showing no clear evidence that they were ancestors of Cambrian phyla, and, rightly, he emphasises that we know little about their biology: how did they feed and reproduce? Can the quilted body structure advocated by Seilacher be substantiated? Thus Martin Brasier shows that Darwin's Dilemma is far from solved. In contrast to the widely-held belief that jellyfish should have been the most primitive forms of life, he expresses the opinion that none of the disc-like fossils in Ediacaran rocks were jellyfish impressions; some were holdfast of fronds, but others appear to have been too complex or too large to be holdfasts. He argues that the "embryos" found in the Doushanto Formation of China could have been clusters of algal/bacterial cells, with the dark blob in the centre being a carbonized part of the inner cell layers, not an animal cell nucleus. Martin also briefly discusses the "Snowball Earth" hypothesis when world-wide glaciations and deglaciations may have stimulated the evolution of multi-cellular life forms.

After discussing the pros and cons of the arguments offered by palaeontologists around the world, Martin Brasier comes to a conclusion that the absence of trace-fossils such as worm trails in late Precambrian rocks indicates that the bioturbation caused by worm-like animals was a critical factor and that such creatures only arose at the beginning of Cambrian times. Without worms or bioturbation in Neoproterozoic times, organic detritus was buried in sea-floor sediments and not readily available as food for other marine life. Hence the evolution of burrowing, sediment-feeding worms may have been the trigger for the development of more complex life forms such as Archaeocyatha, often dubiously grouped with sponges, and trilobites. This hypothesis will be tested by future researchers.

In reviewing how Martin Brasier sees Darwin's Lost World, it should be noted that he has little to say about stromatolites, the carbonate structures built by cyano-bacterial colonies which Russian palaeontologists in particular have tried to use as form-genera with stratigraphic significance for subdividing and correlating Proterozoic strata. Nor does he have much to say about the Precambrian unicellular organisms generally known as acritarchs, used for stratigraphic correlation by G. Vidal and others. Both stromatolites and acritarchs are known far back into the Precambrian, long before the appearance of the Ediacaran biota. The microbes found in siliceous stromatolitic structures in the Gunflint Chert of Canada are noted but little is said about the paleo-environment of the Banded Iron Formations of which the Gunflint Chert is a part. However, these shortcomings are only of minor significance in the context and Martin has provided us with a highly readable and entertaining book. Some will disagree with some of his comparisons and aside remarks but there is plenty of food for thought about what really might have happened in late Precambrian times, the "Lost World" of Charles Darwin.

There is an eight-page colour photographic section and a scatter of line-drawings but I felt the book could have been improved with more illustrations and simple geological maps or sections of the strata at the localities visited. The book concludes with 210 end-notes, some of which should have been integrated with the main text, and a full bibliography and index.

Trevor Ford

The Making of a Land: Geology of Norway edited by I. Ramberg, I. Bryhni, A. Nottvedt and K. Rangnes, 2008. Norsk Geologisk Forening, ISBN 978-82-92-39442-7. 624 pp, £40.

This is an incredible book, a true tome of monumental proportions, yet beautifully produced, with lots of specially created artwork, and all at a ridiculous price. It is a treasure to peruse and enjoy, especially, but not only, by anyone planning a visit to the fiordlands. The geology of Norway is complicated by the massive structural deformations of the Caledonian, and is presented here largely as an assembled interpretation, which is a fascinating insight to the depths of modern understanding.

There is a wealth of geological information on Norway and its northern outpost of Svalbard. There are also many boxed texts on special themes – including Ediacaran fossils, sulphide ores, ophiolites, the larvikites, the Kongsberg silver, the Storrega submarine slide and the strandflats. New, important and interesting data about the Scandinavian glaciations take 70 pages. Norway is famous for its igneous and metamorphic terrains, but the geology offshore (and across much of Svalbard) is largely sedimentary, and so important for the mainly Jurassic source rocks and reservoir rocks that yield both oil and gas. It is good to read that the broad picture suggests that only 1% of Norway's hydrocarbons have yet been found.

With over 600 pages, more than 450 photos, a similar number of diagrams and maps, and a large (A1) geological map of Norway in an end-pocket, this book is remarkable value. That's what comes of oil company sponsors (and freedom from any commercial publisher). But it means that you've already half-paid for it by filling up with petrol. So whether or not that petrol is for the drive north to catch the Bergen ferry, it's worth shelling out just a little more to obtain this truly splendid book.

Tony Waltham

Minerals of Golconda Mine (page 205)