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East Midlands Geological Society

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Front cover: The Breedon Hill limestone quarry seen from the north (see page 139). Photo P542174 from British Geological Survey.

Back cover: Coast erosion at Holderness, east of Hull, where cliffs of glacial till recede by successive rotational landslides, though armour stone and sea-walls protect hard points and cause increased erosion down-drift. Photos and map by Tony Waltham.

Contents

Reports

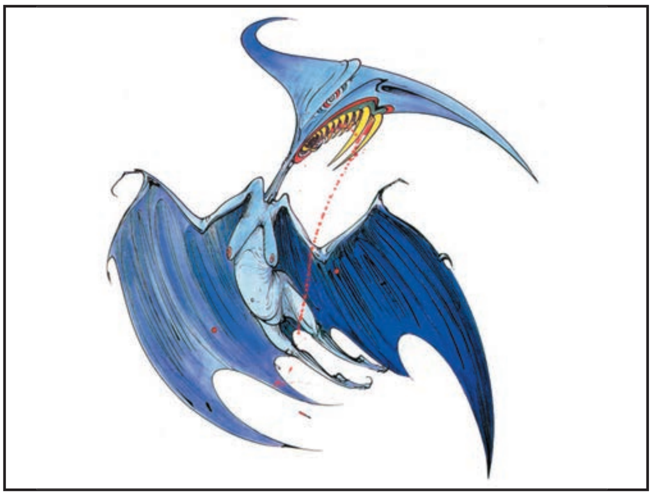
GEOBROWSER

They're getting younger all the time...

The story of how two 14-year-old schoolboys, Richard Blachford and Roger Mason, found the Precambrian fossils *Charnia* and *Charniodiscus* in Charnwood Forest (see *Mercian*, 2011, p226) bears out a somewhat anecdotal suggestion that many important geological discoveries have not actually been made by geologists. But the possibility that those in the forefront of field-discovery are becoming even younger was confirmed in 2009, when a five-year-old girl noticed fossilized bones along the sea shore on the Isle of Wight. Her find was made in a landslip area on the Atherfield Clay Formation, and was brought to the attention of palaeontologists at the University of Southampton. The partial pelvis and associated sacral and dorsal vertebrae were subsequently confirmed as belonging to a new species of pterosaur, and are described in the online publication PLOS ONE of March 2013 (doi:10.1371/journal.pone.0058451). The species, which is from the Lower Cretaceous about 115 million years ago, was named *Vectidraco daisymorrisae*, which honours both the name of its young discoverer and also the location - *Vectidraco* meaning "dragon from the Isle of Wight".

Another predatory dinosaur

Yet another newly discovered species of flying dinosaur, this time from the late Jurassic strata in Kimmeridge Bay, Dorset, has been given an unusual name which is, for this year, particularly topical. The specimen has been called *Cuspicephalus scarfi* after the satirical political cartoonist Gerald Scarfe, who was chosen because his caricatures of the late Margaret Thatcher once famously depicted her as a pointy-nosed *Torydactyl*. Found by fossil collector Steve Etches, and identified by University of Portsmouth palaeontologist Dr David Martill, it is believed to be the most substantial pterosaur skull to be found in Britain for nearly 200 years (Acta Palaeontologica Polonica, doi:10.4202/app.2011.0071). The specimen, 33 cm long, is now in Dorset's Museum of Jurassic Marine Life, and according to Dr. Martill is unique because of its complete skull, which is extraordinarily slender, hence its 'pointed head' name. Gerald Scarfe said he was "... thrilled and flattered - I never thought Mrs Thatcher would do anything for me - even if it is to be immortalised as a 155-million-year-old fossil. I have spent many holidays in Kimmeridge and to think my namesake was buried beneath my feet is wonderfully bizarre."



Evolution, creationism and flying spaghetti

The Church of the Flying Spaghetti Monsters is a spoof rival to the creationist school of thought, and is generally held to be a light-hearted parody religion whose devotees are called 'Pastafarians'. The church's name was first coined in a satirical open letter written by Bobby Henderson in 2005 to protest the Kansas State Board of Education's decision to permit teaching intelligent design as an alternative to 'Darwinian' evolution in public school science classes. Perhaps because of the mirth that it engenders, but also because of its more serious undertones with regard to the teaching of science in schools, the Flying Spaghetti Monster has had widespread exposure on the internet. Its underlying tenet relates to an argument (*Russell's teapot)* put forward by Bertrand Russell, which refutes the notion that the burden of proof lies upon the skeptic to disprove the claims of religions, and concludes instead that the philosophical burden of proof lies upon those who make unfalsifiable claims (for example supporting a literal interpretation of the Book of Genesis), and not on those who reject them.

In his letter, Henderson satirized creationist ideas by suggesting that whenever a scientist carbon dates an object, a supernatural creator that closely resembles spaghetti and meatballs is there "changing the results". Arguing the equal validity of his beliefs, Henderson called for Flying Spaghetti Monsterism to be allotted equal time in science classrooms alongside intelligent design and evolution. The theme was elaborated further in Henderson's book, *The Gospel of the Flying Spaghetti Monster*, which preaches that an invisible and undetectable Flying Spaghetti Monster created the universe. Pirates are revered as the original Pastafarians, and their important role in causing global warming is demonstrated by a graph showing a steady decline in numbers of pirates plotted against rising global temperature. This argument was put forward to show that correlation does not always imply causation, and is a counter to the suggestion from some religious groups that the high numbers of disasters, famines, and wars in the world is due to the increasing lack of respect and worship shown towards their deity.

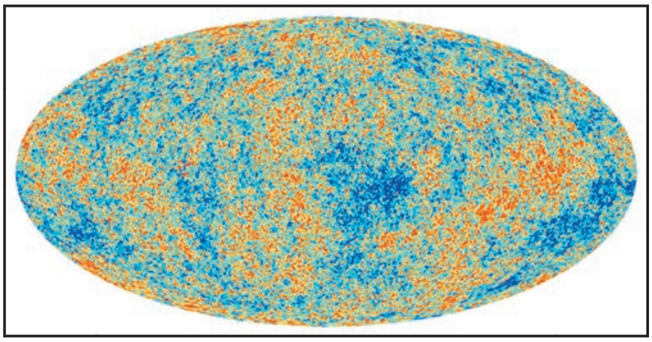
Creationism can be identified with a variant of Christian fundamentalism that has persisted down the centuries, often resulting in the persecution of scientists and philosophers. However, in a 2012 paper entitled *The Evolution of Creationism* (*GSA Today*, v22, n11, p4-9) David Montgomery argues that the modern creationist school finds its roots in the teachings of George McCready Price (1870–1963). A Canadian Seventh-day Adventist, Price was an amateur geologist with no formal training who in 1923 published a book with the rather misleading title *The New Geology: A Textbook for Colleges, Normal Schools, and Training Schools; and For the General Reader*. Here he asserted that there was no order to the fossil record, and that the apparently logical progression of species-types favoured by geologists was really just a mixed-up sampling of communities that lived in different parts of the ancient world. He considered the fossil record too incomplete to confidently reconstruct the past, citing the occasional discovery of animals previously thought to be extinct and known only from fossils.

Trouble in Paradise?

While geological thought has evolved over the past several centuries, so too has Christianity, and Montgomery notes that the creationist school is currently being torn apart by bitter arguments. *Young-Earth creationists* believe the world is no older than about 10,000 years, and that Noah's Flood formed its present-day topography during a single event a few thousand years ago. *Old-Earth creationists* accept much geological evidence but endorse ideas such as progressive creationism (also known as theistic evolution), which argues that God guided evolution in creating the diversity of life. In a later step, creationism was repackaged as *intelligent design*, which embodies the inherently untestable assertion that God designed the world with a particular purpose or goal in mind. Interestingly, the name *God-particle* has strayed into the realms of astrophysics, although it is a populist term disliked by many scientists and clergy alike and, in any case, it has recently been supplanted by the discovery of the Higgs-boson. Montgomery concludes that after losing repeated court battles over efforts to teach creationist views in science classrooms, the creationist strategy appears to have shifted to questioning evolution, particularly in the wake of the Charles Darwin bicentenary celebrations (see G*eobrowser* 2009). He notes that "Geologists assess theories by how well they fit the data, and creationists evaluate facts by how well they fit their theories", which are philosophies that cannot be reconciled. By discussing the development of creationism in classrooms alongside the teaching of evidence-based Natural Sciences, students could be given useful insights into the science *vs* spirituality debate, and how the two approaches can be evaluated evidentially in the context of the planet's geological evolution.

...and there was light

Thanks to the European Space Agency's Planck telescope, we are now within a chronological hairsbreadth of observing the very act of Creation. The latest images of the cosmic microwave background constitute the most detailed map yet of the situation that prevailed only 380,000 years after the Big Bang. They show variations in the heat-radiation left over from that event, with red and blue regions representing areas that are slightly warmer and colder, respectively. It is these small fluctuations in the early universe that developed into the stars and galaxies we see today. This map of the remnant glow largely affirms scientists' theories about the universe's early history (The Guardian, 21 March, 2013).



For example, the data support the theory of simple inflation in which, around 10-30 seconds after the Big Bang, the universe briefly expanded faster than the speed of light. It also broadly confirms previous calculations of universe age, but with the proviso that it commenced 13.81 billion years ago, some 80 million years earlier than previously thought. As with all major scientific advances, there are also some new problems to solve. The universe now seems to contain more matter, of both visible and invisible types, and less of the mysterious entity called dark energy than earlier observations suggested. The Planck data also delivered an unexpectedly low rate of expansion for the universe, a figure called the Hubble constant that describes how dark energy is increasingly stretching the fabric of space. "This is one of the most exciting parts of the data," says Martin White, a Planck scientist at the University of California, Berkeley, "the hope would be that this is actually pointing to extra physics we're not aware of." This should move us closer to answering the two outstanding questions about our existence – what happened at the Big Bang, and what came before it?

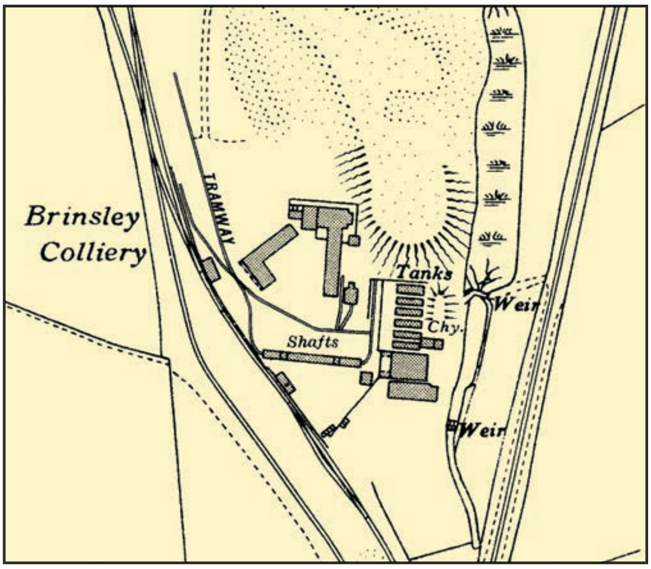
FROM THE ARCHIVES

Headstocks at Brinsley Colliery

The opening scene of the 1960 film of D. H. Lawrence's *Sons and Lovers* presents an idyllic view of sheep grazing contentedly on a hilltop in the shade of an overhanging tree. As the camera slowly pans right we see a pleasant rural valley revealed, which then unexpectedly gives way to a scene of stark industrial activity, at the centre of which stand the iconic tandem headstocks of Brinsley Colliery.

Situated some 2.5 km north of Eastwood, in Nottinghamshire near the Derbyshire border, Brinsley and the surrounding area had been at the heart of coal mining activity for over 700 years. The last Brinsley Colliery (there has been more than one) was established sometime after 1842 by Barber Walker and Co.. A company report dated April 1855 records that Brinsley Colliery had been deepened to the level of the Deep Soft Coal, having previously worked the Top Hard Coal. In 1872 working was extended to the Deep Hard Coal at a depth of 780 ft, and a second shaft, adjacent to the first, was newly sunk. The Coal Mines Regulation Act of 1872 commanded that no person should be employed in a mine unless there are at least two shafts in communication with each seam being worked. The tandem headstocks date from that time.

D. H. Lawrence's father worked at Brinsley Colliery, which in *Sons and Lovers* is called 'Beggarlee' (there had formerly been a mine of this name located near Moorgreen Colliery), and later 'Bretty'. The novel, which is largely autobiographical, was published in May 1913. Brinsley Colliery also features, under its proper name, in an earlier short story by Lawrence entitled *Odour of Chrysanthemums*, which he wrote in 1909. The story opens with a description of the colliery as seen from the cabin of a coal train approaching from the north: 'The fields were dreary and forsaken, and in the marshy strip that led to the whimsey, a reedy pit-pond, the fowls had already abandoned their run among the alders, to roost in the tarred fowl-house. The pit-bank loomed up beyond the pond, flames like red sores licking its ashy sides in the afternoon's stagnant light. Just beyond rose the tapering chimneys and the clumsy black headstocks of Brinsley Colliery. The two wheels were spinning fast up against the sky, and the winding engine rapped out its little spasms. The miners were being turned up.' In Lawrence's day the timber framing above the shafts, which supported the cages, was partly clad and thus appeared more 'clumsy' than the elegant structure that can be seen today.



Surface plan of Brinsley Colliery (modified from Ordnance Survey map of 1938).

Brinsley Colliery looking to the south. This picture, by an unknown photographer, was probably taken shortly before the headstocks were dismantled in the first week of June 1970. The building on the far left contained the winding engine. During the making of the film Sons and Lovers (1959–60) the headstocks were painted a light blue colour to make them stand out. Eastwood church is just visible on the skyline (photo: British Geological Survey archives, P711164).

After 1918 Brinsley was connected underground to neighbouring collieries at Underwood (Selston) and Moorgreen. Activity became focused at Moorgreen, with the result that Brinsley was abandoned for coal winding, but the shafts were kept open to provide access and ventilation to adjoining collieries. In 1930 its winding engines were converted from steam to compressed air for hoisting men and materials only. The colliery finally closed in 1970. The headstocks were dismantled and moved to the National Mining Museum at Lound Hall in the north of the county. When the museum closed in 1989, British Coal acceded to a request from Nottinghamshire County Council to reassemble the headstocks at their original location, now landscaped, where they would become the focal point of a park and serve as a reminder of the county's industrial heritage. By this time much of the original timber was rotten and had to be replaced or conserved. The restored headstocks were reassembled on their original site (more or less) on 30 July 1992 at a cost to British Coal of more than £70,000.

Since 2008 a group called The Friends of Brinsley Headstocks has been working to develop the area as a heritage and nature reserve with the support of Nottinghamshire County Council and Broxtowe Borough Council.

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Whitelock, G. C. H., 1957. *250 years in coal: the history of Barber Walker and Company Limited, colliery proprietors in Nottinghamshire & Yorkshire, 1680–1946.* Derby & London: Bemrose, 256 pp.

Newspaper articles: *Nottingham Evening News*, 31 Jan 1908 (description of Brinsley Colliery); *Nottingham Evening Post*, 3 June 1970 (dismantling of headstocks); *Nottingham Evening Post*, 30 July, *Eastwood & Kimberley Advertiser*, 14 Aug 1992 (Brinsley headstocks reinstated).

David G. Bate, British Geological Survey

The reassembled headstocks at Brinsley, now within a picnic area and nature reserve.

THE RECORD

Our membership now stands at 334, including individual, joint and institutional members, and we welcome the new members who have joined the Society during the year.

Indoor Meetings

Following the Annual General Meeting in March Ian Sutton discussed New Zealand's major historic earthquakes in the country's tectonic context.

A Members' Evening in April had three presentations: by Don Cameron on the BGS Mines and Quarries Database (BRITPITS) from 1845 to the present day; by Geoff Warrington on the legacy of mining at Alderley Edge in Cheshire; and by Richard Hamblin on the Upper Greensand of the Haldon Hills in Devon.

The winter season of lectures started in October when Keith Ambrose brought us up to date with a revised lithostratigraphy for the Triassic Sherwood Sandstone Group of England and Scotland.

To mark its centenary in November, the story of the infamous Piltdown forgery was unfolded by David Bate.

In December, Colin Small described 56 years of flying aircraft into ash clouds, before everyone retreated to enjoy the Christmas Buffet.

January 2013 had Mike Searle's lecture on the thermal and structural evolution of the Himalayan and Karakoram continental crust.

At February's meeting David Tappin described his research into recent devastating tsunamis, and this was followed by the Society's Annual Dinner.

Field Excursions

A combination of circumstances left the Society with an atypically short programme of just three field trips in the summer season.

May saw a day-visit to the Wren's Nest at Dudley and the Saltwells Local Nature Reserve, led by Graham Worton, and also an evening walk led by Albert Benghiat to the limestone reefs of the Manifold Valley.

Tim Colman and Neil Turner led an evening walk around Nottingham Rock Cemetery in June.

Council

With the large increase in postage, this year's copy of Mercian Geologist was available for collection at the first indoor meetings in an effort to reduce costs. This proved very successful with 50% received by members post-free. Our thanks go to those members who delivered Mercians to others.

As a result of a generous bequest from the estate of the late Beryl Whittaker, the Society proposes to offer a Regional Geology Student prize of £250 in her name.

Rock boxes continue to be distributed to schools and community groups in the region. More than fifty have been given away so far.

MERCIAN NEWS

Carboniferous stratigraphy

Recently available is the definitive report on the correlation and stratigraphy of the Carboniferous of the British Isles (Waters et al., 2011). Its significance is that it will be a key handbook essential for any future work on the geology of the Pennines and of the adjacent basins where these rocks underlie large parts of the East Midlands and elsewhere.

This report revises and expands upon the publications for the Dinantian (George *et al*., 1976) and Silesian (Ramsbottom *et al*., 1978), accepting the demise of these two terms to combine them into a single account of the Carboniferous of the British Isles.

In 25 chapters it describes the considerable advances in Carboniferous chronostratigraphy, biostratigraphy and international correlation since publication of the previous editions. The main content is a series of regional descriptions, including ones of local interest for the southern Pennine Basin margin and Peak District and north Staffordshire. Each regional chapter includes a summary geological map and correlation panel, with Coal Measures areas also having a more detailed correlation of coals and marine bands.

For onshore chapters in England, Scotland and Wales the report uses the lithostratigraphy previously described (in Waters *et al*., 2009 and Dean *et al*., 2011), with the text concentrating upon description of the key biostratigraphical evidence for constraining the ages of the successions presented in the correlation panels. The report reflects the great contribution that the search for hydrocarbons, mainly post-dating publication of the previous reports, has had to the understanding of the offshore Carboniferous successions. The report also has a more thorough description of successions in Ireland.

Dean, M.T., Browne, M.A.E. & Waters, C.N., 2011. A lithostratigraphical framework for the Carboniferous successions of northern Great Britain (onshore). *British Geological Survey Research Report*, RR/10/07, free download at www.bgs.co.uk .

George, T.N. and 6 others, 1976. A correlation of Dinantian rocks in the British Isles. *Geological Society Special Report*, **7**, 87pp.

Ramsbottom, W.H.C. and 6 others, 1978. A correlation of Silesian rocks in the British Isles. *Geological Society Special Report*, **10**, 81pp.

Waters, C.N., Waters, R.A., Barclay, W.J. & Davies, J.R., 2009. Lithostratigraphical framework for Carboniferous successions of Southern Great Britain (Onshore). *British Geological Survey Research Report*, RR/09/01.

Waters, C.N. and 18 others, 2011. A Revised Correlation of Carboniferous Rocks in the British Isles. *Geological Society Special Report*, 26, 186 pp, ISBN: 978-1-86239-333-2.

The Ford Fiesta

The Geology Section of the Leicester Literary and Philosophical Society has a long and distinguished record that includes annual seminars on particular geological themes. The theme for 2013 was to honour Trevor Ford, who has a long association with the Society. A large number of Trevor's friends, colleagues and ex-students gathered at Leicester University to hear six distinguished speakers give presentations covering aspects of Trevor's work and the research that has followed in his footsteps.

The steeply raked lecture theatre with its rear entrance meant that Trevor sat at the very back. But his distinctive resonate tones boomed out from time to time in response to questions or queries from speakers or the audience. The speakers were: Dr Richard Shaw on the life of a modern day caveman; Dr Tony Waltham on Trevor's work in the Grand Canyon; Dr Bill Finches on the geology of the Isle of Man; Dr Noel Worley on Peak District mineralisation in Fordian style; Dr Dave Quirk on the origin of the South Pennine Orefield; Prof John Gunn on the hydrology of the Castleton karst; and Prof Martin Brasier on the iconic Precambrian fossil with a full name that reads as *Charnia masoni* Ford 1958.

These talks showed the wide range of Trevor's research interests and enabled the speakers to reminisce, often very humorously, over their association with him and to illustrate where his pioneering work had led. The day was smoothly organised by Joanne Norris and Andrew Swift, and was a fitting tribute to Trevor's geological career.

Excavations at the Broad Marsh caves

Excavation, clearance and documentation of the sandstone caves under Nottingham has been a long-standing project for a small band of dedicated archaeologists in the Nottingham Historical and Archaeological Society. For the last fifteeen years they have been working in the caves just west of the show cave beneath the Broad Marsh Centre, clearing debris from caves that should one day be part of an extended tourist site. They recently cleared down to a lower level, and had to build a timber bridge to maintain access to the spectacular Willoughby House caves. The East Midlands Geological Society contributed to the work by funding purchase of the materials for the bridge, with a grant to the NHAS; this was sourced from the bequest from Beryl Whittacker's estate, and she would be delighted to know that she has supported this work in her home town.

Geological map of Chesterfield

A new version of the geological map of Chesterfield has been published by BGS, as sheet 112 in the 1:50,000 series. Its coverage of the Matlock area gives it local interest for Society members, and it is a step forward from the old One-inch map with a wealth of detail and useful material in the style of the newer BGS maps.

Precambrian fossil discoveries and new fossil localities in Charnwood Forest, Leicestershire

Aron Bowers

Abstract: New localities with Precambrian fossils have been found in Charnwood Forest. New specimens include *Hadrynichorde* aff. *catalinensis*, which is a species potentially new to Britain. Also revealed are juvenile forms of organisms not recorded previously, and fossil forms that have no clear associations with currently recognised species.

Precambrian rocks have only limited exposures in Britain, as they are mostly buried beneath thousands of metres of younger strata. Even more limited are the sedimentary strata – tuffaceous and volcaniclastic rocks, which in Leicestershire are the result of locally extensive volcanic activity (Moseley and Ford, 1989; Carney, 2010).

Great swathes of Precambrian sedimentary rocks are exposed in Newfoundland, Canada, and in the Ediacara Hills of Australia, as well as in Russia, Eastern Europe and Africa, and these outcrops have yielded thousands of fossils belonging to the Ediacaran biota. In Britain, exposures of sedimentary Precambrian rocks relate to outcrops and quarries in Charnwood Forest, Leicestershire, with other exposures in Shropshire and in Southern Wales (Cope, 2000). With such restricted areas of exposed rock, the number of specimens discovered has been small.

Following the casting with silicone rubber of a Leicestershire quarry face famed for the holotypes of *Charnia masoni* and *Charniodiscus concentricus* (Ford, 1958), several hundred new specimens have come to light in a community termed the 'Mercian Assemblage' (Wilby *et al.,* 2011); this includes species previously unrecognised outside of Canada, and also new species that are unique to Britain.

Two new fossil localities can be added to the six already known in Charnwood Forest. A review of the known Bradgate Park fossil location has also yielded many new specimens. These include a plethora of juvenile forms, and proposed species that are previously unrecognised in Britain. Additionally, several unusual specimens, not akin to previously recorded forms, may be regarded as new elements of the Ediacaran biota.

History of fossil discoveries

The story of how the then-schoolboy Roger Mason discovered the holotype of *Charnia masoni* is well known (Ford, 1958). In 1957 he and two friends came across the fossil specimens while climbing in a quarry near Woodhouse Eaves. Bringing the specimens to the attention of Trevor Ford, at the University of Leicester, the specimens (*Charnia masoni* and *Charniodiscus concentricus*) were formally described up as the first unequivocal, macroscopic, Precambrian fossils to have been discovered (Ford, 1958).

In truth, the fossils had been discovered a year previously by a schoolgirl, Tina Negus (née Batty). But, without contacts within geology circles, she was only able to bring the specimen to the attention of her school teachers, where her find fell on deaf ears (Ford, 2011). The quarry location had several mentions in old texts. In 1848, J. Plant and J Harley had discovered ring-like impressions on the bedding surfaces, and the find was relayed to the geologist Prof. A. C. Ramsay (Howe *et al*., 2012). He interpreted the rings as being tethered seaweeds, blown about by currents to scribe circular scratch marks on the seabed (rather like the genus *Kullingia* (Kulling, 1964; Jensen *et al.*, 2002)). Prior to this, the ring marks had been well known to the quarry men, who colloquially referred to the site as the 'Ring Quarry'. It was later presumed that the marks were inorganic in origin (see *Mercian Geologist*, 2008, 4-5).

Discoveries in the 1970s by Trevor Ford, Bob King, and later Helen Boynton, revealed five new fossil sites. New species were described, namely *Bradgatia linfordensis*, *Ivesheadia lobata*, *Shepshedia palmata* and *Blackbrookia oaksi* (Boynton & Ford, 1995).

Fossiliferous bedding planes from all six localities have been cast in plaster by the British Geological Survey (Edwards and Williams, 2011), and the casts are now housed at the B.G.S. stores at Keyworth, Nottingham. From the casting in the large quarry from which the *Charnia* specimen was originally found, hundreds of new specimens have been discovered and several new species are currently being described (Wilby *et al.*, 2011).

Geological setting

The outcrops of Precambrian rocks in rural Leicestershire represent the core of a Charnwood Anticline, where the Blackbrook Group is succeeded by the Maplewell Group (Moseley and Ford, 1985). The Blackbrook Group includes the rocks of the Ives Head Formation, which is famed for the occurrence of a bedding plane where fossil species *Ivesheadia lobata, Blackbrookia oaksi* and *Shepshedia palmata* were discovered (Boynton and Ford, 1995). These fossils may represent *Charnia* like organisms in a state of decay prior to lithification, and as such these 'ivesheadiomorphs' have been interpreted as taphomorphs (Liu *et al.*, 2010). Within the Maplewell Group, the Beacon Hill

Formation has few fossil forms associated with it, but microbial matting and sparse discs occur in Bradgate Park. The overlying Bradgate Formation is the source of most of Charnwood's Precambrian fossils, including the iconic *Charnia masoni* (Ford, 1958).

The rocks of the Charnian Supergroup are mainly of volcanoclastic origin, consisting of grains derived from primary volcanic eruptions; material derived from the erosion of pre-existing volcanic deposits seems relatively rare (Carney, 2010). The reason that such delicate fossils exist, is that the finer grained ashy material periodically settled out onto the sea floor, engulfing living organisms and allowing them to be preserved. A possible explanation of why the Bradgate Formation contains the most fossil horizons is that the Maplewell Group represents a period of maximal volcanic activity, and subsequent volcanic ash fall out (Carney, 2010).

The new fossil locations

Within Bradgate Park, already famous for its fossil bed containing *Charnia* and *Bradgatia* genera (Boynton and Ford, 1995), a new fossil locality has been recognised on a bedding plane of about 20 m^2, which is extensively covered by lichen that obscures much of the finer structures. This bedding plane lies 4-5m stratigraphically below that on which lie the first Charnian fossils to have been recorded (Boynton & Ford, 1995); it is of a similar composition to the original site and lies within the Sliding Stone Slump Breccia beds (Bradgate Formation), but not in beds as coarse as the fossil-bearing bedding plane in the Beacon Hill Formation.

Two large ovate discs are exposed, together with an unusual form, reminiscent of a species of *Charniodiscus* (this specimen is faint, and warrants further investigation following cleaning of the rock surface). One of the discs is a large ovoid, 100x75 mm, in negative epirelief; it consists of two concentric rings with a faint halo of an outer ring just visible, nearly doubling its overall size; no attached frond is visible. The second disc is ovoid, measures 120x100 mm and is in negative epirelief; it has seven distinct concentric bands around a central ovoid depression that is 45x35 mm, but there is no frondose element or stem attached. A rock fracture bisects the fossil, which is thus stepped by 10 mm (Fig. 1).

The two fossil forms have attributes relating to *Aspidella* aff. *terranovica* (Billings, 1872). However, forms with such concentric rings have also been seen at the Quarry at Woodhouse Eaves (Wilby *et al*., 2011), where they occur as holdfasts of *Primocandelabrum* species (Hofmann *et al*., 2008). No frondose structures are visible at the new locality, so the association with *Primocandelabrum* cannot be confirmed.

A second locality occurs on the south-western limb of the Charnwood anticline, within an area known locally as the Altar Stones. Two coarse beds are interleaved with finer grained beds. Within the latter a discoid fossil with possible attached frondose element has been found. On the same bedding plane, two more discoid forms have been recognised. The initial specimen is a prominent, roughly circular disc, 36x34 mm, enclosing three faint concentric rings (Fig. 2). From a break in its outer margin a presumed, faint, undulating stem

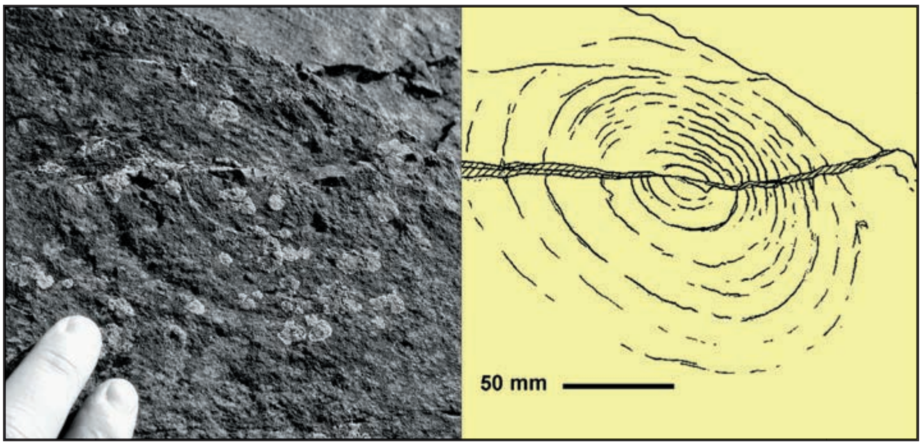


***Figure 1**. Large, concentric-ringed holdfast disc, with surface features partially obscured by lichens on the bedding plane.*

***Figure 2**. Discoid holdfast with possible conjoined, sinuous stem and mop-headed structure.*

Charnia grandis – one specimen
Bradgatia linfordensis – 15 specimens
Aspidella aff. *terranovica* – >150 specimens
Cf. *Primocandelabrum* – 3 specimens *
Hiemalora sp. – 2 specimens *
Cf. *Hadrynichorde* – 4 specimens *
Juvenile colony forms – 35 specimens *
Filament forms *
Problematica, inc. possible worm traces

***Table 1**. Fossils recorded in the new investigations in Bradgate Park; asterisks denote newly recorded species and forms.*

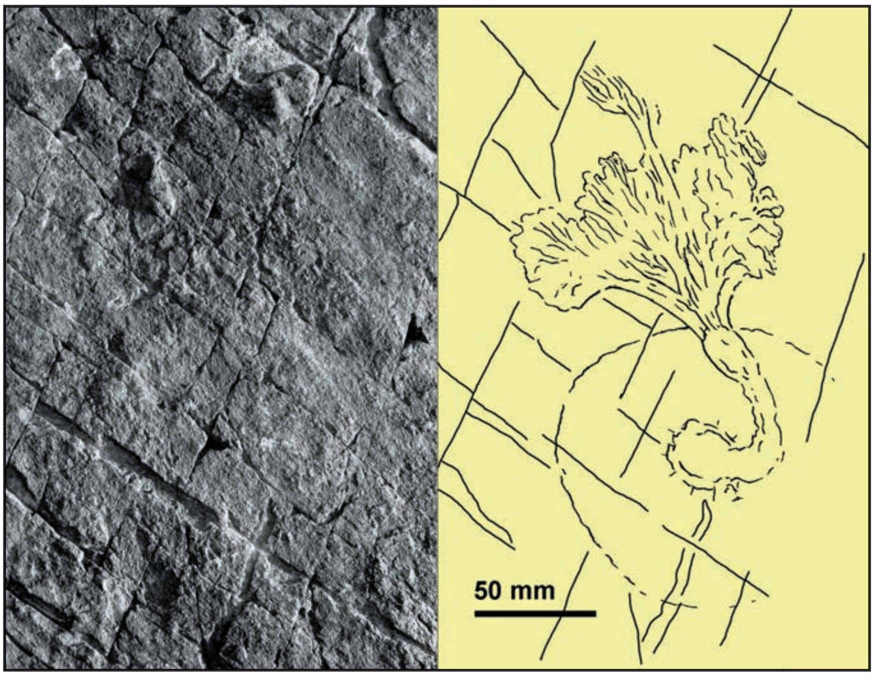


***Figure 3**. Fossil comparable with* Primocandelabrum*, with large circular holdfast, curved stem and cauliflower-like frond complex.*

***Figure 4**. Presumed* Primocandelabrum *multi-ringed discoid form with a break in its outer ring and an emerging stem with globose frond attached.*

extends for 57 mm to terminate in a bulbous ‘mop-headed’ structure that is 55x35 mm. The total length of the specimen is 147 mm. Two further three-ringed circular discs have diameters of 34 and 31 mm. The fossil horizons correlate with the Sliding Stone Slump Breccia, at the base of the Bradgate Formation, and are at the same stratigraphical level as the original fossil locality in Bradgate Park.

The Bradgate Park fossil plane

Bradgate Park is a large enclosed area of parkland that contains the classic fossil locality (Boynton and Ford, 1995), which is a bedding plane at the top of 25 or more distinct silty laminae. This offers an insight to a Precambrian sea floor of about 563 million years ago (Wilby *et al*., 2011). The surface shows little signs of current-activity, indicating that the sea floor was well below the storm wave base, probably beneath water that was over 50 m deep (Carney, 2010).

The site had previously yielded more than 50 fossil forms, including the holotype and paratypes of *Bradgatia linfordensis* (Boynton and Ford, 1995). Fossils previously described consist largely of discoid forms (*Aspidella* aff. *terranovica*), *Bradgatia* specimens, a large *Charnia grandis* (Boynton and Ford, 1995; Ford, 1999) and a small juvenile specimen of a *Charnia* frond only 17mm long. The new investigation of the classic Bradgate Park fossil plane has revealed more than 200 fossil forms, including species not recognised previously (Table 1).

Forms comparable with *Primocandelabrum*

A genus previously thought to be endemic to Newfoundland, *Primocandelabrum* (Hofmann *et al*., 2008), has recently been discovered at the Quarry at Woodhouse Eaves (Wilby *et al*., 2011). Two *Primocandelabrum* forms also exist on the Bradgate Park fossil plane; they are visible only at dawn, with oblique natural lighting. A possible third specimen is a juvenile (see below).

One specimen has a circular disc (holdfast) 142 mm in diameter, with an off-centred attached stem 70 mm long, terminating in a slightly bulbous swelling before the emergence of a cauliflower-like frond complex 150 mm wide and 170 mm high (Fig. 3).

The second specimen has an ovoid disc 90x80 mm, with seven concentric rings broken where a stem 80 mm long emerges and terminates in a globose structure, roughly circular and 65 mm in diameter (Fig. 4). Among the *Primocandelabrum* related species from

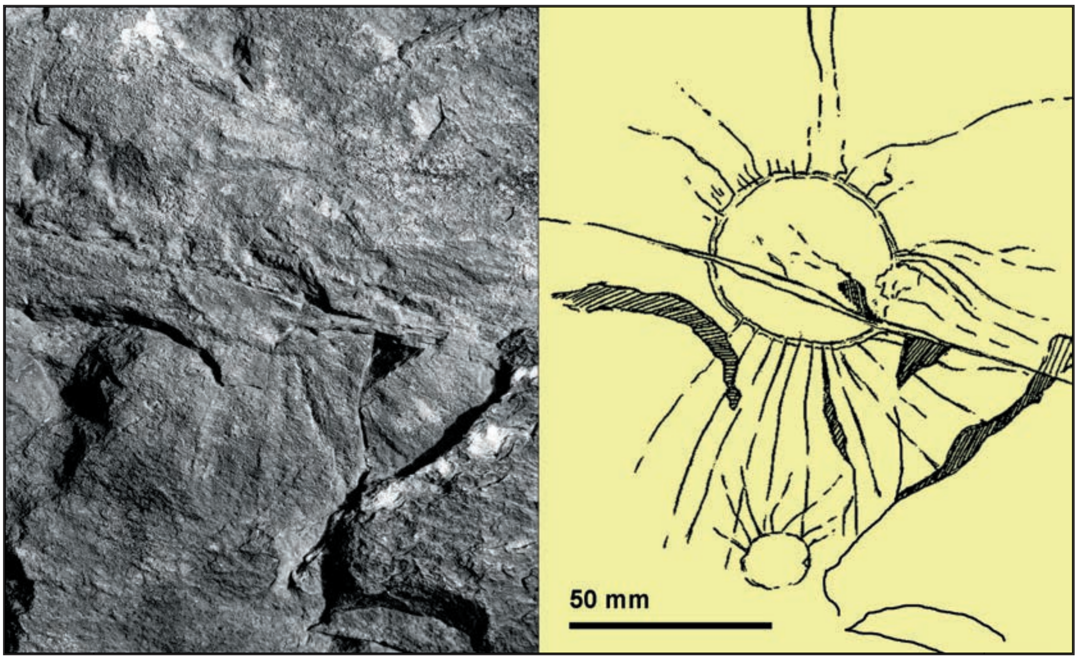


***Figure 5**. Two specimens of different sizes of* Hiemalora *aff.* stellaris, *with their raised-rimmed holdfasts and stellate, radiating, anchoring filaments.*

Leicestershire, a globose-headed, ‘dumb-bell’ taxon (Wilby *et al*., 2011) may possibly relate, albeit the frond of the Bradgate Park specimen is rather faint.

Hiemalora specimens

Two distinct *Hiemalora* aff. *stellaris* (Fedonkin, 1982) specimens have been discovered at the Bradgate Park fossil plane. This also is a species previously thought endemic to Newfoundland, but which has recently been described from the Quarry at Woodhouse Eaves (Wilby *et al*., 2011). It was once thought to be a medusoid form, but it may refer to an anchored holdfast of *Primocandelabrum hiemaloranum* of Newfoundland (Hofmann *et al*., 2008).

The Bradgate Park fossils consist of two forms in close proximity (Fig. 5). The holdfasts are discoid structures, with a well-defined raised rim, from which numerous anchoring filaments arise and radiate. The larger specimen has a disc 50x38 mm, with filamentous anchoring arms up to 50 mm long. Beside the larger specimen, a smaller one consists of a circular disc 16 mm across, with anchoring filaments to 20 mm long.

Specimens comparable with *Hadrynichorde*

With the advantage of natural oblique lighting, several long filamentous structures are visible with a morphology that mirrors specimens of *Hadrynichorde catalinensis* (Hofmann *et al*., 2008) from Newfoundland. The species has been interpreted variously as fine worm traces comparable with *Planolites*, or whip-like algal forms, and also possibly related to the *Laminaria*-like kelp fossil *Hadryniscala avalonica*, also from Newfoundland (Hofmann *et al*., 2008). The *Hadrynichorde* genus is typified by a raised ovoid disc attached to a long, fine, filament structure 1 mm in relief, 1.0–2.5 mm wide and up to 730 mm long. The filament is typically tapered, with graceful curves along its length, with small bulbous swellings, so that it resembles knotted string.

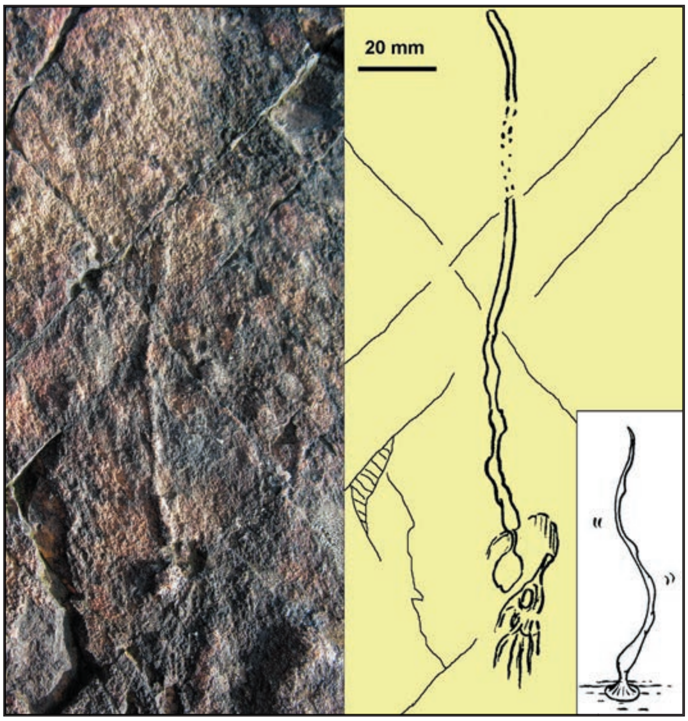


***Figure 6**. A fine filamentous item, possibly* Hadrynichorde *aff.* catalinensis.

The largest of the newly discovered Bradgate Park forms is 430 mm long, with a small ovoid, basal holdfast 16x10 mm. Its relief is about 1 mm, and it tapers from 2 mm wide to 1 mm at its tip. A smaller specimen, 150 mm long, has small thickenings along its length, again in the style of knotted string (Fig. 6). These fossils appear to be *Hadrynichorde* aff. *catalinensis*, which would be a genus and species new to Britain and Europe.

It is proposed that *Hadrynichorde* species may represent an extinct forerunner of extant species described as sea-whips, which are colonial forms of deep-water environments. Modern colonies (eg. extant species *Funiculina quadrangularis* of British waters) are found in close association with sea-pens (*Pennatula* sp.). It is notable that *Charnia* was for many years

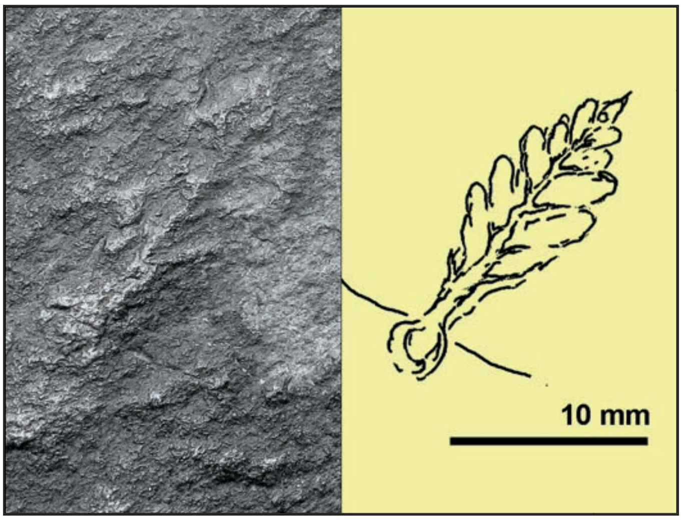


***Figure** 7. Fossil comparable with* Charniodiscus*, with disc holdfast, conjoined stem, and branches from central rachis.*

presumed to be a sea-pen, until cleary demonstrated not to be related (Antcliffe and Brasier, 2007). That sea-whips and sea-pens co-exist in today's deep oceans seems to mirror a Precambrian deep-water environment where *Charnia* and *Hadrynichorde* coexisted.

Juvenile fossil forms

Juvenile fossil forms of Precambrian age are exemplified by the Drook Formation of Newfoundland, which has revealed a bedding plane on which juvenile specimens occur amidst specimens of *Ivesheadia lobata* (Liu *et al*., 2012, 2013). The so-called Ivesheadiomorphs are interpreted as being taphomorphs derived from decayed frondose organisms such as *Charnia*, and as such have been called 'effaced' specimens (Liu *et al*., 2010). The association between juvenile specimens, with no fully developed adult specimens, and dead, rotting, specimens is ecologically significant. It suggests the fossil plane shows re-colonisation of the seabed after a mass mortality event (Liu *et al*., 2012).

The Bradgate Park fossil plane has multiple large 'adult' forms of *Bradgatia linfordensis* and *Charnia grandis* present, and yet about 35 specimens of small, juvenile fossils have been found. The range of lengths of the juveniles is 11–38 mm, with one *Charniodiscus* specimen of 78 mm. That specimens of juvenile size should co-exist with adult-sized forms suggests a vibrant environment, where reproduction is occurring and both young and old organisms exist side by side. It is not indicative of re-colonisation of an area of seabed following a mass mortality event.

The only previous reference to juvenile forms at Bradgate Park was to a *Charnia* specimen of 17 mm length (Boynton and Ford, 1995). With a small disc, pronounced stem, and a frond with a central rachis and paired branching forms, it seems more reminiscent of *Charniodiscus*, but this is open to interpretation.

The interpretation of juvenile fossil forms is difficult, as the specimens, by their very nature, are small, and some of the fine details required for identification are lacking. Fossils from the Drook Formation fall into several categories, akin to genera *Charnia*, *Charniodiscus*, the Newfoundland genus *Trepassia* (Narbonne *et al*., 2009), and indeterminate forms (Liu *et al*., 2012). The juvenile forms on the Bradgate Park bedding plane fall into six groups (Table 2).

Forms comparable with *Charnia masoni*

Two specimens from the Bradgate Park fossil plane have primary, secondary and, on one of the specimens, possible tertiary branches visible. In spite of their small size (15 mm) the apices are clearly visible, but the basal ends of the forms are missing, so full estimation of overall length is not possible.

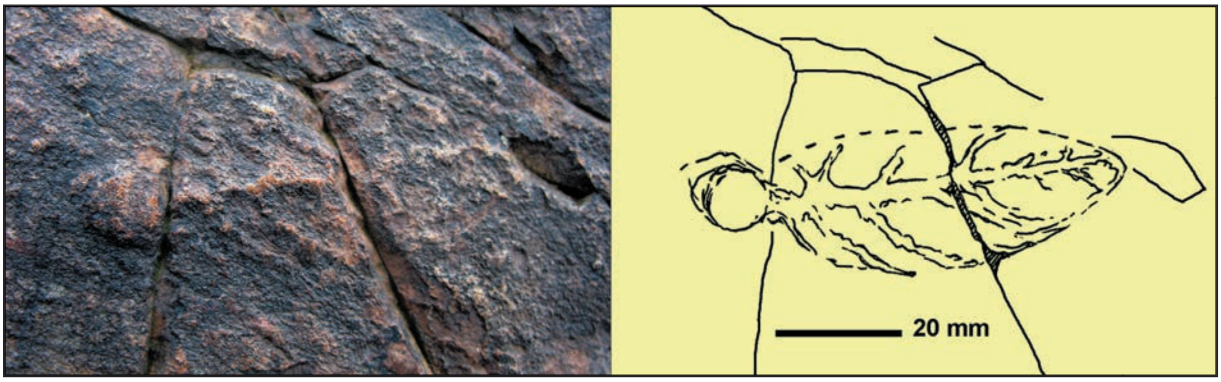
Forms comparable with *Charniodiscus*

There are several juvenile forms with morphology akin to the genus *Charniodiscus*. They typically feature a small round disc, with a short stem attached to a lanceolate, tapered frond, with a prominent rachis. From the rachis arise paired, angled branches (Fig. 7). Some of the forms have markedly tapered fronds, terminating almost in a spike, like the species *C. spinosus* (Hofmann *et al*., 2008). This analogy is open to interpretation, but the species is not known from British assemblages. Also present on the bedding plane is a *Charniodiscus* type of intermediate size, 78 mm long (Fig. 8).

Cf. *Charnia masoni*
Cf. *Charniodiscus*
Charniomorph forms
Multi-filamentous forms
Primocandelabrum forms
Disc and stem forms

***Table** 2. Juvenile forms of fossils that have been recognised at Bradgate Park.*

***Figure 8**.* Charniodiscus *form.*



Charniomorph forms

Several forms have distinct *Charnia* like morphologies, but the specimens lack the fine details of first and second order branching to assign a species. Specimens of discs, with attached stems and lanceolate fronds are reminiscent of *Charniodiscus*, but are also too weathered to reveal finer detailing. A small disc holdfast, with long stem, lanceolate frond and possible crenulations along its edge, may have *Charniodiscus* affinities (Fig. 9). An unusual specimen has a small, faint disc, no stem, and a long rachis with many paired branches that emerge nearly perpendicular to the rachis (Fig. 10). A narrow, lanceolate form, it does not seem to resemble the current known genera of fossils from the Mercian Assemblage at Charnwood Forest.

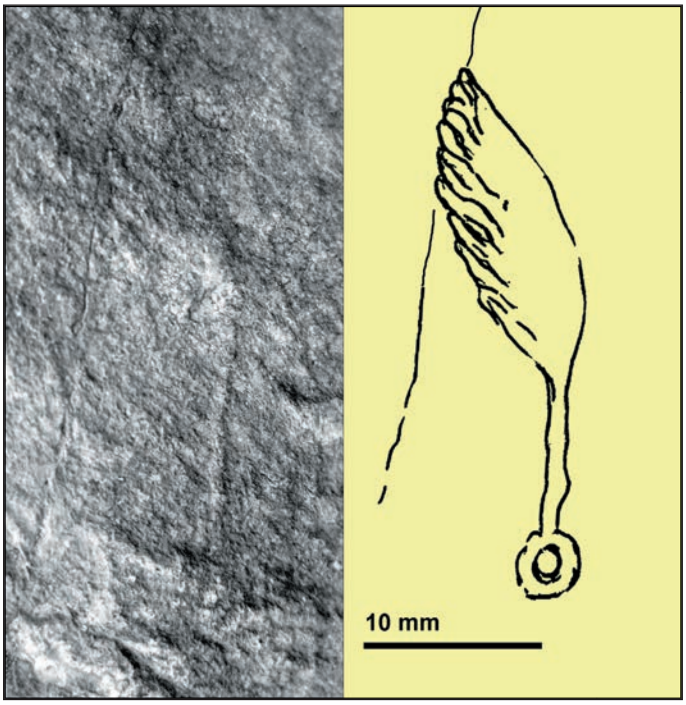


Figure 9. *Charniomorph, with concentric disc holdfast, conjoined long stem and frond.*

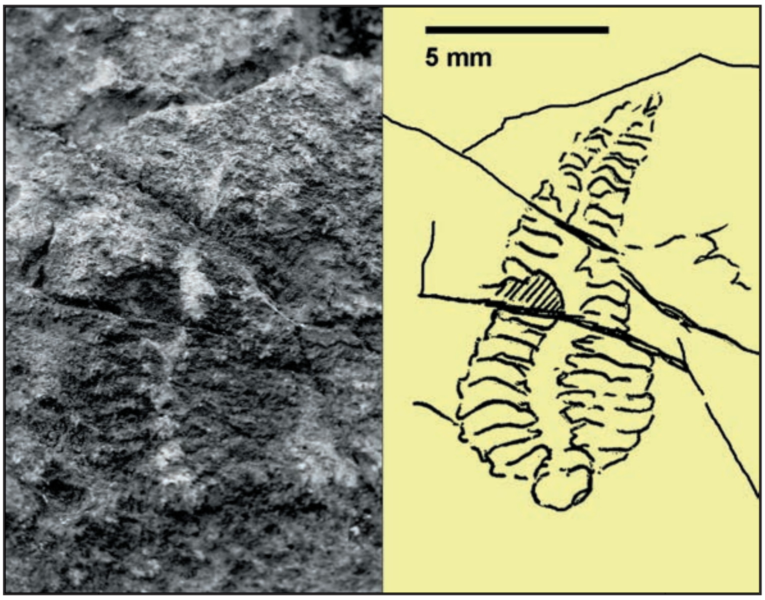


Figure 10. *Charniomorph with a faint disc, no stem, long rachis, and near-perpendicular branches.*

Multi-filamentous forms

Two of the new specimens have morphologies quite unlike other fossil species of the Mercian Assemblage. One specimen had previously been interpreted as the 'type-D' variant of *Bradgatia linfordensis* (Boynton and Ford, 1995), but this may be incorrect. The specimen is slightly broken, but no distortion is present. It does not show the *Charnia*-like elements (Boynton and Ford, 1995), but possesses at least seven separate filament structures, each tapering to a blunt point (Fig. 11). The filaments arise from a central source, now obscured as a result of vandalism, and one filament appears to be angled, near its tip, at 45° degrees, such that it overlaps the adjacent strand above. An estimate of overall length is 50 mm. A second multi-filamentous fossil (Fig. 12) has a small, faint disc structure attached to an off-centred rachis, from which emanate filamentous strands, each about 25 mm long, which are separated but extending parallel with each other. Total length of the partial form exposed is 42 mm. The morphology of these forms poses many questions; they may be juvenile forms of known genera, or potential new species.

Specimen comparable with *Primocandelabrum*

A single specimen on the fossil bedding plane has a morphology reminiscent of the many specimens of *Primocandelabrum* sp. as described elsewhere in Charnwood Forest (Wilby *et al*., 2011). It is 60 mm long with a discoid holdfast and an attached, tapered stem (Fig. 13). The stem terminates in a calyx-like form, from which emerges a rounded cluster of branches.

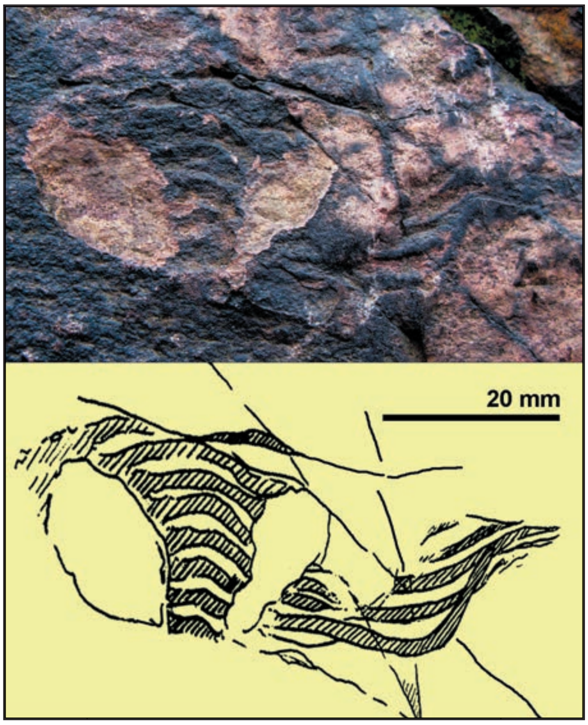


Figure 11. *Multi-filamentous form with an indeterminate base and seven sinuous filaments.*

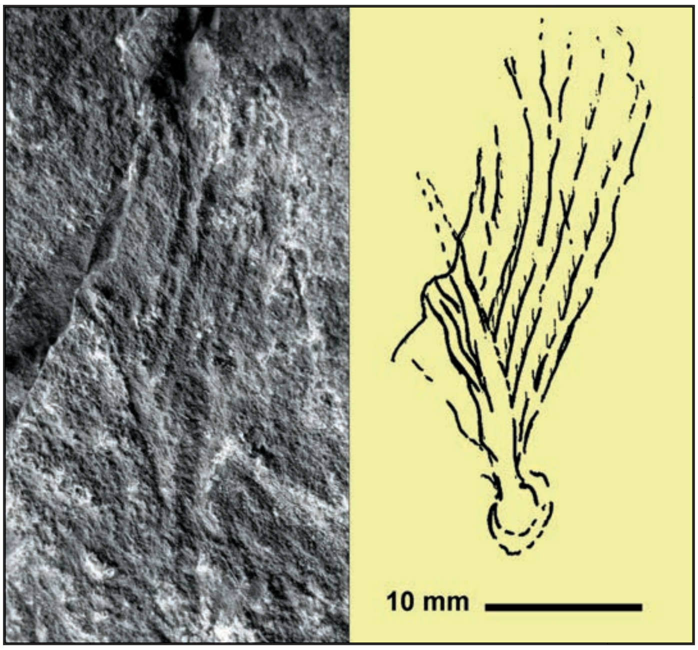


Figure 12*. Multi-filamentous form with a faint disc and with parallel branches emanating from its rachis.*

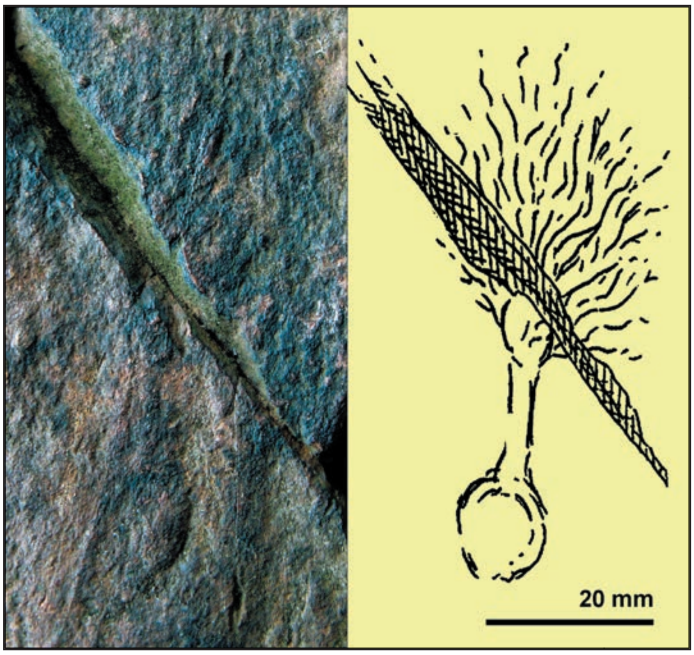


Figure 13*. Fossil comparable with* Primocandelabrum*, with a comparatively large disc holdfast, stout stem, and cluster of branches.*

Disc and stem forms

Many specimens exist of small disc-like holdfasts, 3–5 mm in diameter, with conjoined stems from their centres, but with no definable frond structure attached. Whether the delicate frond features were destroyed in the fossilisation process, or were ripped away by sea current activity is unknown. These specimens are difficult to classify taxonomically, but seem to add to the many, larger specimens of *Aspidella* aff. *terranovica* on the fossil plane and disc holdfast fossils of unknown affinity.

Problematica

There are specimens on the bedding plane that show no affinity to known genera of Precambrian fossils from Charnwood. Interpretation of these forms is difficult, as they are often isolated examples. Of note is the fossil interpreted as worm trail like *Planolites* (Boynton and Ford, 1995).

The Mercian Assemblage environment

Although the areas of Precambrian rocks in Charnwood Forest are small compared with extensive fossil planes in Newfoundland, they do show promise for future fossil discoveries. Investigations in 2012 have revealed two new fossil localities, one in Bradgate Park, an area already famed for Precambrian fossils, and another at the Altar Stones, in rocks of similar stratigraphical age. The new discoveries, from the two new localities, are largely discoid fossil forms, between 32 and 120 mm in diameter.

The well-known Bradgate Park fossil plane has revealed many new fossils, and the number of known fossil species has greatly increased, with the inclusion of the genera *Primocandelabrum*, *Hiemalora* and probably *Hadrynichorde*. The probable *Hadrynichorde* specimens may represent a species that is new to Britain and Europe. Of particular note are the large numbers of juvenile Precambrian organisms that have been found, many with affinities with the known fossil genera from Leicestershire, but others that may represent new species.

The juxtaposition of juvenile forms with similar larger organisms indicates a vibrant life assemblage on the Precambrian sea floor in what is now rural Leicestershire (Fig. 20). The biota of Newfoundland represents a deep-water environment, not dissimilar to that of the Leicestershire biota. Being so similar, these two environments share many species, which presumably occupy the same niches. *Charnia*, *Charniodiscus*, *Bradgatia*, *Aspidella* and the possible effaced taphomorphs *Ivesheadia* and *Blackbrookia* are all known to be common to both the Avalonian Assemblage in Newfoundland and the Mercian Assemblage in Leicestershire.

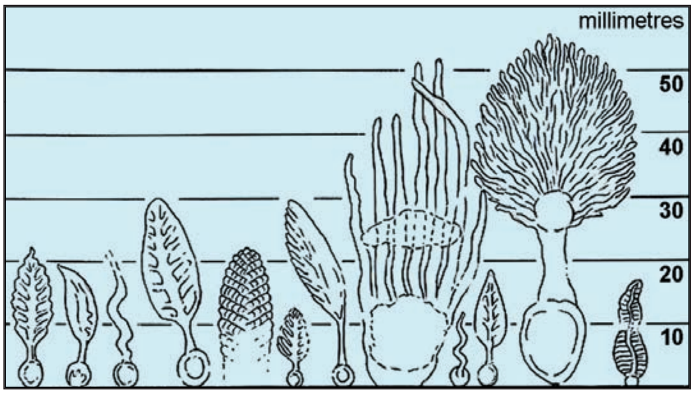


Figure 14*. Some of the juvenile fossils that occur on the bedding plane in Bradgate Park.*

New casting techniques of classic Charnwood Forest sites have revealed that presumed Avalonian endemic genera, such as *Hiemalora*, *Primocandelabrum* and *Thectardis*, are also found in the Mercian Assemblage, and the degree of endemism presumed for Newfoundland has been over-estimated (Wilby *et al.*, 2011). The probable *Hadrynichorde* forms of Bradgate Park may represent another species no longer endemic to Newfoundland, but common to the Leicestershire biota.

Acknowledgements

The author would like to thank Alex Liu, Helen Boynton, Arthur King and Trevor Ford for their discussions and opinions.

Site access

Classic localities of Precambrian fossils have been victims of mindless vandalism and also attempts at fossil extraction. Details of site locations are therefore now withheld, but legitimate researchers can gain information by contacting Dr. Mike Howe (at mhowe@bgs.ac.uk or at British Geological Survey, Keyworth, Nottingham NG12 5GG, UK).

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Tufa deposits in the Via Gellia, Derbyshire

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Anthony H Cooper and Peter F Jones**

Abstract: Detailed mapping, sampling and petrological analysis of a tufa deposit in the Via Gellia, above Cromford in Derbyshire, has enabled interpretation of the depositional and post-depositional history of the tufa in context of the geomorphology and hydrogeology of the area.

Holocene deposits of cool-water travertine (also known as tufa or secondary carbonate) are extensive and well-studied in Italy (Buccino *et al*., 1978; Chafetz & Folk, 1984; Conti *et al*., 1979; Ford & Pedley, 1996), where they form an extensive resource that is used for construction (Buccino *et al*., 1978). Although widely distributed, tufa deposits in Britain are generally less extensive (Ford & Pedley, 1996; Viles & Goudie, 1990; Ford, 2006). This makes the thick and once-economically viable deposits of tufa in the Peak District all the more interesting. Examples include the barrage deposits of Lathkill Dale and the Wye in Taddington Dale (Pedley, 1993; Pedley *et al*., 2000) and the perched spring-line deposits in Matlock (Pentecost, 1999).

The exploitation of tufa as a construction material in the Peak District dates back at least to the development of the Peak District thermal waters as Hydros, or Spas, including the opening of Matlock Baths in 1698 (Hey, 2008). A typical example of the use of tufa as a decorative stone has been retained in the grotto of the Winter Gardens at Matlock (Fig. 1). Historically tufa was also exploited for land improvement, and its use as a source of lime predates its use in construction: “the softer parts of the Tufa or deposits made by Springs from the Limestone Rocks at Matlock Bath and some other places are called *marl*, and according to tradition, were formerly used as such, but the practice is quite laid aside I believe” (Farey, 1811, v1, p457). More recently, it was observed that the soil above tufa is very fertile and that “many tons of it are annually sent out of Derbyshire” (Adam, 1851, p33) so its exploitation had not been completely set aside by 1811. Evidence of this exploitation is limited to a small number of abandoned quarry sites, including the roadside Alport Quarry and a small outcrop in the Via Gellia.

Figure 1. Tufa wall in the Winter Gardens, at County Hall, Matlock (photo: University of Derby).

Figure 2. Tufa Cottage in the Via Gellia (photo: Tony Waltham).

Tufa in the Via Gellia

An old quarry lies close to the south-eastern boundary of the White Peak, in the Via Gellia, above Cromford and south-west of Matlock. Tufa deposits crop out to the west and north-west of Tufa Cottage, a well-known landmark constructed of tufa (Fig. 2). Historic maps indicate that the quarry, which once surrounded the cottage, was in existence by 1884 and was disused by 1938. Tufa Cottage, formerly known as Marl Cottage, was built as a gamekeeper’s cottage in around 1830. The two Dunsley Springs lie at the head of the tufa deposit (Figs. 3 and 4).

Previous references to these deposits suggest that the tufa dates to 9000 to 4000 BP (Ford & Pedley, 1996). Others have recorded the stable isotopes of oxygen and carbon as a means of determining the depositional environment (Thorpe *et al*., 1980; Viles & Goudie, 1990). The aim of the current work was to map the extent of the tufa, establish its relationship with the underlying geology, examine the morphology, macro- and micro- structure of the tufa and monitor the associated spring chemistry to determine whether active deposition or erosion was occurring.

The Via Gellia tufa lies on the Bee Low Limestone Formation (Fig. 4, Table 1), which comprises thickly bedded, shallow-water limestones interbedded with basaltic volcanic rocks (Brossler, 1998; Flindall and Hayes, 1971; Macdonald et al., 1984, and Smith et al., 1967). The tufa is formed on the beds immediately underlying the Matlock Lower Lava, which occurs at a stratigraphically equivalent level to the Miller’s Dale Member around Buxton. The overlying Matlock

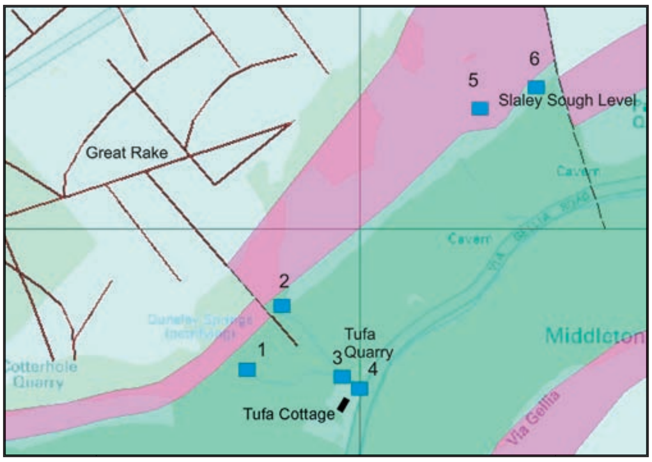

***Figure 3**. Geology around Tufa Cottage and the spring monitoring points; the Dunsley Springs are sites 1 and 2, and the Dunsley Spring Level was not monitored.*

Group comprise dark grey and grey limestones with, locally, much chert. The site lies immediately south of the Cronkston-Bonsall Fault, a significant basement fault associated with dolomitization of the limestones (Gutteridge, 1987). A sporadic cover of superficial deposits includes head on the valley sides, particularly on the southern side of the valley, pockets of glacial till on the plateau surface, tufa on the northern side of the valley (Fig. 4), and alluvium along the valley floors.

A number of NW-SE trending mineral veins cross the area and are intersected by the NE-SW trending Great Rake (Fig. 3). The lead-zinc mineralization was exploited in a number of phases, possibly even dating back to the Roman occupation of the area (Brossler, 1998). Ore minerals include galena and sphalerite, with gangue largely of calcite, barite and fluorite, and with small pockets of secondary ochre, wad and smithsonite. The latter was worked in the Bonsall Leys Liberty for the brass-making industry (Brossler, 1998; Rieuwerts, 2010). Flindall and Hayes (1971) reported on the findings of a survey undertaken on the north side of the Via Gellia by the Mines Survey Group of the Peak District Mines Historical Society (PDMHS). Beneath Bonsall Leys, the Yule Cheese Vein was drained by the Dunsley Spring Level, 150 m south-west of the Dunsley Springs (Flindall and Hayes, 1971). The southern of the Dunsley Springs aligns with the southern end of one of the NW-SE rakes, and the northern spring is close to a parallel rake.

Stage	*Group*	*Formation*
Brigantian	Craven	Longstone Mudstone
	Peak Limestone	Eyam Limestone
		Monsal Dale Limestone
Asbian		Bee Low Limestone *with Lower Matlock Lava*
Holkerian		Woo Dale Limestone

***Table 1**. Stratigraphy of the limestone.*

The Peak District forms the southern part of the Pennines, comprising a dissected upland terrain. Its karst geomorphology includes deep valleys, limestone gorges, scree-clad slopes, a range of dolines, ridges, tors and rock pinnacles (Dalton *et al*., 1999). The area exhibits a complex geomorphology that reflects a long history of uplift and erosion, with response to glacial, glaciofluvial and periglacial processes, and considerable anthropogenic modification.

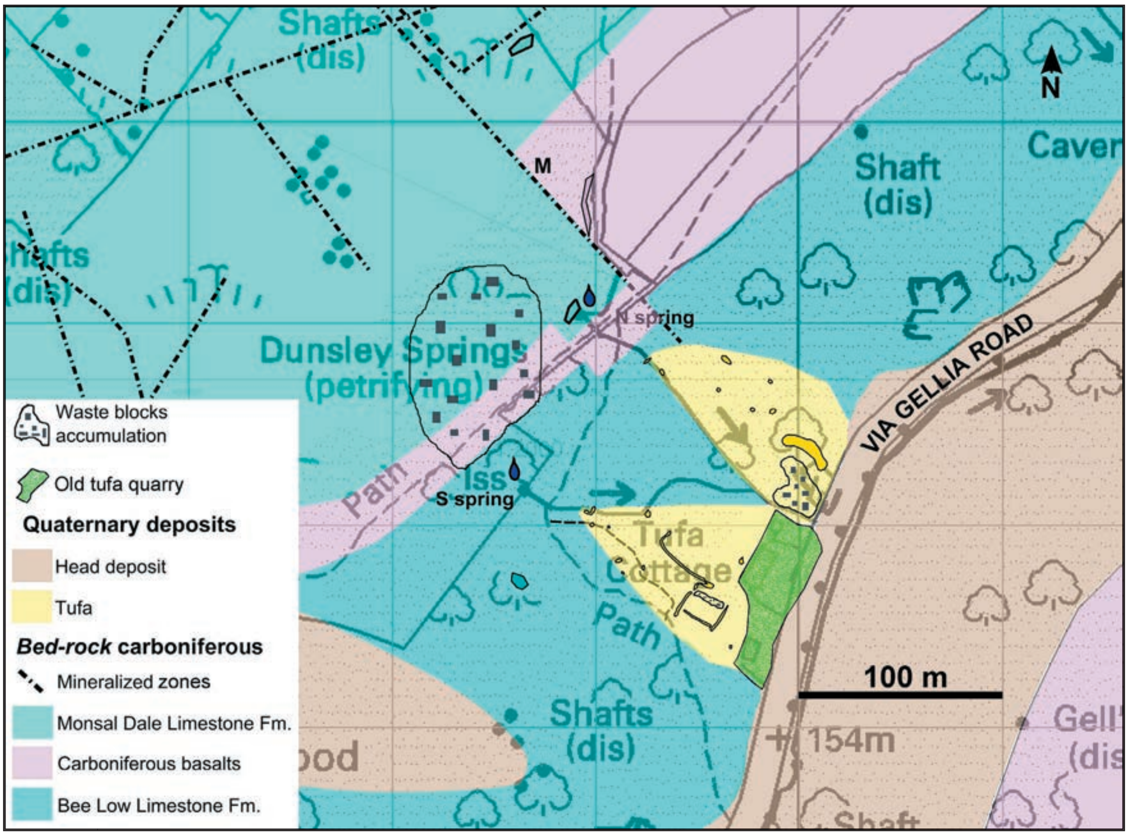

***Figure 4**. Revised geological map of the tufa in the Via Gellia; earlier maps had been generalised to show only a single patch of tufa. Broken material previously mapped as landslide debris is re-interpreted as an accumulation of mine waste derived from the mining in Bonsall Leys Liberty, which extended across the limestone plateau.*

The Via Gellia is a deeply incised, wooded valley, draining eastwards to its confluence with the River Derwent at Cromford, and is around 100 m deep in the vicinity of the tufa deposit. The profile of the valley is steep sided and symmetrically V-shaped, with a meandering thalweg. Tufa Cottage and the associated tufa deposits occupy the northern side of the valley, on the outside of a meander. The valley floor alluvium is currently occupied by an intermittent stream that receives water from both natural sources and mine adits; the stream is perennial downstream of the Dunsley Springs.

At around 325 m OD, the plateau surface above the Via Gellia largely comprises fields of pasture that are bounded by stone walls and are interrupted by scars of the former mining activity. Where they are undeveloped, the valley sides have a thick cover of deciduous woodland. Slopes of 25° or more, attributable to rapid valley incision, have resulted in slope instability and landslides, particularly in areas where beds of limestone are underlain by the basalts. The karst is locally less developed than in other areas of the Peak District; the Good Luck Mine on the south side of the Via Gellia has a long series of narrow adits, crosscuts and small stopes of the early 19th century, which have intersected a number of small solution caverns (Barker & Beck, 2010).

Anthropogenic impacts on the geomorphology of the Via Gellia are dominated by mineral exploitation, quarrying, agricultural modification and industrial development. While quarrying of the tufa has ceased, the more extensive quarrying for limestone continues. Agricultural modification has included enclosure of fields, which have been primarily used for grazing. Modification to springs to facilitate water supply for mining and industry has been widespread. Examples of this lie in documents held in the Derbyshire County Records Office at Matlock (Table 2). Historically, the springs had been used as a source for watering cattle, and during periods of drought the inhabitants of Middleton and elsewhere fetched water from the springs for their own use. Industrial development in the valley was focused on the watercourse, with a water wheel situated in the Via Gellia Mill at the junction of Bonsall Road. In 1936 the mill owner alleged that if the waters were taken from the Dunsley Springs the power and efficiency of the wheel would diminish with a consequential loss of value to the mill. The County Council (in 1934) noted that in the summer the Via Gellia Stream dries about 300 m downstream of Marl Cottage and the loss of this water is at the Whitecliffe Fault, through which it is believed water escapes into the Meerbrook Sough. A thermal spring, known as Middleton Bath, was located opposite Tufa Cottage until it ceased to flow after driving of the Cromford Sough (Ford & Gunn, 2007), but its hydrology may have been totally independent of the Dunsley springs. It is, or was, one among many small springs in the Via Gellia valley.

Date	*Action*
1935	Monitoring of the Dunsley Springs at Marl Cottage. The discharge ranged between 7.53 and 5.18 L/s between April and August 1935.
20.05. 1936	Agreement between Thomas Harold Walker of Via Gellia Road, Cromford and the Urban District Council of Wirksworth, which allowed the Council to impound and use water from Dunsley Spring in the Via Gellia in the Parish of Bonsall, in the Urban District of the Matlocks. Given the notice of the Ministry of Health regarding the urgent need for water for the people of Middleton Mr Walker agreed to withdraw his opposition in return for compensation of £127.
14.08. 1936	Agreement that with regard to the supply of water to the Marl Cottage the Council shall enclose Spring No.1 and provide a storage tank at Spring No. 2. Mr Key (of Cromford) agreed to the alteration of the line of the pipetrack so as to avoid a newly opened quarry at the line previously intended for the pipeline.

***Table 2**. Records from the Derbyshire Records Office pertaining to the Dunsley Springs (file items # D7017/6/32 and D7167/6/30).*

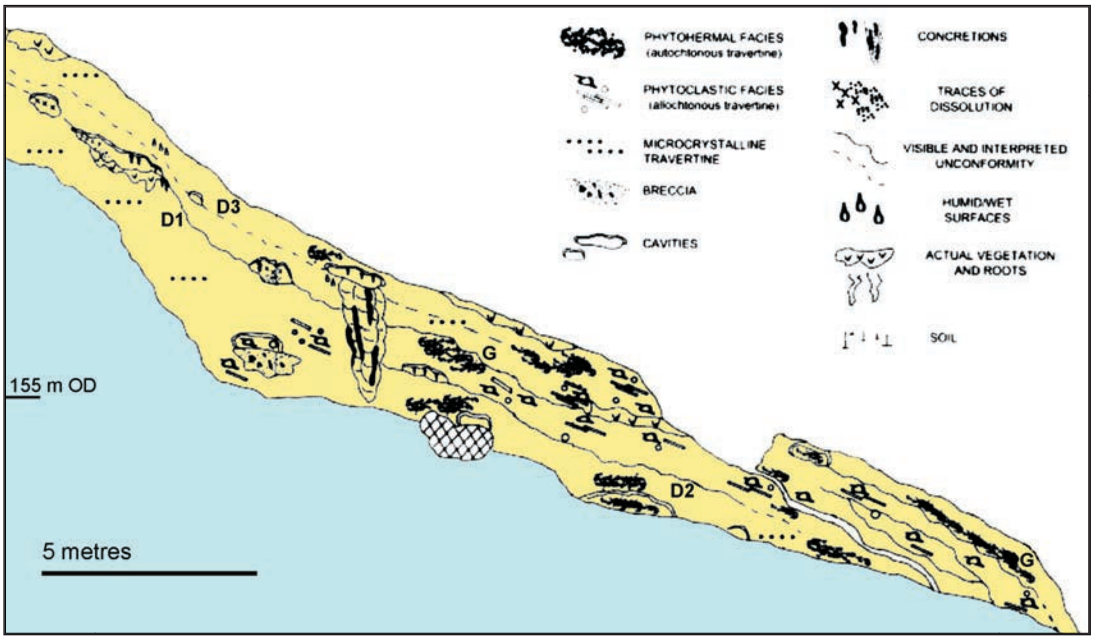

***Figure 5**. Profile of the quarried exposure within the tufa bank at SK 27015 56829.*
D1, D2 and D3 are unconformities, and G denotes a step in the tufa surface.

New mapping reveals that the tufa comprises two discrete cones over the carbonate bedrock (Fig. 4). In the dense woodland, slope angles were significant for the mapping. The upper surface of the Lower Matlock Lava forms a low-angle, bedding-parallel surface, whereas the limestones form steep slopes (> 25°) that are modified by the overlying tufa (resting at angles of up to 25°). A quarried face 40 m north-east of Tufa Cottage provides a section through the northern cone of tufa (Fig. 5). This section shows a fan-shaped form, with higher slope angles on the upper valley side giving way to lower slope angles lower down the valley side. Erosional unconformities (D1, D2 and D3) in the quarry section suggests that it comprises at least four beds of tufa. Five exposures of the southern cone reveal comparable features.

Morphology of the tufa

The quarry section (Fig. 5) exposes a variety of depositional and erosional, macroscopic features of the tufa. Zones of developed (*in situ*) phytoherm (Fig. 6) appear to be more extensive higher in the sequence and comprise interwoven stems of a number of different plant species. Typically the plant stems have diameters of 1 to 5 mm and include *Cratoneurom filicinum* and *Eucladium verticillatum*. These zones are better exposed where they are blanketed by actively growing mosses. Phytoclastic (washed in) facies include foliage, stems, tree branches and tree trunks (Fig. 7) and comprise fragments of organic matter that were preserved in the tufa at the time of formation.

Microcrystalline tufa, which is grey in colour, has a sugary texture and is interpreted as reverting from sparry calcite (Fig. 8A). This tufa is generally massive and relatively dense, but with local dissolutional porosity. Speleothems and encrustations (Fig. 8) occur in a number of cavities and fractures and at a variety of sizes. Stalactites are common, with diameters of 2 mm to 2 cm. Encrustation of pre-existing phytoherm reduces the porosity of the tufa. Breccias are either matrix- or carbonate cement- supported. Dissolutional cavities include both primary and secondary cavities associated with speleothems and encrustations. Pinkish brown clayey silt deposits line a number of the dissolution cavities, and would appear to have been introduced by vadose flow.

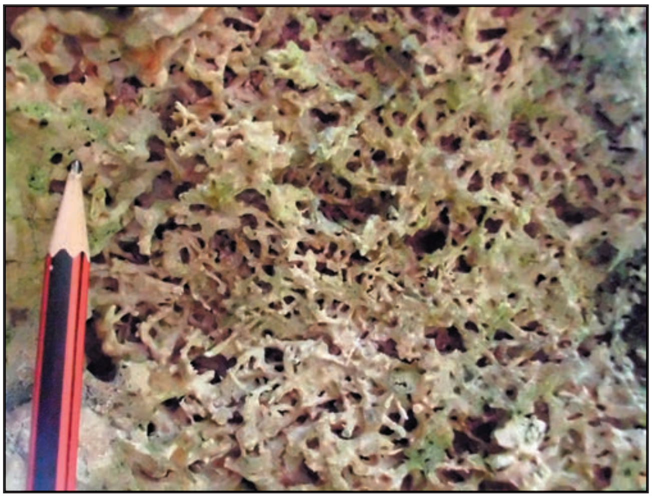

***Figure 6 (left)**. Autochthonous tufa with bush-like morphology probably derived from cemented* Cratoneurom filicinum.

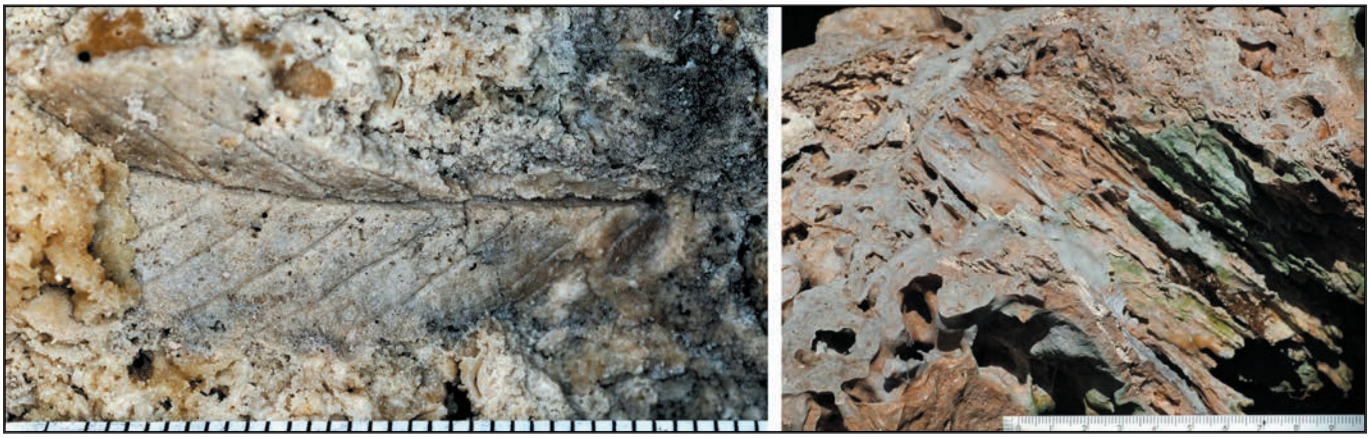

***Figure 7**. A leaf and a tree trunk preserved in the tufa at the Via Gellia; leaf scale is in mm, tree scale is in cm.*

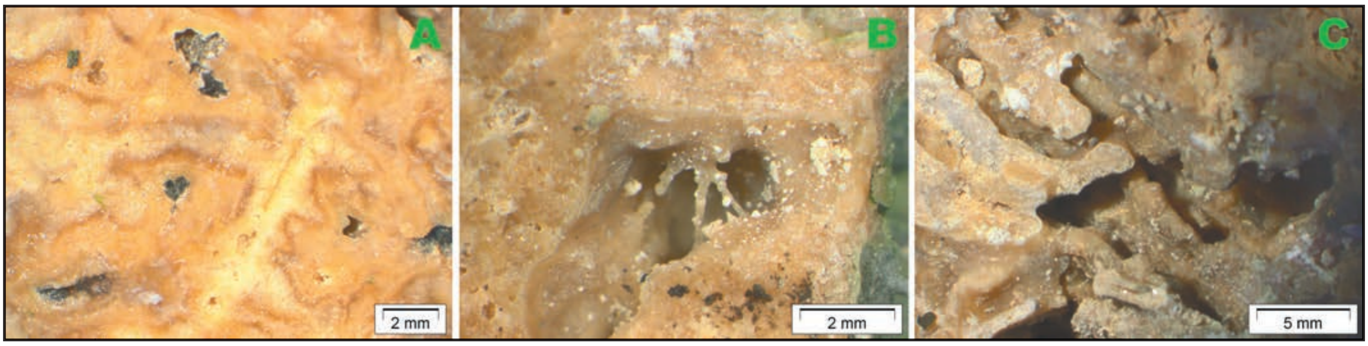

***Figure 8**. A : microcrystalline spar. B : speleothem. C : encrustations. All from the Via Gellia tufa.*

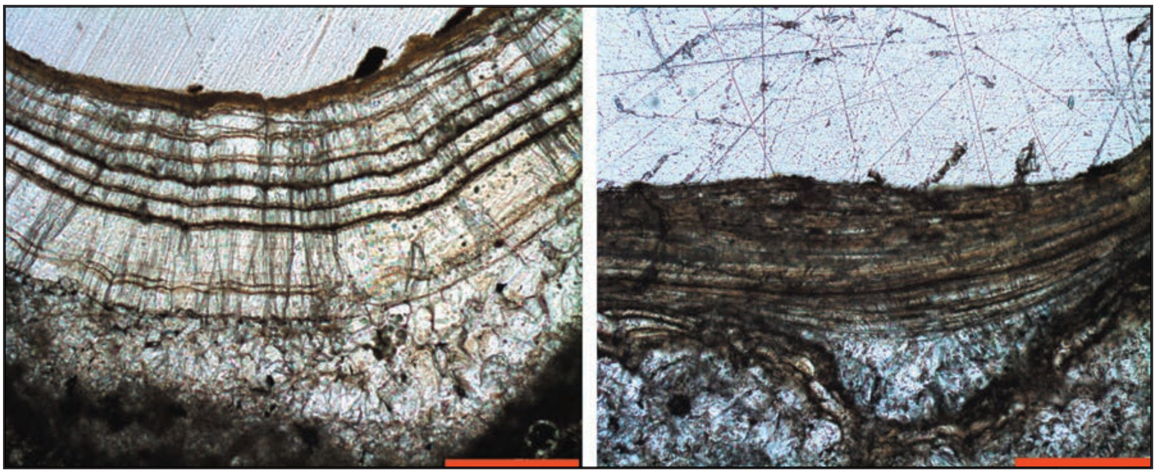

***Figure 9**. Two variations of the banding between the micrite and the sparite in the Via Gellia tufa; bar scales are 250 µm long.*

Petrography of the tufa

Encrustation of the tufa commences with a granular micritic layer that hosts an alternating sequence of sub-millimetre spar and micrite layers of variable thickness and frequency (Fig. 9). The deposits are colour banded with darker bands comprising micrite and lighter bands sparite of mosaic, acicular and palisade forms. The porosity of the darker layers is usually high as a consequence of void formation due to the decay of organic matter and the paucity of diagenetic cementation of the resultant voids.

Cementation of the phytoclastic facies differs from that in the phytohermal facies in that allochthonous (transported) fragments are encrusted with a single, encrusting micritic fringe, rather than a layered sequence. It is suspected that this results from the commencement of cementation during transport of the plant particles, which is followed by further cementation once the particle settles at its point of accumulation. The microcrystalline (Fig. 10) facies is dominated by clotted micrite. The resultant micropeloids (Fig. 10) are globular with low crystalline resolution; under the polarising microscope they appear dark brown with single and crossed nicols, and do not show the normal birefringence colours of micrite, possibly as a consequence of the accumulation of non-carbonate material. Volumetrically less significant is the occurrence of microcrystalline micrite (Fig. 11), in which crystals are distinguishable under crossed nicols. The spar occurs as both cement and debris. The microcrystalline facies appear to be associated with bryophyte cementation, debris accumulation and diagenesis. Diagenetic crystallisation can occur as a consequence of dissolution and re-precipitation, which destroys the original fabric of the tufa.

Porosity types in the tufa can be classified under the microscope (Fig. 12, Table 3). Cementation of both the primary and secondary pores takes a variety of forms that reflect the nature and degree of competition for cementation nuclei. Biological mediation of tufa precipitation is evident in the recent deposits, where diatoms and bacterial colonies are particularly abundant (Fig. 13). Characteristically, cementation commences with a primary rind of dogtooth spar or acicular prismatic crystals that form the nucleus for subsequent, drusy spar growth. Less commonly, botryoidal forms occur. Detrital filling by terrigenous silt, clotted micrite, lithoclasts and organic remains also occurs.

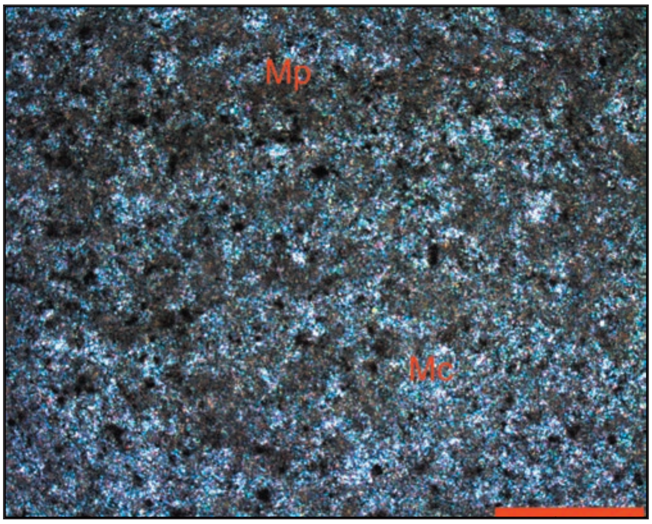

***Figure 10**. Micrite (Mc) and clotted micropeloid (Mp) in micrite tufa; scale bar = 250 µm.*

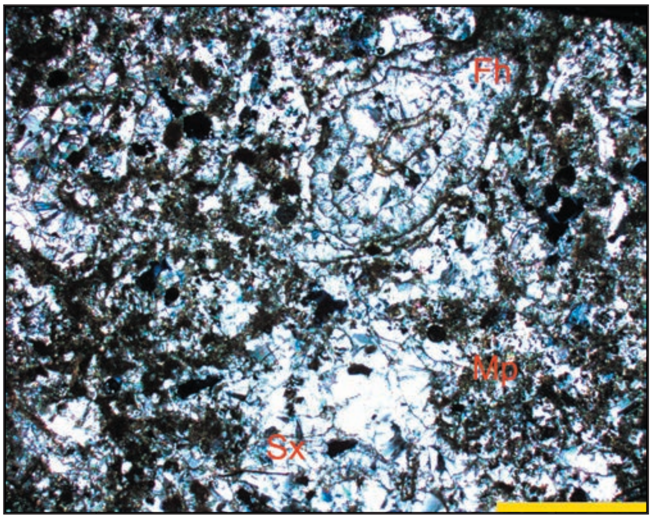

***Figure 11**. Microcrystalline tufa, with micropeloid (Mp), spar (Sx) and phytoherm (Fh); bar scale = 1 mm.*

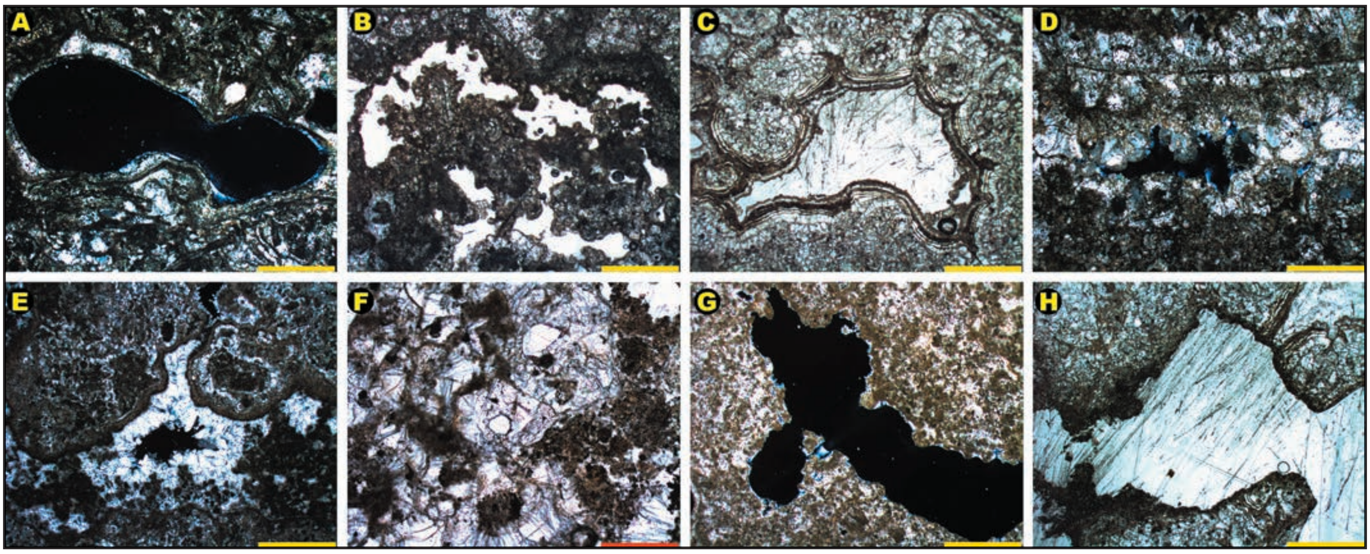

Figure 12. Microphotographs of various porosity types in the Via Gellia tufa (see Table 3). A – plant decay. B – vuggy. C – intergranular. D – intercrystalline. E – incomplete cementation. F – degassing. G – dissolution. H – biodissolution. Red bar = 250 µm. Yellow bars = 1 mm.

Porosity type	*Description*
Plant decay	Principal cause of void creation, especially in the phytohermal facies, with rounded to rectilinear pores with voids on mm to cm scale, varying with the organic matter.
Vuggy	Due to encrustation of bryophytes, usually at the millimetre scale.
Intergranular	Voids between the encrusted allochthonous fragments; commonly visible to the naked eye and tending to be flat and linear with irregular and sinuous boundaries.
Intercrystalline	Micrometric porosity between some crystals, maybe due to imperfections in crystal growth
Incomplete cementation	Commonly at the millimetre scale.
Degassing	Resulting from the escape of carbon dioxide gas bubbles leaving rounded or flattened “caries-like” sub millimetre voids occurring commonly in the microcrystalline facies.
Dissolution	Secondary porosity due to weathering and commonly acting on pre-existing pores, leaving irregular voids of mm to cm scale.
Bio-dissolution	Dissolution pores that result from plant etching, by lichens and mosses, commonly by enlargement of pre-existing pores; common in tufa that has a high primary porosity and is characterised by dark residual material on the pore boundaries.

***Table 3**. Classification of porosity types in tufa.*

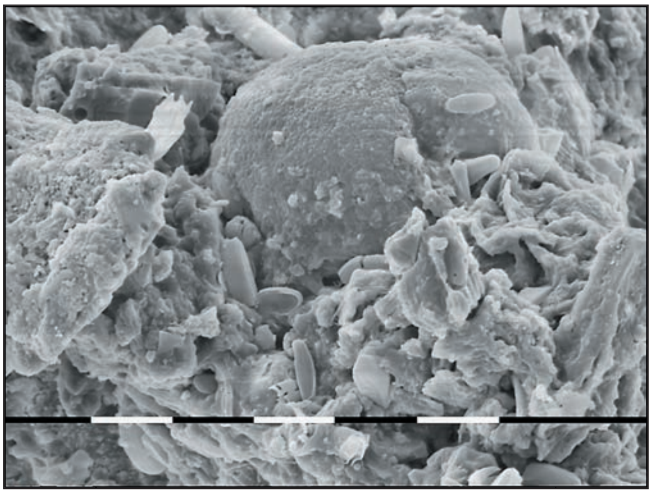

***Figure 13**. Tufa with peloids, tubes and diatoms, seen under the electron microscope; white sections on the scale bar are each 10 µm long.*

Hydrogeochemistry of the tufa deposition

Calcium carbonate encrustations of mosses (Fig. 14) indicate active precipitation of tufa downstream in the channels below both springs (Fig. 15). The precipitation of tufa from water that is saturated with calcium carbonate occurs as a consequence of inorganic or organic degassing of carbon dioxide. The former may be due to physical agitation of the water, whereas the latter results from biological removal of carbon dioxide from the water. Plant material commonly forms the nucleus for tufa precipitation. Plants can therefore have either an active (removal of carbon dioxide) or passive (substrate for precipitation) role in tufa precipitation.

Sampling of the spring waters and determinations of discharges were undertaken on four occasions at six sites (Fig. 3, Tables 4, 5). Sites 1 and 2 were the Dunsley Springs, site 3 was immediately downstream of their confluence and site 4 was where the stream discharges to the culvert beneath the Via Gellia road. The headwaters of two additional springs, lying 250 m north-east of Dunsley Springs were also sampled to provide a base-line against which the tufa-precipitating springs could be compared.

Conventional field sampling used a Hanna Instruments portable multi-parameter meter and a Columbia 2 impeller-type flow meter. Laboratory testing comprised ICP-AES (Varian Vista Axial) determinations and ion chromatography in the BGS laboratories, and ionic balances in the range 0.06 to 4.34% were achieved. Geochemical modelling to determine saturation index used SOLMINEQ.GW (Hitchon *et al*., 1999).

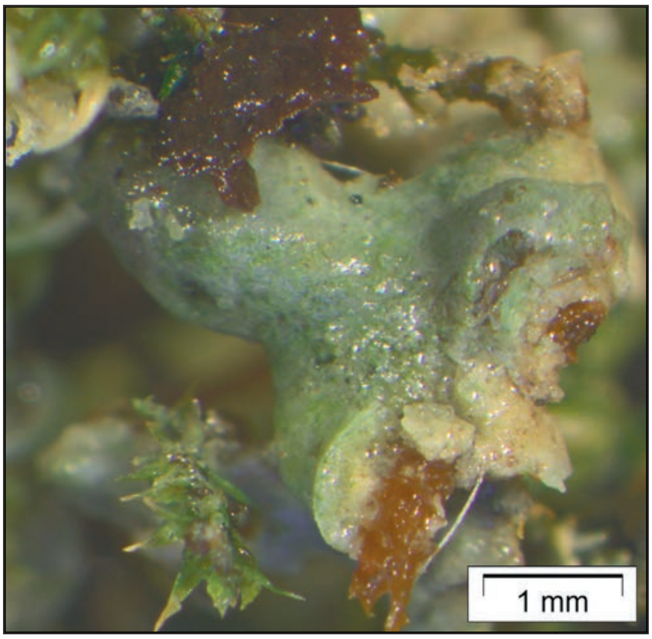

Figure 14. *Actively precipitating tufa.*

With the exception of some of the nitrate and chloride concentrations, the spring chemistries fell within the range of the groundwater baseline data for the Derbyshire Dome (Abesser & Smedley, 2008). Whereas the chloride concentrations were unusually low, the upper concentrations of nitrate were higher than is usual for the Carboniferous Limestone. It is likely that the elevated nitrate concentrations are derived from cattle silage. In the Peak District fluoride concentrations have been found to be the best indicator of mineralisation (Bertenshaw, 1981). In the Via Gellia data, fluoride concentrations of >1 mg/L in samples 1 to 5 contrast with that of sample 6, with <1 mg/L, suggesting that the water from the Dunsley Springs has been affected by contact with the mineralization. Calcium, zinc, strontium and uranium concentrations appear to discriminate between the Dunsley Springs (>100 mg/L Ca, >120 µg/L Zn, > 100 µg/L Sr and >0.8 µg/L U) and the two springs to the north-east, though they fall within the expected range for the aquifer (Table 5). There are strong correlations between the calcium and strontium and the calcium and zinc concentrations. The Dunsley Springs also differ from those to the north-east by exhibiting lower concentrations of potassium (<1 mg/L), manganese (<1 mg/L), chloride (<6.5 mg/L), sulphate (<18 mg/L) and nitrate (<17 mg/L).

Spring geochemistry provides an indication of the extent and seasonality of water/rock interaction and flow processes in the aquifer. While there are significant changes in the spring discharges, their correlation with calcium concentrations is weak and the spring-water chemistries show little seasonality. Flux (product of discharge and concentration) shows a strong positive correlation with flow. Within the surface watercourses, there is downstream increase in the calcium flux; this suggests overall erosion of the tufa at present, even though observation reveals local deposition.

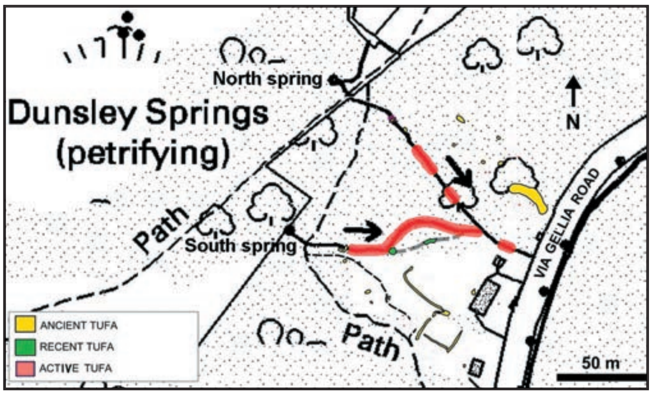

Figure 15. *Zones of active precipitation of tufa.*

Date	*Site*	*E.C. (uS/cm)*	*Oxygen (ppm)*	*pH*	*°C*	*Flow (L/sec)*
18 June 2011	1	420	10.7	7.72	8.71	16.4
	2	454	9.99	6.97	8.79	8.5
	3	386	12.51	8.73	9.35	29.2
	4	395	10.69	8.35	9.16	39.5
	5	196	9.97	7.26	8.89	n.d.
	6	n.m.				
3 July 2011	1	448	12.57	7.84	10.54	n.d.
	2	484	8.9	7.89	8.81	n.d.
	3	461	10.45	9.00	10.33	n.d.
	4	463	10.33	8.35	10.70	10.0
	5	199	9.51	7.33	14.87	0.1
	6	213	13.4	8.33	18.11	0.1
23 Sept 2011	1	119	9.29	8.77	8.79	0.6
	2	252	6.54	8.42	9.32	0.1
	3	478	8.75	8.41	10.33	0.5
	4	9	9.51	8.57	10.42	1.0
	5	87	8.87	7.47	14.74	0.1
	6	n.m.				
9 January 2012	1	499	10.47	7.07	8.79	57.1
	2	487	10.66	6.99	8.77	21.8
	3	275	14.64	8.49	8.80	108.7
	4	n.d.	12.0	8.33	8.81	137.5
	5	377	10.36	7.09	9.19	0.6
	6	473	9.25	6.91	9.63	0.1

Table 4. *Field records of sampled waters.*

Deposition and erosion of the tufa

Re-mapping of the tufa has identified two overlapping cones (Fig. 4), which are indicative of point sources for the dissolved carbonate. This supports classification of the deposit as a cascade (spring-line) tufa (Pedley, 1990). The tufa is unusual in that it is the only significant deposit in the Peak District that is on the Bee Low Limestone; most are associated with the Monsal Dale Limestone. However, the hydrogeological properties of the upper part of the Bee Low Limestone are comparable with those of the Monsal Dale Limestone, and have been grouped in the same hydrogeological unit (Banks *et al*., 2009). The Via Gellia tufa is formed immediately beneath the Lower Matlock Lava, towards the top of the Bee Low Limestone, where it is likely to be associated with significant palaeokarstic surfaces and clay wayboards, as in the Hoptonwood Quarry where dissolution pits reach 10 m deep (Waters *et al*., 2006).

Date	Site	pH	Ca	Mg	Na	K	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Sr	F^-	Zn	Mn	U	SIc	Ca Flux
			mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	mg l^{-1}	µg l^{-1}	mg l^{-1}	µg l^{-1}	µg l^{-1}	µg l^{-1}		mg s^{-1}
18/05/11	1	8.11	114	1.62	4.9	0.71	295	6.25	17.2	14.9	114	1.27	153	0.9	0.820	1.134	1869.6
18/05/11	2	7.94	103	1.44	4.2	0.66	294	6.27	17.2	14.1	103	1.31	165	0.8	0.853	0.935	875.5
18/05/11	3	7.96	103	1.43	4.1	0.60	276	6.18	17.2	14.7	103	1.27	126	0.2	0.988	0.929	3007.6
18/05/11	4	8.08	103	1.45	4.2	0.64	281	6.15	17.2	14.9	104	1.28	126	<0.2	0.877	1.050	4068.5
18/05/11	5	7.91	80	1.80	5.8	0.92	208	9.58	24.2	15.7	85	1.21	55	10.4	0.718	0.667	
18/05/11	6	7.89	87	2.26	9.3	1.23	222	15.0	24.4	25.5	79	0.95	17	8.8	0.480	0.705	
03/07/11	1	8.24	104	1.44	4.1	0.59	293	6.25	17.4	15.4	103	1.26	160	3.4	0.829	1.218	
03/07/11	2	8.20	104	1.44	4.1	0.63	293	6.25	17.4	15.1	103	1.30	159	<0.2	0.819	1.156	
03/07/11	3	8.31	111	1.55	4.8	0.97	291	6.64	17.5	15.8	112	1.27	120	0.7	0.880	1.303	
03/07/11	4	8.20	104	1.45	4.5	0.98	292	6.78	17.4	17.0	104	1.27	124	0.4	0.866	1.180	1040.0
03/07/11	5	8.09	80	1.81	5.8	1.17	210	10.9	25.0	16.1	85	1.21	57	1.4	0.738	0.847	4.5
03/07/11	6	8.12	85	2.13	8.8	1.37	216	14.8	24.6	25.4	77	0.96	9	2.3	0.493	0.907	0.17
25/09/11	1	7.91	109	1.48	4.2	0.65	295	6.46	17.9	16.1	107	1.25	139	0.6	0.831	0.928	68.1
25/09/11	2	8.09	116	1.54	4.4	0.68	293	6.46	17.9	15.9	113	1.28	151	0.2	0.921	1.119	17.4
25/09/11	3	8.31	102	1.40	3.9	0.70	291	6.48	17.9	15.6	101	1.25	113	0.4	0.877	1.272	56.1
25/09/11	4	8.36	112	1.54	4.3	0.76	290	6.51	18.0	15.8	111	1.25	114	0.7	0.821	1.350	112.0
25/09/11	5	7.99	85	1.93	5.6	0.95	208	9.92	25.9	15.3	90	1.19	52	11.7	0.742	0.770	8.53
09/01/12	1	7.93	114	1.70	4.9	0.68	285	7.01	16.7	17.5	111	1.20	153	1.5	0.871	0.950	6512.8
09/01/12	2	8.02	106	1.59	4.7	0.64	277	7.01	16.8	16.7	107	1.28	142	0.2	0.893	0.998	2308.7
09/01/12	3	8.37	104	1.53	4.5	0.62	283	7.04	16.8	16.7	106	1.24	126	0.5	0.885	1.322	11301.7
09/01/12	4	8.34	108	1.57	4.6	0.64	283	7.13	17.0	17.4	109	1.25	130	0.3	0.886	1.309	14854.3
09/01/12	5	8.00	77	1.86	5.2	1.81	193	8.01	20.5	18.3	82	1.12	52	0.5	0.598	0.713	43.9
09/01/12	6	8.07	88	2.15	7.8	0.94	230	13.7	21.2	30.5	78	0.91	13	0.5	0.467	0.902	7.61
Baseline min max		5.94 9.17	2.36 171	0.27 36.3	3.89 192	<0.5 13.5	21 367	7.32 266	4.96 311	<0.5 12.6	37.1 8440	0.025 1.780	2.2 1840	<0.5 4840	<0.02 5.68		

***Table 5**. Spring-water chemistry; SIc is the saturation index with respect to calcite; max and min baseline values are from Abesser and Smedley, 2008.*

It appears that the Via Gellia valley intercepts south-westerly water flow paths in the limestone immediately beneath the Lower Matlock Lava. The source of carbonate in the spring waters is likely to be related to dissolution in the epikarst, during recharge, and to anastomosing palaeokarst along vadose flow paths (Banks et al., 2009). Concentrations of magnesium and sulphate are low, indicating that the carbonate is less likely to result from the dissolution of dolomite or to be due to sulphate dissolution associated with the weathering of pyrite. The high concentrations of zinc suggest an additional contribution from the dissolution of smithsonite (Brossler, 1998).

The Via Gellia tufa appears to be largely a Holocene deposit (Thorpe et al., 1980; Viles and Goudie, 1990). During this period of post-glacial climatic amelioration the proliferation of vegetation would have facilitated carbon dioxide saturation of recharge water, resulting in increased limestone dissolution in the vadose zone. The banding with dark micrite and light sparite (of mosaic, acicular and palisade forms) is comparable with other tufa deposits in Britain and Europe (Brasier *et al*., 2011). The occurrence of these two types of calcium carbonate can, at least in part, be attributed to the interplay between chemical precipitation of sparite and biologically mediated precipitation of micrite (Brasier *et al*., 2011; Pedley *et al*., 1996). The macro-fauna includes leaves and trunks of deciduous trees, which formed the substrate for tufa precipitation. It comprised a cemented breccia deposit, which together with the local preservation of organic matter suggests rapid deposition of tufa in a relatively unstable environment. It is suspected that high stream flows undercut the banks, thereby triggering tree falls. Such processes may, in part, have been due to rapid incision driven by glacio-isostatic readjustment. Discontinuities in the deposits (Fig. 5) indicate that precipitation of tufa was not continuous. Progradation of the two tufa cones may have been contemporaneous or may represent migration of deposition from one spring to another.

Calculated saturation indices with respect to calcite (Table 5) indicate that the present precipitation of tufa is most likely during the summer months when biological activity is at a maximum, thereby increasing limestone dissolution with higher levels of biogenic carbon dioxide. The saturation indices also confirm active dissolution of the main body of the tufa (sample points 3 and 4). In part this is supported by field evidence, indicating that some cavities in the tufa are primary, representing the voids behind small tufa dams whereas other voids are post-depositional dissolution cavities due to weathering. Some dissolution cavities are lined with speleothems and encrustations that are regarded as third-order deposits with the calcium carbonate being derived from the tufa itself rather than the limestone bedrock. The distribution of these deposits reflects the vadose zone flow paths, which have been modified in the areas that have been quarried.

While the depositional environment of the tufa and its subsequent erosional history is broadly understood, there remain a number of unanswered questions. In particular, the source of the carbonate has not been fully established, the age of the Via Gellia tufa has not been verified, and dating of the unconformities within the tufa has yet to be attempted. More frequent monitoring could determine annual rates of precipitation and erosion of the tufa. The physical appearance of the tufa deposits of the Peak District varies considerably, and the adoption of a descriptive classification would be of value within vernacular architecture, particularly where maintenance works are required.

Acknowledgements

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The aeolian sand record in the Trent valley

Colin Baker, Mark Bateman, Paul Bateman and Howard Jones

Abstract: Literature on the aeolian sand record of the Trent valley is reviewed. The wind-blown sediments provide an archive of changing environmental conditions through the Late Pleistocene and Holocene. Data relating to the now-closed Girton quarry, near Newark, identify sand dune stratigraphy previously unknown within the East Midlands. This dates to the end of the Younger Dryas, with reactivation during a cold dry episode in the Early Holocene, with reversed easterly gales implied by high-angle dune bedding. The infill of an adjacent palaeo-channel yields evidence of local environmental stress at about the same time. The Early Holocene was punctuated by short sharp anomalies, including climatic oscillations at 9.3 ka and 8.2 ka, well-documented on the continent but elusive in most British palaeo-records.

The East Midlands is one of the few regions in Britain that retain evidence of Late Pleistocene coversands (Buckland, 1976; Gaunt, 1981; Bateman, 1995, 1998). These deposits consist of fine to medium-grained, well-sorted sand, lacking interstitial silt and clay. Well rounded spherical grains and rare wind-polished ventifacts are testimony to past wind abrasion. Layering is largely horizontal or sub-horizontal, and only rarely displays slip-face bedding. Besides the broad sweep of windblown sand in North Lincolnshire and the Humberhead Levels, the East Nottinghamshire sandlands around Girton occupy a small but significant outlier on the east side of the Trent valley between Newark and Gainsborough (Fig. 1). The Farndon sands (Harding *et al*, 2013) represent the most southerly surviving fragment of this former coversand sheet, and, beyond the confines of the Trent valley, involutions at Cadeby (Douglas, 1982) contain the only evidence of remnant coversand within Leicestershire, demonstrating that aeolian activity must have once extended well to the south-west.

The Lower Trent coversands are formally recognised as the Spalford Sand Member of the Trent Valley Formation (Brandon and Sumbler, 1988). These deposits were intermittently exposed in the now-closed Girton quarry in the 1990s, and examined by Trent and Peak Archaeology as part of planning conditions (funded by Lafarge Tarmac Ltd.). These archaeological records, including many unpublished reports and photographic archives, have recently been re-evaluated, and these form the basis of the interpretations outlined in this paper.

Context and palaeogeography

The Spalford Sand Member is assigned to the Last Cold Stage (MIS2) and is associated with the deposition of the last fluvial terrace of the Trent, underlain by the Holme Pierrepont Sand and Gravel. Aggradation occurred in two phases, the first at ~28 ka, the second at ~13 ka, and reconstructions of the terrace environment suggest the presence of a wide periglacial sandur or braidplain characterised by a mosaic of vegetation generally referred to as "mammoth steppe" (Howard *et al.,* 2007). The Trent valley south of the Isle of Axholme was effectively ice-free but was inundated by proglacial Lake Humber which existed for about 4000 years during MIS2, achieving its high level stand (about 30 m O.D.) briefly at 16.6 ka (Bateman *et al.* 2008).

In Holderness, the full glacial Dimlington Stadial, including the Last Glacial Maximum (LGM), is dated to between 22 ka and 15 ka (Bateman *et al*, 2008). Within the Trent valley ice-free zone, permafrost left ice-wedge casts, involutions and some patterned ground (Fig. 2). Also periglacial in origin, coversands signify aeolian activity attributable to either the LGM or to the Younger Dryas, and their distribution is interpreted as indicating a westerly provenance, originating primarily from Sherwood Sandstone (Straw, 1979; Bateman, 1995). Sandy sediments associated with the drained bed of proglacial Lake Humber and the Trent valley sandur provided additional exposed surfaces for aeolian deflation, transportation and deposition.

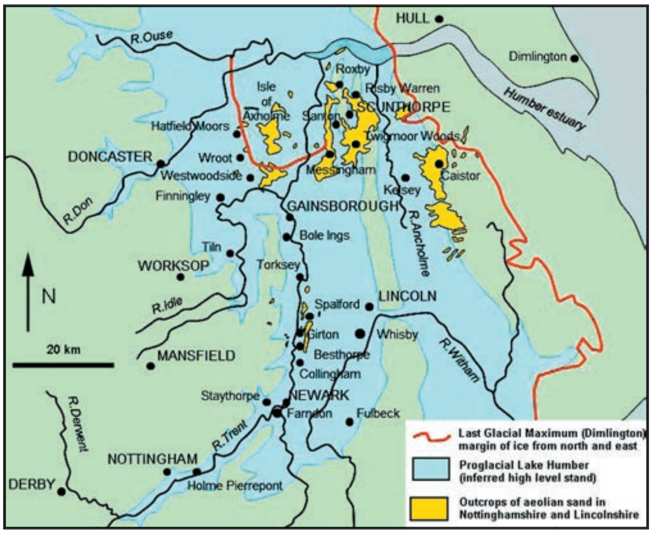

***Figure 1**. Distribution of coversand (after Knight and Howard, 2004), Devensian ice margins and the extent of Lake Humber (based on the BRITICE database, Clark et al., 2004), and main sites mentioned in the text.*

Radiocarbon dates are in calibrated years BP (prior to 1950), using IntCal09 (OxCal version 4.1), with error range expressed at 95% probability (2σ). Luminescence ages refer to number of years prior to date of measurement, with error range at 68% probability (1σ).

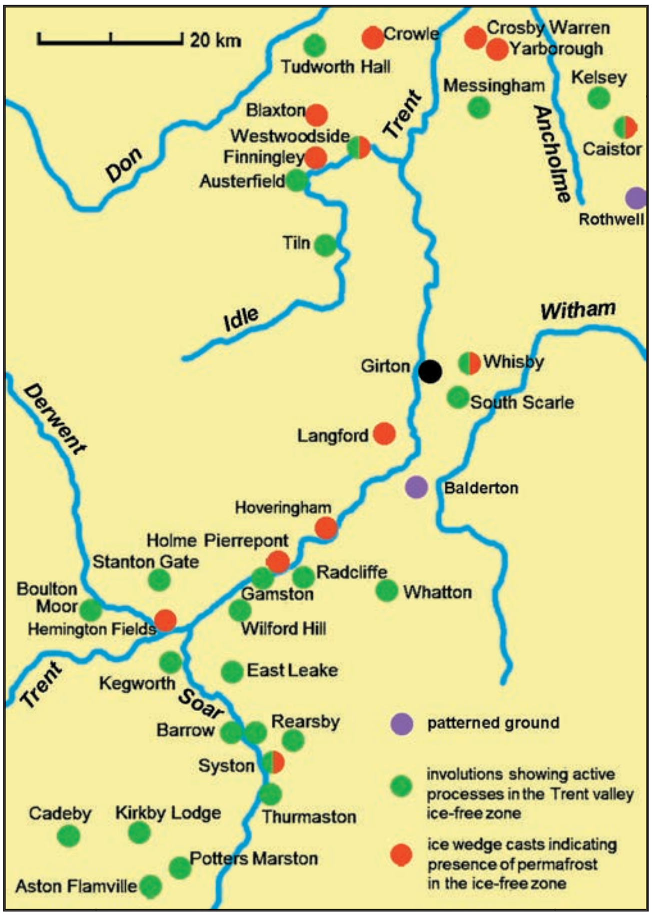

***Figure 2**. Sites of Devensian permafrost features [based on Deeley (1886), Lamplugh et al. (1908), Straw (1963, 1979), Bell et al. (1972), Gaunt (1981), Douglas (1982), Buckland (1984), Brandon and Sumbler (1991), Bateman et al. (2000, 2001b, 2008), Murton et al. (2001), Gaunt et al. (2006), Knight and Howard (2004), Howard (1995), Howard et al. (1999, 2007, 2011) and A.S.Howard et al (2009)].*

Coversands and periglacial chronology

Coversands at the southern edge of the Humberhead Levels lie on the River Idle first terrace at Tiln (Howard *et al.*, 1999), where four sedimentary units provide a chronological framework. From the base upwards these are: an organic channel peat (C14 dated to 13,470±240 BP), a cryoturbated arctic palaeosol (Tiln Bed), horizontally-bedded coversand (TL dated to 13.71±1.3 ka), and upper drift sand (TL dated to 8.51±0.8 ka) (Fig. 3). This places local coversand after the final drainage of proglacial Lake Humber, and within the earlier part of the Younger Dryas. It also postdates a significant period of periglacial cryoturbation that appears to coincide with the Upper Periglacial Surface of Gaunt (1981). If Gaunt's Lower and Upper Periglacial Surfaces are accepted as diagnostic markers in the Lower Trent ice-free zone, they offer a potential means of differentiating coversand horizons.

Sites of Windermere Interstadial age (some of which contain evidence for periglacial activity) provide a maximum age for the principal aeolian activity to follow in the Younger Dryas. Within the coversands, however, there are no indisputable intraformational periglacial structures (Buckland, 1984) (Table 1). Of the three potential Last Glacial Maximum coversands, that at Cadeby on the Soar-Tame watershed survives within decapitated involutions that penetrate Oadby Till (Douglas, 1982) (Fig. 4). Based on typical grain properties, they were thought to equate with Younger Dryas coversand, but extreme cryoturbation implies greater age (Terry Douglas, *pers. com.*); they resemble intense permafrost degradation structures in Kent coversands dated firmly to between 23 and 21 ka (Murton *et al.*, 2003).

***Figure 3**. Coversand section exposed at Bellmoor Quarry, Tiln (photo: Andy Howard).*

Few of the periglacial sites in Figure 2 are fully documented or dated; some may relate to early cold episodes within the Trent Valley Formation, perhaps as far back as the Early Devensian. Where small remnants of coversand of presumed Dimlington Stadial age have survived, they would appear to have been exposed to a period of intense periglacial deformation. This is why the majority of East Midlands coversands are recognised as Younger Dryas; their lack of cryoturbation implies the younger age.

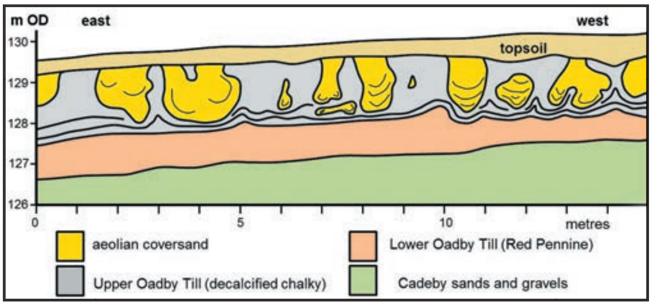

***Figure 4**. Involuted coversand of possible Dimlington Stadial age at Cadeby (after Douglas, 1982).*

***Table 1**. Association of the coversand horizons with the recorded periglacial stratigraphy in the ice-free zone of the Trent valley.*

Stage	Main sites	Other probable equivalents
Late Glacial Stadial (Younger Dryas)	Main coversands in the Humberhead Levels and North Lincolnshire (Buckland, 1984).	Spalford Sands (this study) Farndon Sands (Harding *et al,* 2013).
Late Glacial Interstadial (Windermere)	Upper Periglacial Surface probably relates to a cold phase, at Finningley and Tudworth (Gaunt *et al.*, 2006), and Tiln (Howard *et al.*, 1999), where cryoturbation is associated with Lake Humber deposits and coversand.	Peat beneath coversands at Messingham (12,300 BP), Nettleton (12,490 BP), Fonaby (13,850 BP) (Buckland, 1984). Sand wedge casts below peat at Crosby Warren, Caistor (Straw, 1963), Santon (Bateman, 1998; Murton *et al.*, 2001), Westwoodside (Bateman *et al.*, 2001b).
Last Glacial Maximum Stadial (Dimlington)	Lower Periglacial Surface at Finningley and Tudworth (Gaunt *et al.*, 2006). Cryoturbation of Lake Humber sediments at Kelsey to 22.7±1.4 (Bateman *et al.*, 2000).	Involutions and ice wedge casts containing aeolian sand in the Balderton Terrace at Whisby (Brandon and Sumbler, 1991; Knight and Howard, 2004). Ice wedging at 35–15 ka at Baston, Lincolnshire (Briant *et al.*, 2004). Cryoturbation of coversands at Cadeby (Douglas, 1982).

Continental correlation

The East Midlands coversands almost entirely correlate with the Dutch Younger Coversand II phase (Bateman and van Huistedden, 1999) (Table 2). Earlier episodes on the European mainland, such as Older Coversand I, were subject to intense permafrost degradation and wind deflation (the Beuningen Gravel), which appears to correlate with Gaunt's Lower Periglacial Surface. The subsequent Older Coversand II is poorly represented in Britain but might be found in dated sands at Bagmoor (17.8±2.5 ka) and Fonaby (18.6±2.0 ka) (Bateman, 1998).

Late Pleniglacial sandlands on the continent are dominated by horizontal or low-angled bedding in both Older and Younger Coversands, with only limited preservation of dune structures. While parabolic sand dune formation was well-developed along the Polish lowland valleys in Younger Coversand I (Isarin *et al.,* 1997), the main dune period occurred later, in Younger Coversand II. Aeolian activity in the Netherlands also appears to have increased at this time, when horizontal coversands were starting to be reworked into hummocky dunefields mainly confined to the Scheldt, Maas and Rhine valleys (Schwan, 1988). A combination of cold aridity and partial vegetation cover in the Younger Dryas promoted effective dune formation; however, evidence of high-angle slipface cross-bedding is reported in very few instances (Kasse, 2002; Renssen *et al.,* 2007).

Reactivated sands within the Holocene were invariably associated with human disturbance (van Huissteden *et al.,* 2001; Koster, 2009). "Drift sands" in the Trent valley show similar reactivation throughout the mid and late Holocene, and were almost certainly the result of vegetation removal, soil disturbance and exploitation, coupled with natural episodes of drought and high winds. The environmental impact of these combined factors was demonstrated by the unusual Lincolnshire sandstorm of March 1968 (Robinson, 1968), and sandblow continues today wherever surface vegetation is temporarily removed (Fig. 5).

***Figure 5**. Sandblow during archaeological work at Girton quarry in February 1999, in conditions that were probably common during and after the Neolithic period (photo: TPA).*

***Table 2**. Correlations of coversand stratigraphy (after Bateman, 1998; Bateman & van Huissteden, 1999; van Huissteden et al., 2001; van Geel et al., 1989; Kaiser et al., 2009).*

Stage	Age (ka)	Chronozones	Lithostratigraphy		
			East Midlands	East Netherlands	Central European Lowlands
Holocene	11.65	Subatlantic Subboreal	Human impact from Neolithic onwards	Inland dune fields and drift sands, Veluwe, Twente (Kootwijk)	Human-triggered dune period
		Atlantic Boreal Preboreal	Reactivated drift sands, Tiln unit 1, Girton units 3-4, Farndon units 3-4		Small dune reactivation
Late Glacial Stadial (GS-1)	12.85	Younger Dryas	Humberhead and North Lincolnshire coversands, Spalford Sands (Girton unit 1), Tiln unit 2, Farndon unit 5	Younger Coversand II (Wierden)	Main dune period
Late Glacial Interstadial (GI-1)	14.7	Windermere (Allerød, Bølling) Interstadial	Sub-coversand peat horizon	Usselo palaeosol	Finow palaeosol
				Younger Coversand I	Dune period
			Tiln units 3 and 4 Upper Periglacial Surface (?)	Lower loam	
Last Glacial Maximum Stadial (GS-2) (Late Pleniglacial)	23.0	Dimlington Stadial	Proglacial Lake Humber Bagmoor sand unit V Fonaby sand unit V	Older Coversand II (Lutterzand)	Coversand period Kamion palaeosol
			Lower Periglacial Surface (?)	Deflation surface (Beuningen) Intense permafrost degradation	Ventifact horizons Continuous permafrost
			Cadeby sand (?) Whisby cover deposit unit 4 (?) Brough patterned ground (?) Baston sand (?)	Older Coversand I (Beverborg)	Fluvio-aeolian period

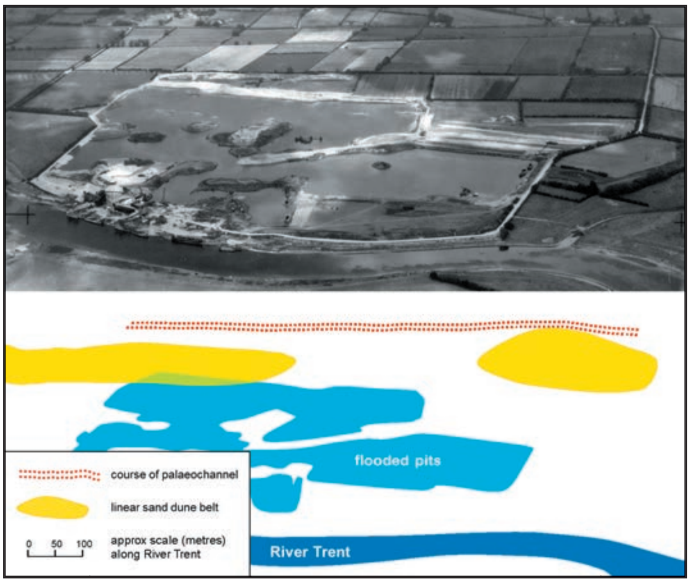

***Figure 6**. Girton quarry in oblique aerial photograph towards the east (Photo: Cambridge University), with positions of the linear sand dune mound and the palaeochannel.*

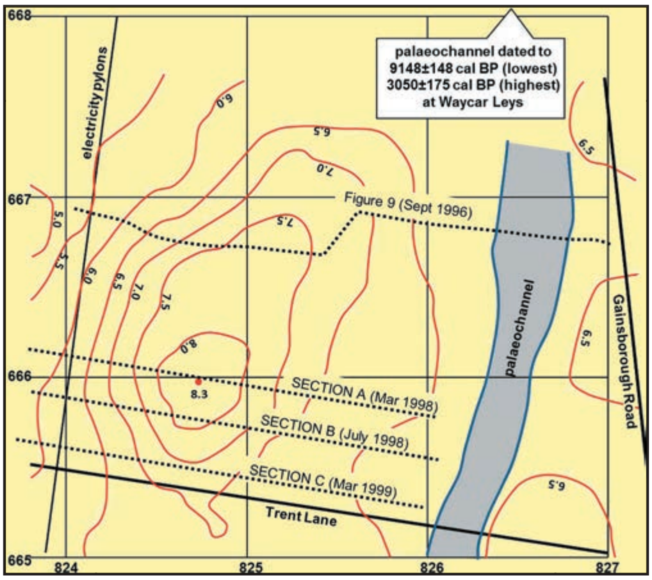

***Figure 7**. Girton dune mound topography, with positions of cross-sections and the Holocene palaeochannel (EDM survey after Ensor et al., 1996).*

The Girton sand dune complex

Girton quarry, 15 km downstream of Newark, lies in the edge of the main body of East Nottinghamshire aeolian sands extending about 10 km between North Clifton and Besthorpe. Outliers of sand also survive around Sutton-on-Trent, Torksey and Farndon. At Girton a linear dune-like mound about 1 km long and 200 m wide rises to 8 m O.D.; it stands about 3 m above floodplain level, and to the east, a palaeochannel lies beneath a swale channel (the northern extension of The Fleet) between the sand mound and Gainsborough Road (Fig. 6)

Gravel extraction at Girton quarry revealed the internal structure of the coversand overburden in west-east sections cut between September 1996 and March 1999 (Fig. 7). In 1998, the receding north-facing quarry wall revealed in its centre a double-crested dune profile rising gently to 8 m.O.D. (Fig. 8), and the face had revealed both the dune and the channel in 1996 (Ensor *et al.,* 1996) (Fig. 9).

Sand dune sedimentology

Early archaeological reports (Grattan, 1990; Lillie and Gearey, 1992) failed to establish a direct link between dune sand and palaeochannel organic sediments, but the 1996 section confirmed that the palaeochannel cuts into, and thus postdates, *in situ* coversand and is itself overridden by later drift sand. Quarry exposures in March 1999 revealed more of the dune's internal structure (Fig. 10). Sand beds achieve a maximum thickness of 4 m, lying conformably on Holme Pierrepont terrace sands and gravels. In its lowest layers, the sandsheet is horizontally or sub-horizontally bedded with clear laminations (Fig. 11), which is interpreted as aeolian sediment modified by snowmelt or seasonal river flow (Buckland, 1982; Schwan, 1988; Kasse, 2002).

Horizontal bedding extends for about 100 m (Fig. 10C, a to j) in sand derived from the adjacent Trent sandur to the west, under prevailing westerly palaeowinds. The highest 2-3 metres of the sand dune have been modified into at least five small north-

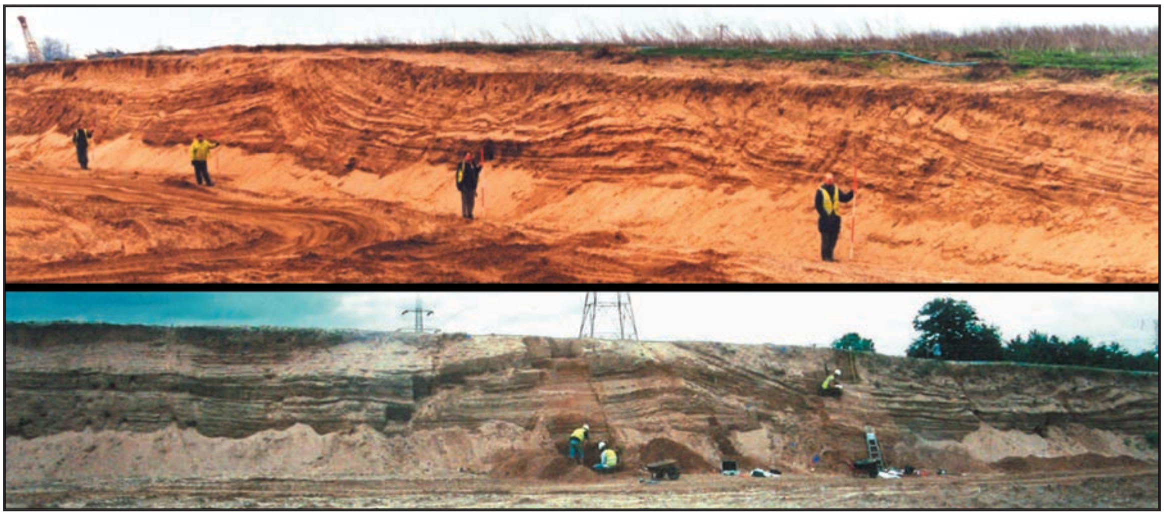

***Figure 8**. Dune stratigraphy exposed in north-facing quarry walls (with east on the left) at Girton, above in March 1998 and below in July 1998 (photos: Trent and Peak Archaeology).*

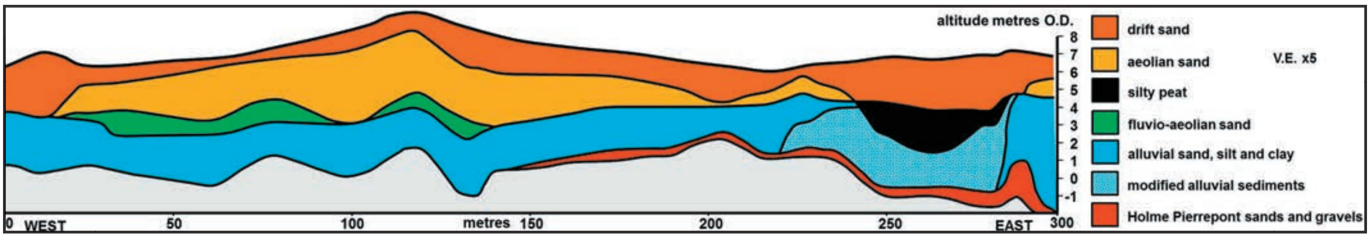

Figure 9. *Stratigraphic relationship between sand dune and palaeochannel in a reversed section of the north-facing quarry wall at Girton in September 1996 (after Ensor et al., 1996).*

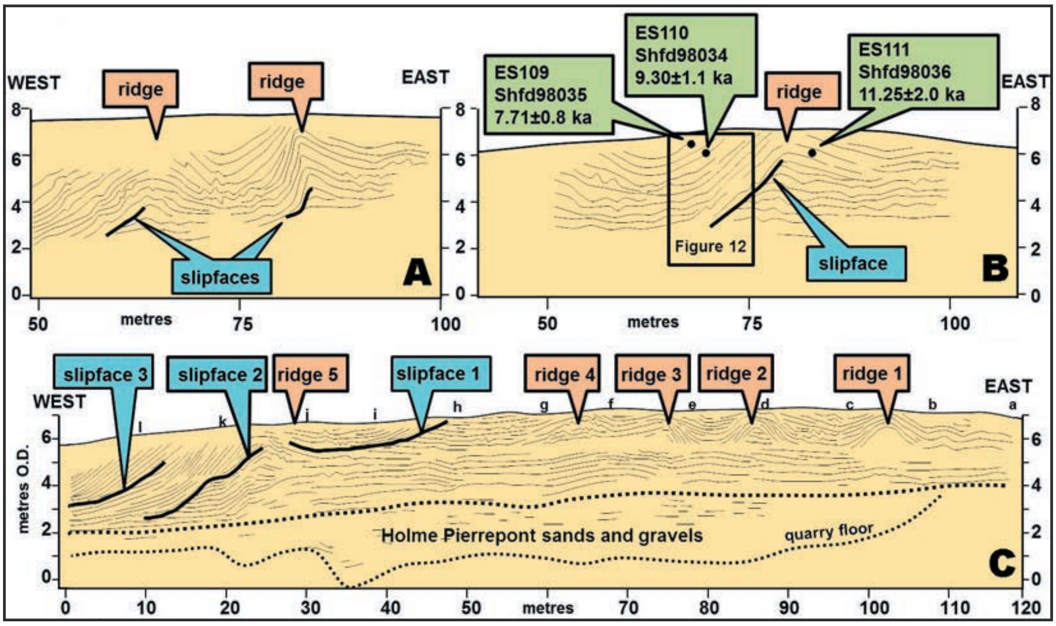

Figure 10. *Interpretation of three quarry sections based on Trent and Peak Archaeology photographs, showing increased dune complexity southwards. Section A was in March 1998, section B was in July 1998 and section C was in March 1999. Note that all sections, originally visible on north-facing quarry walls, have been reversed. Vertical exaggeration is x3.*

south transverse ridges. Coversand layering is further modified (h to m) where three inclined slipface planes cut across horizontal beds. Two of these, between k and m, are associated with sand descending steeply on the western flank. This high-angle slipface bedding is interpreted in terms of an easterly palaeowind driving sand temporarily backwards across the mound to then avalanche down the western (lee) side.

A slipface sequence within Section B (Fig. 10) was sampled in detail (Fig. 12). Grain size distribution (Fig. 13) centres on well-sorted medium sand, typically aeolian but slightly coarser than coversands in North Lincolnshire; this may reflect closer proximity of the Trent sandur as source area. Further analysis (Fig. 14) shows four sand units, below and above the slipface horizon. Below, unit 1 contains fluvio-aeolian elements, characterised by fine sand-silt laminae; to the east of the slipface, this expands into typically well-sorted, horizontal coversand beds. Above and ahead of the slipface, unit 2 consists of steeply-inclined (20º), moderately-sorted, gravelly coarse sand, cross-cutting the horizontal beds below. Unit 3 is well-sorted medium sand, inclined to the west at lower dips. Unit 4 is structureless fine reddish-brown drift sand. This four-fold sequence is interpreted as initial coversand

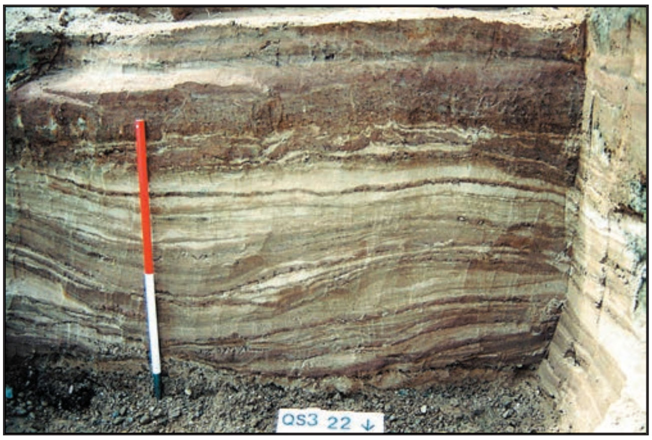

Figure 11. *Sand laminations within the basal fluvio-aeolian layers of the coversand sheet, exposed in June, 1998 (photo: Trent and Peak Archaeology).*

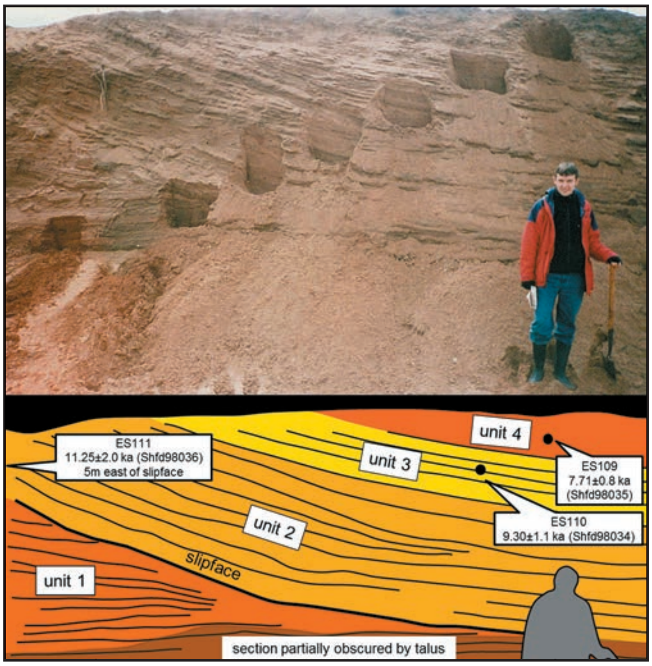

Figure 12. *High-angle dune bedding in Section B of Figure 10.*

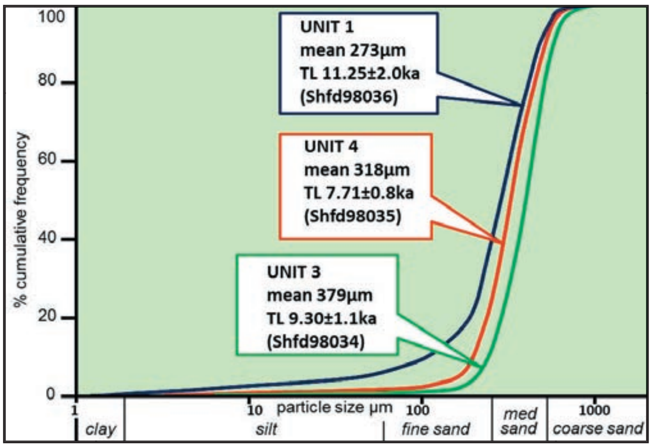

Figure 13. *Grain size distribution for three sedimentary units in Section B.*

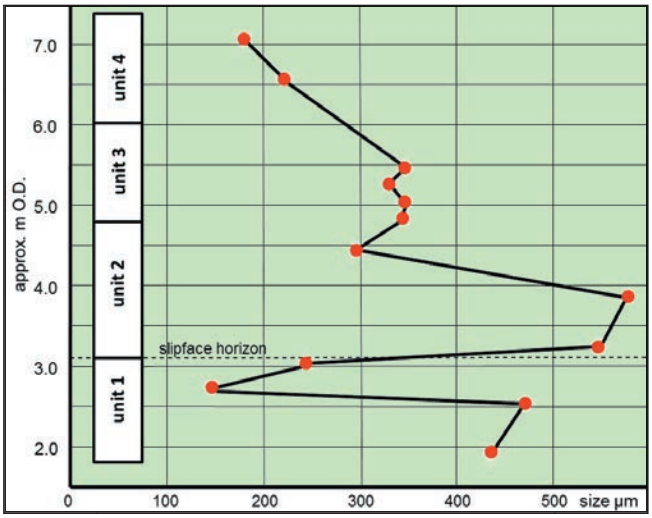

Figure 14. *Mean grain size variation for four units in Section B.*

deposited in the Younger Dryas, followed by at least two phases of reactivation in the Early Holocene. Sand avalanching occurred at least three times (Fig. 10C).

Unit 2 is notably coarse, with individual gravel clasts up to 10mm in size. Since no higher bedrock or terrace source exists locally for such coarse material, it must have been introduced directly by wind-saltation. Fine gravel (2-5 mm) can be raised to a height of 50 cm during winter storms with winds exceeding 8 m/s, or 30 km/h (De Ploey, 1977). Because of its higher density, cold air may be more effective in transporting coarser aeolian sediment (McKenna Neumann, 1993). Winds responsible for the deposition of unit 2 were therefore strong (in excess of 30km/h), from the east, and almost certainly indicative of cold winter events. Reduction in easterly wind speed is inferred in unit 3, after which more normal westerly winds resumed. Rapid burial beneath units 3 and 4 ensured preservation of the cross-bedded structure in unit 2.

Palaeochannel infill

A well-defined Holocene palaeochannel lies parallel to the sand dune mound (Fig. 6) and is in contact at one point (Fig. 9). Base of the channel lies at about 2 m O.D. near Trent Lane, dropping to 1.6 m O.D. at Waycar Pasture and below O.D. at Clifton Hill. It is matched elsewhere in the Lower Trent valley by similar palaeochannels at Staythorpe and Bole Ings. Organic silts and peats are over 2 m thick in the meander channel (Grattan, 1990) (Fig.15). Unstratified aeolian sands appear to have been eroded laterally on its outer east bank. Its inner west bank is composed of stratified and cross-bedded fluvial beds interpreted as point bar and chute bar sediments prograding from west to east. Further west, windblown sands with dune-like structures and some gravel stringers were exposed at about 6m O.D., resembling the aeolian stratigraphy further south, and laminated silts and sands beneath the dune sand might be interpreted as the basal fluvio-aeolian unit.

Five peat samples were radiocarbon dated (Garton, 1999) (Table 3). These suggest that the palaeochannel was probably disconnected from the main river in the pre-boreal period, and remained open for as much as 7000 years throughout the Early-Mid Holocene until the Iron Age, when reactivated drift sand overrode it (Fig. 16). Organic sedimentation is divisible into six zones (G/A to G/F) based on pollen stratigraphy (Green, 1996), three of which yielded beetle assemblages (Dinnin, 1992). Pollen zone G/C, constrained between 9148 and 7454 cal BP (the Later Mesolithic boreal period) converges with the TL sand chronology (see Table 4), falling between 10,000 and 8000 BP. Within this zone, pollen is dominated by hazel shrub (and almost eliminated at one point) with a strong grass component (Girton was only lightly wooded). The coleopteran species list (verified by Paul Buckland) shows a notable reduction in water and woodland indicators; terrestrial beetles are severely abraded, suggestive of local soil erosion. Most significantly, abundant macro-charcoal occurs throughout zone G/C. A period of local drought and fire damage spanning several centuries is inferred.

Environmental stress must have occurred in the boreal period, perhaps a combination of drought, natural fire, and woodland dieback leading to inevitable wind erosion. How widely this extended in eastern Britain is uncertain. The Early Holocene climatic oscillations (well-established in continental records) have so far proved elusive in most British pollen records, and regional pollen sequences from Bole Ings, Routh, Willow Garth and Stafford show no comparable disturbance horizons. No consistent pattern of regional forcing is found in high-resolution

Table 3. *Radiocarbon dates for peat samples from the Waycar Pasture palaeochannel.*

context	*lab code*	*sample depth (cm)*	*height O.D.*	*pollen zone*	*C14 years BP*	*cal years BP*
primary channel	AA 29321	39-40	3.72 m	E/F	2890±60	3050±175
	AA 29320	85-86	3.25 m	D/E	5360±50	6140±139
	AA 29319	119-120	2.91 m	C/D	6565±60	7454±121
	AA 29318	166-167	2.44 m	B/C	8170±60	9148±148
secondary channel	AA 29317	105-106	3.00 m	-	7515±65	8275±112

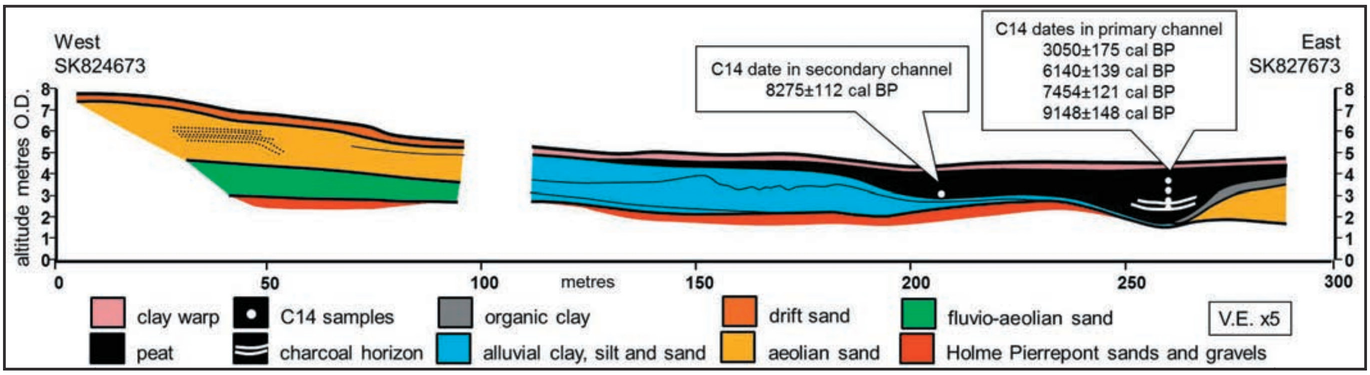

***Figure 15**. Reversed section of Holocene palaeochannel at Waycar Pasture exposed in June 1990 (after Grattan, 1990).*

pollen sites in Holderness (Tweddle & Edwards, 2010). So this suggests that the Girton evidence may be highly localised, confined to vulnerable sandlands more sensitive to short term drought and fire damage, but with perhaps no wider regional significance.

Luminescence dating

Three Girton samples were analysed in August 1998 using quartz-based TL (Table 4). Thermoluminescence (TL) dating methodology is outlined in Bateman (1995). In the 1990s the use of TL for dating sediments was largely superseded by quartz-based OSL (optically-stimulated luminescence) and feldspar-based IRSL (infra-red stimulated luminescence) affording improved precision and accuracy (Wintle, 2008). For the North Lincolnshire coversands, however, Bateman (1998) employed the older TL methodology, but analysed quartz and feldspar components separately, as previous attempts with OSL and IRSL had resulted in gross underestimates of age. These quartz and feldspar splits gave consistent results and fitted well with the radiocarbon chronology, thus placing coversands confidently within the Younger Dryas stadial, and justifying the continued use of TL for dating purposes.

TL results for Girton are both internally consistent and compatible with the North Lincolnshire chronology. Initial coversand sheet and dune construction in unit 1 include an age estimate of 11.25±2.0 ka, suggesting their start late in the Younger Dryas. Later modification under easterly palaeowinds dates to around or just before 9.30±1.1 ka (unit 3), and reactivation of drift sand in unit 4 dates to 7.71±0.8 ka.

Three samples of horizontally-bedded aeolian sand at the interface with Holme Pierrepont sands and gravels at Besthorpe and Girton yielded somewhat older OSL dates of between 25 ka and 18 ka (Schwenninger *et al.,* 2007; White *et al.,* 2007). If these samples are truly Spalford Sands rather than older sand horizons within the terrace sequence, they appear to fall problematically within the Dimlington Stadial. Problems of low quartz sensitivity, high feldspar contamination and extreme moisture variation were acknowledged as likely sources of error.

Holocene reactivation of the sand

At both 9.3 ka (Fleitmann *et al.,* 2008) and 8.2 ka (Baker, 2012) significant cold, dry climatic anomalies may have reactivated sand at Girton, though the overlapping TL error margins (10.4-8.2 ka and 8.51-6.91 ka) mean that any climatic oscillation within the Later Mesolithic might be implicated. This dating points to an episode of major soil erosion in the 9th millennium, after the climatic shifts of the Younger Dryas and pre-boreal oscillations, but before Neolithic woodland clearance, as is recorded by reactivated coversand in East Kent (Baker & Bateman, 2010).

The Girton sand dune entered a stable phase within the mid-Holocene, when it gained Bronze Age and Iron Age plough marks, middens and beaker burials (Kinsley, 1998; Kinsley & Jones, 1999). Above these, up to 2 m of structureless drift sand is present (Fig.16). Sand reactivation took place in two further phases, with features of probable Iron Age date between. The second phase was in turn cut by Late Saxon or medieval ridge and furrow. The later drift sand at Girton thus formed in or after the Iron Age, but probably no later than Late Saxon; reactivation was probably associated with Roman clearance on fragile sandy soils.

There were numerous phases of Holocene sand reactivation in the East Midlands (Table 5). Most of these polycyclic events were short-lived and probably had little or no lasting impact. However, the Later Mesolithic, Neolithic and Iron Age/Roman events redistributed sand on a larger scale. While the Neolithic Revolution seems to have initiated these repeating cycles, sand reactivation within the Mesolithic period is not so easily explained (Knight & Howard, 2004).

Sediment unit	TPAT code	SCIDR code	Depth (m)	K %	U ppm	Th ppm	Water %	Dose (quartz) (Gy/a)	Equivalent dose (Gy)	TL age (ka± 1σ)
Unit 3 (laminated sands, west of slipface)	ES110 QS5.7	Shfd 98034	1.1	1.10	0.90	2.05	3.6	1.56±0.04	14.48±1.6	9.30±1.1
Unit 4 (superficial sand, west of slipface)	ES109 QS5.7	Shfd 98035	0.5	1.23	1.00	2.50	3.1	1.77±0.04	13.67±1.4	7.71±0.8
Unit 1 (laminated sands, east of slipface)	ES111 QS5.6	Shfd 98036	1.6	1.59	1.09	3.10	7.9	2.05±0.05	23.0±3.9	11.25±2.0

***Table 4**. Luminescence dates for the three TL samples from Girton.*

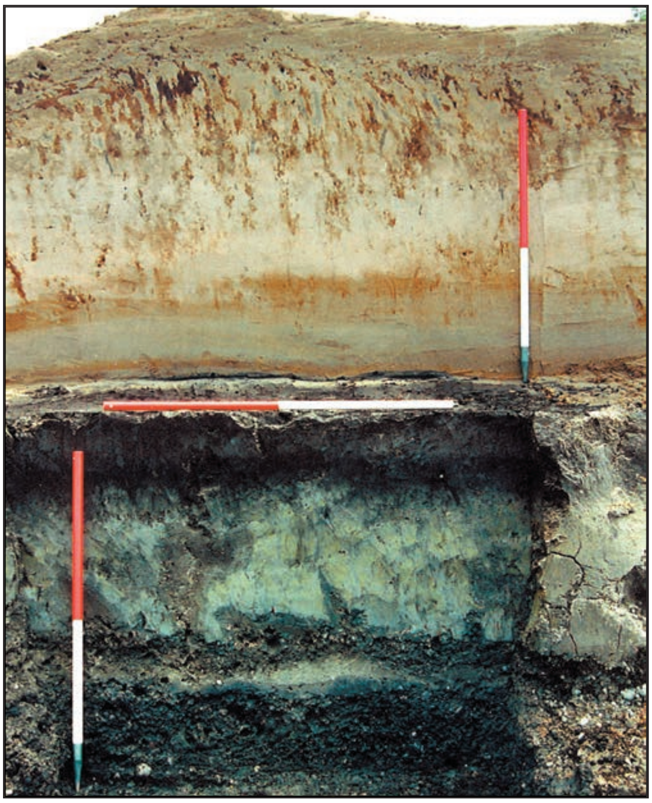

Figure 16. *Structureless, manganese-stained drift sand, probably of Iron Age or later, overlying and terminating the palaeochannel sequence at Girton [826665] (photo: TPA).*

Period	*Location*	*Dates*	
Mesolithic (11500-6000 BP)	Twigmoor Woods	(Preboreal) 10.32±0.8	Pollen TL
	Tiln (Bellmoor)	8.51±0.8	TL
	Tiln (Bellmoor)	7.7±0.7, 7.91±0.7 8.3±0.8	TL
	Westwoodside	7.9±1.6	OSL
	Girton	7.7±0.8, 9.3±1.1	TL
	Yarborough	6.7±2.1	TL
	Farndon	7.98±0.69	OSL
Neolithic (6000-4500 BP)	Kelsey (Caistor)	6.46±0.6	TL
	Twigmoor Woods	5.66±0.6	TL
	Misterton Carr	4958±332 cal BP	C14
	Bagmoor	4.56±0.5	TL
Bronze Age (4500-2700 BP)	Risby Warren	(undated)	Arch
	Girton	(undated)	Arch
	Farndon	2.87±1.29	OSL
Iron Age/ Roman (700 BC-400 AD)	Crosby Warren	2394±276 cal BP 2094±194 cal BP	C14
	Besthorpe	(undated)	Arch
	Torksey	2563±196 cal BP 1869±171 cal BP	C14
Anglo-Saxon (400-1000 AD)	Twigmoor Woods	1.31±0.2	TL
	Fonaby House	(undated)	Arch
Medieval Warm (1000-1400 AD)	"West Lincs"	11th century	Doc
Little Ice Age (1400-1800 AD)	Torksey	(undated)	Arch
	Torksey Lock	1700s	Arch
	Nettleton	1675-1695, 1698	Doc
	Santon, Roxby	1695, 1699	Doc
	Tiln	0.3±0.3	TL
Present (post 1800 AD)	Market Rasen	1888	Obs
	Risby	1900-1910	Obs
	Marston	March 1968	Doc
	Caistor	1972	Doc
	Naylor's Hill	1973	Obs
	Tiln	1996	Obs

Table 5. *Periods of Holocene reactivation of aeolian drift sand in Nottinghamshire and Lincolnshire. Luminescence dates are in ka; C14 in years cal BP; and recent sources in years AD; Arch = archaeological, Doc = documented, Obs = observed. Compiled from multiple sources.*

Location	*Reference*	*Lab codes*	*Age, ka*
Bellmoor Quarry (Tiln)	Bateman *et al.* 1997 Howard *et al.* 1999	Shfd96046	8.51±0.8
		Shfd96044	8.30±0.8
		Shfd96043	7.91±0.7
		Shfd96003	7.70±0.7
Cove Farm	Bateman *et al.* 2001b	Shfd97078	7.90±1.6
Girton	This study	Shfd98034	9.30±1.1
		Shfd98035	7.71±0.8
Farndon	Harding *et al.* 2013	X3738	7.98±0.7

Table 6. *TL and OSL dating of sand mobility in the Trent valley in and around the 8200 BP anomaly.*

Rapid climate change within the Early Holocene, associated with natural fire and woodland dieback, might explain these earlier episodes. The case for climate-driven regional sand mobility within the 8200 BP event is strengthened by the new Girton TL dating (Table 6). Ninth millennium reactivation in the Trent valley may be just one local expression of a more widespread climate oscillation detected in aeolian studies throughout Britain and the near-continent (Janotta *et al.*, 1997; Gilbertson *et al.*, 1999; Dalsgaard and Vad Odgaard, 2001; Wilson, 2002; Hitchens, 2009; Baker and Bateman, 2010).

Palaeowind reconstruction

The wind regime throughout the Last Glacial Maximum and Late Glacial is generally recognised as being similar to that of the present, with a prevailing westerly source. Dune ridge alignment in the Lower Trent, and inferred palaeowind directions within the coversands (Fig. 17), are broadly consistent with this view. Local dunes are arranged in lines or *en échelon*, with long axes aligned east to west, with steeper slopes facing north (Lamplugh *et al.,* 1911). Dunes in the Messingham area, near Scunthorpe, have 78% trending W-E and 22% N-S (George, 1992). Among a sample of 197 dunes, there is a preference for W-E alignment in the Ancholme valley, whereas the Trent valley has equal numbers of W-E and N-S ridges (Bateman, 1998). Whether these are longitudinal or transverse dictates whether perpendicular or parallel palaeowinds may be inferred. The Girton evidence points to asymmetrical transverse ridges, with strong easterly gales driving north-south dunes westwards. By contrast, chaotic dune orientation at Twigmoor Woods reveals compound wind directions, reflecting both bio-topographic origin and deflation in inter-dune blowouts (Bateman *et al.,* 2001a).

The main argument for westerly provenance of local coversands is sandsheet geometry, with aeolian sand banked against the windward west-facing slopes of the Isle of Axholme and the Lincolnshire ridges (Straw, 1963, 1979; Gaunt, 1981; Buckland, 1982; Bateman, 1998). Sandsheet thickness decreases eastwards, with little or no sand found east of the Wolds, though the coversand distribution in Figure 1 may be an under-estimate (Sumbler, 1993, and Berridge, 1999).

A westerly sand source is compatible with Atmospheric General Circulation Modelling for the Younger Dryas; the net result on the atmosphere of the relocation of the Icelandic low and compressed

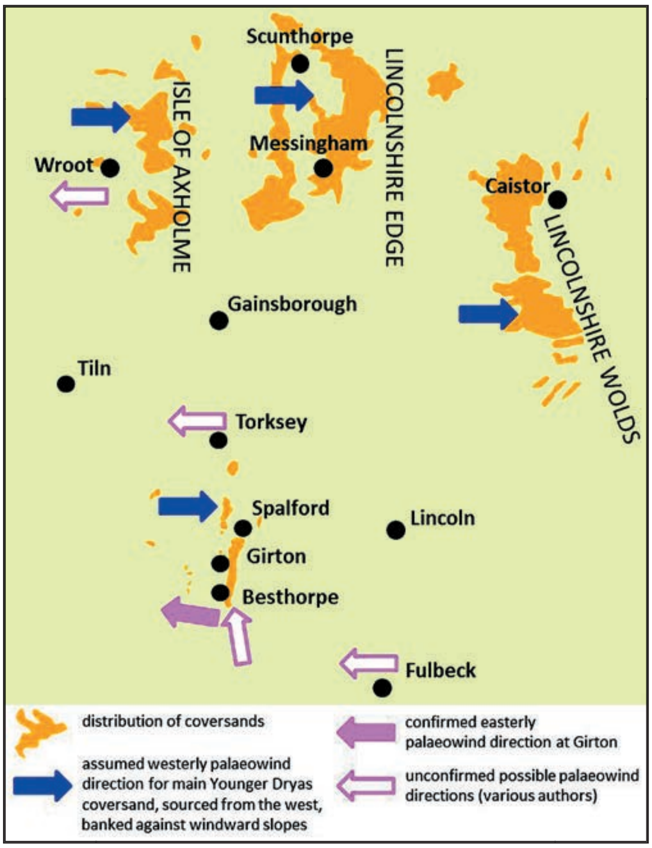

***Figure** 17. Palaeowind directions within the East Midlands coversand sequence (part after Bateman, 1998; Bateman et al., 2001a; Gaunt, 1994; Sumbler, 1993; Lamplugh et al., 1911).*

pressure gradient over the ice-covered North Atlantic would have been greatly to increase the speed of westerly winds over Europe (Isarin *et al*, 1997). Van Huissteden *et al.* (2001) identify mainly westerly winds for the Dutch Older Coversands, and prevalence of westerly winds over the whole European Sand Belt is generally agreed (Schwan, 1988; Kasse, 2002; Renssen *et al*., 2007; Koster, 2009). This would have been applicable throughout the Last Glacial Maximum to Early Holocene periods.

There are local exceptions, such as at Vrijdijk (van Huissteden *et al.,* 2001) which has an easterly component, while wind polish on Younger Dryas boulders in the Scottish Highlands indicates dominant winds from both north and south (Christiansen, 2004). Palaeowinds were not unidirectional, partly due to Atlantic depressions sweeping across Britain (Williams, 1975), but easterly winds may have been due to a blocking anticyclone over Scandinavia (Isarin *et al.,* 1997; Lamb, 1977; Gaunt, 1981; van Huissteden *et al.,* 2001), or they may have been generated by katabatic flow across those areas closest to the Scandinavian ice margin (Kasse, 2002; Renssen *et al.,* 2007).

This demonstrable variability in wind direction questions whether an easterly palaeowind can be convincingly recognised in the East Midlands. The case for easterly winds has been made by Gaunt (1981, 1994) (Fig. 17). The Humberhead dunes are barchan-like with westward-facing horns, but Bateman (1998) questions whether these are not perhaps parabolic, and thus could

***Table** 7. The Girton palaeoenvironmental reconstruction.*

ka BP	*Pollen zones*	*Archaeology*	*Climate trends*	*Climate events*	*Coversand TL dates*	*Channel C14 dates*	*Environments*
1	sub-atlantic		warming	Little Ice Age			
2		Anglo-Saxon Romano-British	cooling				Major reactivation of drift sand due to woodland clearance and intensive land use during the Iron Age. Palaeochannel is overridden, terminating the infill. Zone G/F shows reversion to reed swamp with heath, disturbed species and weeds of cultivation
3	sub-boreal	Iron Age					
4		Bronze Age				3050±175	Dune stability, its weathered sand surface studded with archaeological features. Cutoff continues to infill, zones G/D and G/E recording mature diverse woodland dominated by alder carr, with reed-fringed fenland around the closing palaeochannel. Burnt mound debris and sand lenses interbed with the peat. Recovery of water and woodland-dependent beetles.
5		Later Neolithic					
6	atlantic	Earlier Neolithic	thermal maximum				
7		Later Mesolithic				6140±139	Palaeochannel zone G/C records a period of environmental stress (hazel nearly eliminated, restricted water beetles, severely abraded terrestrial beetles, and abundant macro-charcoal). Natural fire damage inferred. A further phase of sand reactivation deposits drift sand across the dune surface, possibly related to a second climatic reversal (at 8.2ka).
8	boreal		warming	8.2 ka	7.71±0.8ka	7454±121	
9							
10				9.3 ka	9.30±1.1ka	9148±148	After initial period of postglacial warming and woodland development, a brief climatic reversal (at 9.3ka) intervenes with cold dry winter easterlies reactivating sand. Dune topography is formed, with multiple asymmetric transverse ridges. Eutrophic fen is established around the palaeochannel, away from the main river, and surrounded by hazel shrubland.
11	pre-boreal	Earlier Mesolithic					
12				11.4 ka	11.25±2ka		
13	younger dryas	Late Upper Palaeolithic	GS-1 cooling				Active channel in the periglacial Trent valley sandur. Westerly winds cross the cold arid mammoth steppe, depositing coversand sheet on the east side of valley.

be interpreted in exactly the opposite way. By contrast, most dunes within Lincolnshire are indistinct, providing little or no evidence of wind direction (Bateman, 1998; Bateman *et al,* 2001a). Cases of easterly provenance have also been suggested at Fulbeck Heath (Sumbler, 1993) and Torksey (Samantha Stein, *pers. com.*). The Girton evidence supports temporarily reversed palaeowinds, with an incursion of strong winter easterlies driven by intensified anticyclonic circulation over the dwindling Scandinavian ice sheet. Although Younger Dryas westerly winds certainly activated coversands, strong easterly airflows must also have been experienced, albeit briefly, in the Early Holocene. With the southern North Sea as yet unformed, cold Siberian winds must have blown unhindered into eastern Britain across Doggerland during the Later Mesolithic period.

The Trent Valley palaeo-environment

Although the Spalford Sands at Girton constitute only a small outlier of the East Midlands coversand sheet, they have yielded significant new insights into Late Pleistocene and Early Holocene conditions (Table 7). Sourced from the Trent sandur, these sediments fit a framework of Younger Dryas deposition, post-dating the Holme Pierrepont terrace, and correlating with the continental Younger Coversand II. Involutions and ice-wedge casts exist in the former active layer in a few places prior to the coversand sheet, but are absent at Girton. Complex dune structures with unusually clear ridges, slipfaces and high-angle cross-bedding indicate reversed easterly winds probably driven by a strong blocking anticyclone over Scandinavia in the Early Holocene. This conforms with the standard palaeoclimatic model of prevailing westerly airflow; coversands were initially sourced from the west during the Younger Dryas, but were modified in the final stages of dune stabilisation possibly linked to climatic anomalies at 9.3 ka and 8.2 ka. Multiple phases of reactivation in polycyclic drift sands include three at Girton, at around 9.3 and 7.7 ka and then during the Iron Age or Roman period. Palaeochannel sediments indicate a period of environmental stress in the 10th and 9th millennia, overlapping in time with the aeolian events. A scenario of interrelated drought, natural fire, woodland dieback and soil erosion, driven climatically, is thus envisaged for Girton, but this may be confined to the fragile sandy soils of the Lower Trent area.

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The Hunstanton Park esker, northwest Norfolk

Peter Worsley

Abstract: A well-developed, sinuous esker, almost two km long, terminates close to a glacial meltwater channel and is just inside the Devensian glacial advance limit. William Whitaker discovered it in 1882, although initially its glacigenic status was in some doubt. An off-shore bar mechanism was favoured by some until the 1920s, influenced by the presence of a marine fauna. Morphological and sedimentological evidence suggests that the esker was superimposed onto the chalk bedrock from an englacial or supraglacial position, rather than having been formed subglacially. The esker is currently assigned to the Ringstead Sand and Gravel Member, part of the east coast Holderness Formation (including the classic Hessle/Hunstanton Till) of Last Glacial Maximum age at about 20 ka BP.

Eskers are long narrow ridges of sand and gravel of glacigenic (fluvioglacial) origin with an orientation which is generally parallel with the ice flow direction (Fig. 1). They are commonly sinuous and often appear to be independent of the form of the ground upon which they lie (Fig. 2). Ridge location is determined by the former position of confining walls of glacier ice, hence their sides are described as ice-contact slopes. The word esker is derived from *Eiscir* which means a ridge or elevation in Gaelic. In contrast, kames *per se* are today identified as isolated non-linear mounds of glacigenic sand and gravel, but somewhat confusingly kame was originally a synonym in Scotland for esker. Eskers, kames and kettle holes arise from the melt-out of buried, detached ice masses during glacier retreat.

The word esker was introduced into the geological literature by the amateur geologist Rev. Maxwell Close (1867) who was described by Gordon Herries Davis (1995) as 'a most acute observer of Irish glacial phenomena'. David Hummel (1874) developed the original concept of glacial meltwater rivers transporting debris within a glacier which, upon ice retreat, were subsequently left as ridges. He envisaged them being the aggraded infills (sediment casts) of tunnels at the base of a glacier, in a subglacial position, with the meltwater derived from surface melt descending crevasses to the glacier bed. Holst (1876) elaborated the concept by suggesting that sediments transported by meltwater rivers flowing in supraglacial channels might also subsequently produce eskers. These Swedish ideas were brought to English-speaking audiences through the work of James Geikie who had regular contact with Scandinavian workers, so that in his *The Great Ice Age* (1894) he preferred to use the Scandinavian word Ås for them, rather than the Irish-derived esker. However, his successor as the doyen of British glacial geology, the Irish-born W. B. Wright of the Geological Survey of Ireland, favoured the term esker in his *Quaternary Ice Age* (1914), and this has stayed in use in the British literature. Observations of modern eskers in Iceland and Alaska (Price, 1973) demonstrate that buried ice within the esker landform exaggerates their size since after the ice melts the resultant landform is much diminished.

Mainly in the late nineteenth century there was a struggle for terrestrial glaciation concepts to become the established wisdom at the expense of the glacio-marine submergence hypothesis. Studies of contemporary glacial environments by British glacial geologists commenced in 1865 when Archibald and James Geikie together with William Whitaker mounted

***Figure 1**. An esker ridge trending from right to left (across the centre of this image) in front of the retreating glacier of Renardbreen, at Bellsund, west Spitsbergen. The esker is about 4 m high, is parallel with the direction of ice movement direction, and lies on a recently deposited till plain. Isolated kame mounds occur, and the boulder-strewn ridge beyond the esker is a drumlin recently emerged from the glacier margin.*

***Figure 2**. An esker alongside the eastern shore of the glacial lake of Breiðárlón in southern Iceland, with the Breiðamerkurjökull ice margin in the background; this esker is ice-cored and a more poorly defined linear ridge is likely to remain after melt-out.*

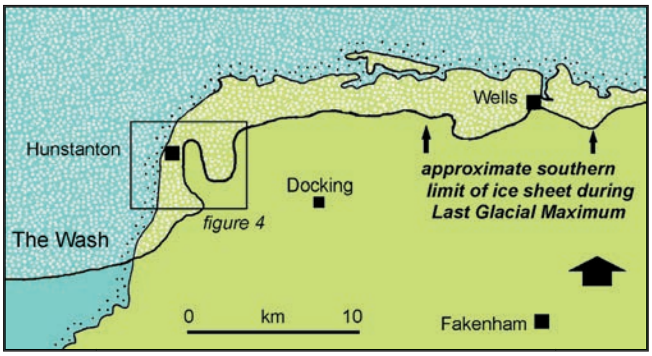

***Figure 3**. The Last Glacial Maximum ice limit in north-west Norfolk in relation to the esker, which has its southern terminus very close to the advance limit (modified after Allan Straw and British Geological Survey).*

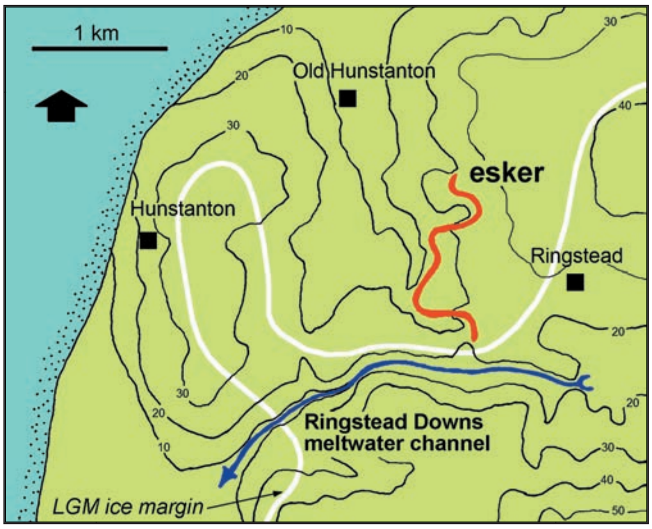

***Figure 4**. Relationship between the Hunstanton esker and the Ringsted meltwater channel; the white line traces the southern margin of the ice sheet during the Last Glacial Maximum, which is very close to the esker's southern limit.*

an expedition to the Norwegian Arctic, although it took several decades for the land ice hypothesis to be fully accepted (Worsley, 2008). Even as late as the early 1920s J. W. Gregory, the Professor of Geology at Glasgow University, was still advocating a marine mechanism for esker genesis (Gregory 1921, 1922).

In England, eskers are not common, but a well-developed esker, some 2 km long, occurs in Hunstanton Park just east of The Wash in north-west Norfolk (Figs. 3, 4). Since it is located in private land, it is not particularly well known. Much of its length is covered by dense woodland that obscures its morphology, such that 'Park House', a ruined hunting lodge dating from 1623, sited on its crest, is almost invisible. The park has only 15 m of relief, and is drained by a small, north-flowing stream (Fig. 5). The esker has been only poorly documented, whereas the Blakeney esker, 30 km to the east has been investigated in detail (Sparks & West, 1964; Grey, 1998; Gale & Hoare, 2007).

Pioneer Victorian investigations

In the Geological Survey's primary mapping of East Anglia, the eastern part of Sheet 69 (published in 1886) covered western Norfolk and was the work of a team of geologists led by William Whitaker. In 1883 he organised a long weekend field meeting for the Geologists' Association to demonstrate the area's geology and this involved an examination of Hunstanton Park where in the southern part 'he shewed them a peculiar long narrow winding ridge of gravel and sand, like similar ridges known as kames in Scotland, and as eskers in Ireland' (Whitaker, 1885, 1891). He appreciated that the landform was constructional in origin rather than an erosional remnant and that it was likely to be a product of glaciation. T. V. Holmes had been with the Survey in 1868-1879 and was familiar with extensive esker-type features in northern Cumberland. Accordingly, Horace Woodward, a senior member of the mapping team, had invited him to see the esker-like landforms in Norfolk, and Whitaker asked him to comment on the structure of the Hunstanton Park esker during his field meeting.

Woodward had been studying the glacial landforms in the lower River Glaven valley, 30 km east of Hunstanton. He had written (1884) '…Blakeney [Wiverton] Down, [is] a ridge that looks in places like a great railway embankment, running in a serpentine course for about 2 miles. In the same neighbourhood are many little hills of gravel, standing out in the midst of ploughed fields; and being uncultivated, and covered with gorse and broom, they form striking objects'. He added that they were 'the last relicts of the Great Ice Age

***Figure 5**. The esker in a view looking east, towards the former Cedar Pit, with the aligned hummocks that misleadingly appear as beaded or segmented.*

… and to have been formed by the floods and torrents that attended its passing away'. Two weeks previous to Whitaker's field excursion, Holmes had read a paper on eskers and kames to the Norwich Geological Society, of which Whitaker was then President (Holmes, 1883). For one of his figures he used a woodcut by Woodward showing the distribution of eskers south of Blakeney.

Despite Woodward having linked the Blakeney eskers and kames to terrestrial glaciation, Holmes took a contrary view; struck by the analogy between the eskers and marine sand banks, he chose to interpret them as products of glacio-marine submergence. He was aware of the common association of eskers and enclosed hollows (kettle holes) but attributed the latter to 'diverse currents'. Holmes (1884) appreciated the irony of promoting a marine offshore environment for esker genesis in the company of Whitaker, who was one of the chief champions of the power of rain and rivers in forming escarpments since he had won the approbation of Charles Darwin for his paper on the subaerial denudation of the North Downs escarpment despite it having been rejected by the Geological Society of London (Whitaker, 1867).

In the discussion following the reading of Holmes's paper in Norwich, Woodward commented on the divergent opinions on esker genesis and noted that James Geikie was in favour of them being a product of subglacial meltwater deposition. Whitaker added that he was struck by the discordant nature of the ridge with respect to the surrounding terrain form. Surprisingly, Whitaker appears not to have then been aware of a derived marine fauna in the esker sediments, although in the Arctic in 1865 (Worsley, 2008) he had observed a glacier pushing fossiliferous marine sediment to form a moraine ridge.

Figure 6. *A subglacial esker emerging from the margin of Fingerbreen, Svartisen, arctic Norway. The smoothly rounded esker ridge is 45 m long and up to 6.5 m high, and emerged during ice recession between 1963 and 1966. A lower linear moraine ridge crosses the foreground, and a similar dark feature lies just in front of the glacier margin on the left; these were formed by annual winter re-advances of the glacier. These sediment features are comparable with those seen by Whitaker in 1865.*

During 1885-6, the American geologist H Carvill Lewis made a detour to Hunstanton to examine the 'so-called' esker during his tour of Britain and Ireland. He found fragments of marine shell in a sand pit at the southern end, and this evidence, combined with an unexpected absence of kame knobs and kettle holes, led him to conclude that the feature was a portion of an old sea beach lying 15 m above the modern sea level (Lewis, 1894), a view in accord with that of Holmes. In the third edition of his magnum opus, James Geikie (1894) commented that 'formerly åsar [eskers] were believed to be of marine origin – heaped up by tidal currents – but that interpretation had now been abandoned'.

The Sheet 69 Memoir (Whitaker & Jukes Browne, 1899), stated '...on the north and west borders of Norfolk, and also north of Boston, there appears to be a different kind of boulder clay which is brown or reddish in colour and contains very little chalk debris, but many stones from distant sources. With this clay are also associated a varied series of loams, sands and gravels'. Clay of this character was known as 'Hessle' (Wood & Rome, 1868). The patches of sand and gravels were assigned to the Hessle Clay group, and these included the esker-like ridge in Hunstanton Park. An old pit cut into the southern end had yielded a derived marine fauna to A.C.G. Cameron, to confirm Lewis's discovery. It was recorded that the esker terminated above a dry valley falling westwards from Ringstead.

Twentieth Century research

Interest in the Hunstanton esker was renewed by Gregory (1922), who uniquely claimed it to be locally known as the Ringstead sand-hills. In the old pit at the southern end he recorded an uppermost bed or surface wash of angular flints over a till that was described as disturbed in patches or sheet-like and <0.6 m thick, overlying an irregularly denuded surface of a sand succession. The sands contained fragmentary marine shells including *Mytilus* sp.. Gregory chose to interpret the esker as a product of denudation, on the basis that the surface wash capping the ridge could only have been derived from a higher source and the slopes of a former valley had enabled the flints to move from the chalk slopes to the ridge crest. He claimed support for this concept in 'outlier' mounds of sand that were also seen as erosional remnants, and therefore regarded the esker as a 'residual kame'. An immediate challenge to his interpretation came from Percy Kendall (1922) but others simply ignored Gregory's paper.

There had been a suggestion that the Last Glaciation ice limit might lie within the conventional one at Flamborough Head (Farringdon & Mitchell, 1951), but the established view concerning the limit, based upon fresh landforms and the distribution of the Hessle till was confirmed by Suggate and West (1959), with only minor changes. The latter noted that the only known locality where the Hessle till could be seen unambiguously above a chalk-rich till was at Welton le Wold, in Lincolnshire. Their investigation of the biostratigraphy of the fill of a possible kettle hole at Aby Grange, southeast of Louth, demonstrated that the Hessle Till was directly overlain by a Late-glacial sequence. These data, along with radiocarbon age estimates (then newly available in England), suggested that the till lining the hollow was of Last Glacial age. In accord with Jukes-Browne (1887), they argued that the relief expressed by the Hessle Till indicated a little-modified, deglaciated land surface that characterised the 'Newer Drift' rather than the incised and eroded 'Older Drift'. Within this landform system they noted the presence of 'an excellent example of an esker in Hunstanton Park'.

In 1958 Allan Straw extended his seminal studies of Lincolnshire glacial geomorphology across the Wash into Norfolk (Straw, 1960, 1979). His concern was to compare the patterns of glaciation in Lincolnshire and North Norfolk and to establish the Last Glacial ice limit by determining the extent of the Hunstanton [Hessle] Till. Little was said on the Park esker, other than to record that it was 'a fine one' and 2 km long. The Hunstanton Till was not mapped in the park itself and it was postulated that, prior to the ice advance, a stream had drained north-westwards from Ringsted across Hunstanton Park. He portrayed the maximum ice extent as a lobe from the north that roughly followed the park boundary (Fig. 4). The esker drainage was thought to have discharged into a meltwater channel that is now the dry valley draining westwards from Ringstead.

The character of the uppermost tills in coastal eastern England, variously called Hessle, Hunstanton and Holkham depending on location, is now related to post-depositional weathering, mainly during the Flandrian (Madgett, 1975; Madgett & Catt, 1978). Thus, the Hessle Till is now defined as a pedostratigraphic unit, whereas the parent till is believed to be the Skipsea Till (apart from a restricted area of Withernsea Till in Holderness). Where the till is thin, as in most of northwest Norfolk, its entire thickness is weathered.

The Hunstanton Park esker was designated a SSSI in 1990, and the Ringstead meltwater channel fell into a second SSSI established primarily for its chalk grassland flora. The channel is up to 15 m deep and 60 m wide (Fig. 7). The esker and the meltwater channel were viewed as contemporary, with a knick point where the esker joins taken as indicative of development in two stages. Hywel Evans (1976) documented the morphology and sedimentology of the esker. He also led a field meeting of the Quaternary Research Association that revealed sands and gravels containing a mainly comminuted derived marine fauna in shallow excavations in its southern part (Fig. 8).

The course of the esker was accurately defined for the first time in 1979 on the new Geological Survey map (Sheet 145 with 129, at 1:50,000) and was described in the memoir as being both sinuous and beaded (Gallois, 1994). It was mapped as being flanked by an apron of head wider than the esker itself, and this rested on a thin veneer of till. The head was defined to include post-glacial slope material, which suggests that the esker has degraded in a periglacial environment, and the slope deposits of Evans (1976) probably relate to this.

A review of the glaciation event in north-west Norfolk asserted that it 'should not be assigned to any Stage of the Quaternary prior to the availability of any definite chronostratigraphic or biostratigraphic evidence' (England & Lee, 1991), despite prior work (Gale *et al.,* 1988). Ironically, the first geochronological data consisting of five amino acid D/L ratio assays on derived marine shells (collected from the esker by the writer in 1976) were published in the same year with *Macoma baltica* yielding values of 0.15, 0.16, 0.14 and *Arctica islandica* 0.19, 0.14, (Bowen, 1991; Bowen *et al.,* 2002). These values were interpreted to a Marine Oxygen Isotope Stage 5 age for the fauna (c.95-130 ka BP), which is consistent with a Last Glacial Maximum age of 20 ka BP for the ice advance to the Hunstanton Till limit.

The 2008 1:50,000 geological map for Wells-next-the-Sea (Sheet 130 from the British Geological Survey)

***Figure** 7. The Ringstead Down meltwater channel, with its asymmetric cross profile eroded into the Lower and Middle Chalk; looking east (upstream) towards Ringstead from NGR 688399 adjacent to Downs Farm.*

Figure 8. *Part of the Hunstanton Park esker in September 1977, during the visit by the Quaternary Research Association. The view is towards the west-north-west from NGR 697404 when small-scale quarrying of sand and gravel was in progress. In the foreground, the Cedars pit is similar in extent to when it was examined by Hywel Evans.*

approaches to just a few hundred meters short of the esker, and adopts a more refined lithostratigraphic classification for the glacial Quaternary, with the Hunstanton [Hessle] Till becoming the principle component of a Holderness Formation. This Formation also includes the Red Lion Till Member (restricted to a small area around the eponymous inn at Stiffkey) and the Ringstead Sand and Gravel Member, (McMillan *et al.,* 2011). Curiously the glacigenic Ringstead Sands and Gravels have no formal stratotype, rather a stratotype area embracing Heacham, Ringstead, Hunstanton and Holkham, and covering a broad range of sedimentary geometries, landforms and modes of formation in a veritable bucket of glaciofluvial sediments, including the Hunstanton esker.

The esker geomorphology

The Hunstanton Park esker is sinuous, with a total length of 1.9 km over a north–south extent of 1.25 km (Fig. 10). Parts of its crest are flat, notably around Park House where the flat width is 12 m for just over 100 m along the axis. There the esker attains its greatest height at about 16 m. Some 1300 m of the esker's length covered by dense woodland and largely impenetrable undergrowth of box trees; only two stretches of some 300 and 400 m in length are open grazing land. The esker has been quarried in the past and old pits might simulate kettle holes. Towards the proximal, northern end, and within dense woodland, a dish-shaped hollow on its western flank does have the character of a small kettle hole. West of this, the fields inside the esker bend have two more, shallow, kettle-like depressions. Both Evans and Gallois have used the descriptive term 'beaded' in connection with the esker morphology. Unfortunately this term is not appropriate in the context of its previous usage in the glacial geological literature.

Figure 9. *The esker in November 2012, after restoration of the gravel pits, now levelled and grassed over, seen from about the same location as that in Figure 8.*

A beaded esker is one with zones of widening along its length; the beads are formed where eskers deposited sub-aquatically during ice retreat are punctuated by small deltas that aggrade during the summer months when sediment supply is at a maximum (de Geer, 1897). An English example is in Aqualate Park in Staffordshire (Worsley, 1975). At Hunstanton there is no evidence for sub-aquatic deposition, and tellingly the segment described as 'beaded' (Evans, 1976; Gallois, 1994) is orientated almost normal to the ice movement direction. This part of the esker is atypical, with its short series of linear hummocks, but it is possible that these are erosional forms and not depositional.

The esker sedimentology

Within Hunstanton Park glacigenic materials are thin, and the esker rests mainly on chalk bedrock. Exposures in former pits are grassed over, so previous documentation (Evans, 1976) of the small Cedar Pit (55 by 20 m), near the southern end of the esker, are vital to understanding the genesis (Fig. 11). A maximum thickness of 5 m of

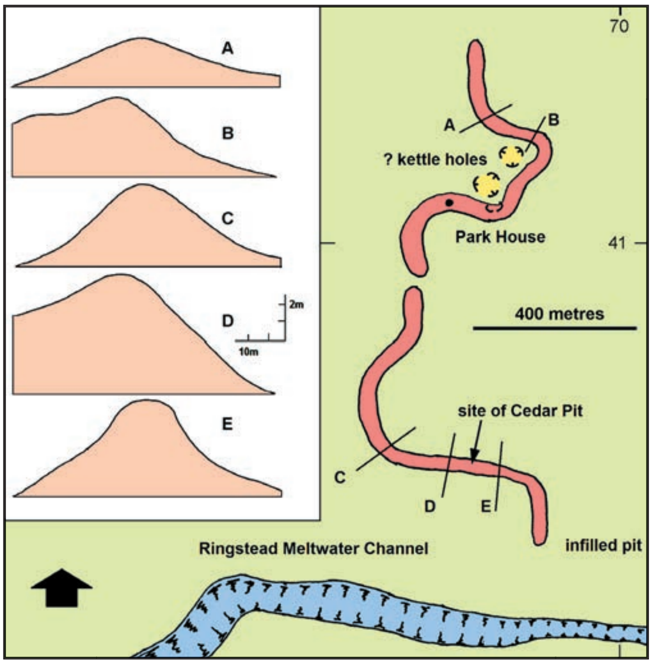

Figure 10. *Geomorphology of the Hunstanton Park esker and part of the Ringsted meltwater channel. Inset has the five levelled cross profiles of the esker drawn with a vertical exaggeration of 20; profiles B and D are asymmetric, reflecting the slope of the surface beneath the esker and suggesting that the esker was superimposed.*

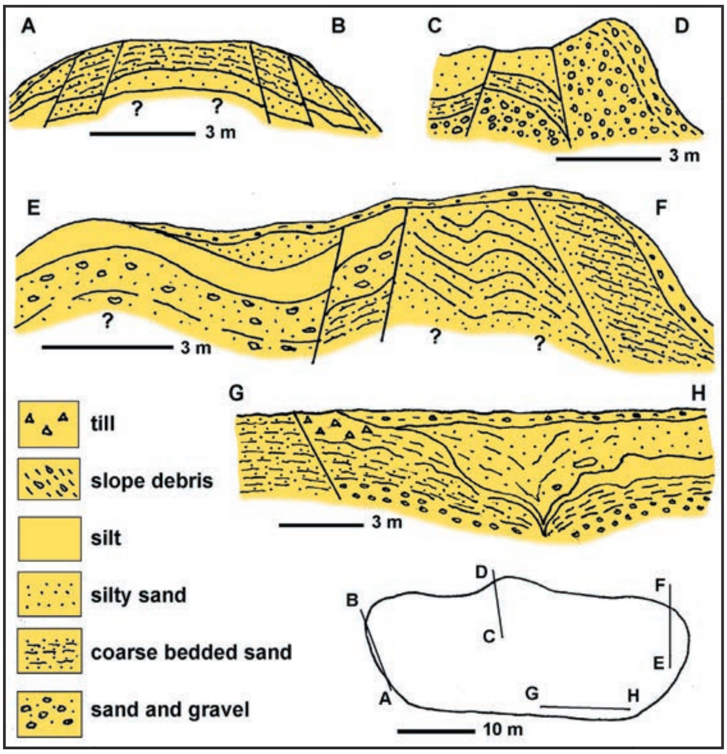

***Figure 11**. Four sketch sections of the esker sediments, and their relative locations in the Cedar gravel pit. Sections AB, CD and EF are transverse to the ridge axis; GH is longitudinal close to the southern margin. The transverse sections show how rapidly the sedimentology changes along about 40 metres length of the same ice-contact slope that defined the esker margin (modified from Evans, 1976).*

fluvioglacial sediments was exposed (Table 1), but the chalk bedrock beneath the esker was not exposed in the pit. In 2012 a small section near the eastern edge of the former Cedar Pit at the crest of cross profile E (Fig.12), was the only exposure along the esker and revealed a succession of seven beds close to the esker crest (Table 2). The presence of diamict confirms earlier reports that a flow till characterised the top of the esker sequence in places. Stone counts from the Cedar Pit (Evans, 1976) gave mean values across three sites (total count = 570) of 40% chalk, 27% flint, 10% Carboniferous sandstones, 7% igneous, with trace amounts of local Red Chalk and Carstone (Fig. 13). The Carstone breaks down to sand. In a boulder bed chalk comprised 61% of the clasts (N = 100), with just 6% of flint. The chalk clasts have a high proportion that are well-rounded and disc-shaped; since chalk has a low durability as bedload clasts, their transport distance was probably limited. Imbrication gave a mean direction of N 166°. Red Chalk crops out on the floor of the Wash 2-3 km northwest of the esker, indicating a minimum transport distance.

Upwards-fining sequence with boulder-sized clasts at the base grading into sandy silts at the top.

Consistent pattern of normal faults trending along the ridge axis with downthrows on each side of <1.15 m, giving an overall anticlinal flexure structure to the a-b cross section in Figure 9.

Localised synclinal sags within the sediments; see Figure 9 g-h.

Till inclusions within the sediments towards the top of the succession (Fig. 9c) and till beds <0.43 m thick on the flanks lying with a sharp contact onto bedded gravels beneath (not shown on the sections).

***Table 1**. Sedimentological characteristics of the esker, as exposed in Cedar Pit (after Evans, 1976).*

***Figure 12**. A section cut 2 metres deep into the former east face of the Cedar Pit in 2012; sited immediately below the esker crest at profile E in Figure 8.*

Diamict (till) forming a bulbous mass <0.5 m.
Massive silt <0.8 m.
Clast-supported coarse gravel, mainly chalk clasts <0.8 m.
Coarse angular gravel 0.8–1.15 m.
Massive fine sand / coarse silt
with small angular chalk clasts 1.15–1.52 m.
Coarse sand-granules 1.52–1.80 m.
Medium sand with minor comminuted shell 1.80–<2.0 m.

***Table 2**. Sequence of sediments exposed in 2012 at the site of Cedar Pit.*

***Figure 13**. Sands and gravels exposed in 2012 on the floor of the old Cedar Pit; rounded chalk clasts dominate (the two largest have fractured due to recent freezing), and flint and Red Chalk are minor components; the coin is 22 mm across.*

The esker palaeontology

The esker sediments contain a derived marine molluscan fauna. Exposed in the Cedar Pit, only the core zone had <0.6 m of grey medium to fine sands with bands of small chalk clasts and a derived fauna (Evans, 1976). At present, finely comminuted and unidentifiable shell material can be found around rabbit burrows. However, whole shells have been collected from working pit faces in the past since the time of Carville Lewis's visit, and material from Cedars Pit is from Mesozoic and Pleistocene age groups (Table 3).

The presence of these faunas within the esker sediments is consistent with ice moving over the North Sea floor. Following a eustatic fall in sea level, the seabed would have had a veneer of abandoned marine and fluvial sediments reworked from earlier glacigenic materials. This mirrors the situation pertaining to similar Pleistocene faunas within the Irish Sea derived-glacigenic succession in Cheshire (Thompson & Worsley, 1966) and in Holderness at Kelsey Hill.

Pre Pleistocene (Mesozoic)

Jurassic: *Acroteuthis lateralis, Gryphaea arcuata, Ostrea* sp., *Rhynchonella* sp., crinoid ossicles.
Gault: *Neohibolites minimus*.
Red Chalk*: Terebratula capillata*?.
Chalk: *Belemnitella mucronata*.

Pleistocene

Ocenebra erinacea (L) (Sting-winkle),
Hinia incrassatus (Ström) (Thick-lipped Dog Welk),
Arctica [Cyprina] *islandica* (L), *Buccinium undatum* (L)
Cerastoderma edule (L.) [syn *Cardium edule*],
Cerastoderma sp., *Macoma balthica* (L), *Ostrea* sp.
Tellina sp. (this might be *Macoma*), *Venus* sp.,
Pomatoceros triquetor (L.), (a keelworm on a chalk clast).

Table 3. *The two age groups of fauna collected from Cedar Pit, by Evans (1976), except for the last six by the author.*

The esker's environment and age

Meltwater from the Hunstanton esker's drainage system discharged to the south. The esker terminates on a slope that extends 150 m down to the Ringstead meltwater channel, but there is no clear morphological link between the two. The main dry valley has a break in the long profile south of the esker's southern end, though an old trackway embankment across the channel clouds the picture. It appears that the esker drainage maintained its englacial course southwards from the preserved esker, and any sedimentary record was obliterated during ice wastage. Downstream, to the west, the meltwater channel is more incised into the chalk, and its asymmetrical cross profile is larger than would have been formed by the esker discharge alone. The channel extends east of the esker towards Ringstead, and carried the main flow of meltwater from sources that are unknown.

Modern examples of meltwater streams emerging from glaciers in southern Iceland

Figure 14. *An englacial meltwater stream emerging from a cave mouth about 3 m high onto the glacier surface, where it becomes supraglacial; at Svinsfellsjökull. This might be analogous to the deglacial environment at Hunstanton Park when its esker was being formed.*

Figure 15. *A subglacial meltwater stream resurgence under hydrostatic pressure at the apparent ice margin of Breiðamerkurjökull. The outflow immediately disappears beneath surface debris.*

Figure 16. *An englacial meltwater channel intersected by an ablating ice cliff, at a stagnant glacier margin at Hrutajókull; the inclined debris bands indicate earlier ice marginal thrusting at the site.*

The precise position of the ice limit, during the Last Glacial Maximum, is difficult to establish since the irregular spread of glacigenic sediments, mapped as the Ringstead Sand and Gravel Member, has a feather edge with no end moraine (Moorlock *et al.,* 2008). The only contemporary feature in eastern England similar to the Hunstanton esker, is a long sinuous ridge near Keyingham in East Yorkshire (Penny, 1963), although little of the esker remains after quarrying. It is composed of the Kelsey Hill Gravels, which contain an abundant derived marine fauna, vertebrate material and the fresh water bivalve *Corbicula fluminalis* (Müller). The *Corbicula* is significant as it is now regarded as an indicator of Marine Isotope Stages 7, 9 or 11, all older than the Ipswichian interglacial (Meijer & Preece, 2000; Penkman *et al.,* 2013. The consensus view is that the Keyingham ridge consists of fluvioglacial sediments deposited as a subglacial esker southwards to a subaerial fan (Catt, 2007). Palaeocurrent indicators showing southward flow along the sinuous ridge, armoured mud balls and small peat-filled kettle holes all support this concept. However, a lithofacies log from the Kelsey Hills Gravels, showing 5 m of mainly flat-lying sands and gravels with a marine fauna sandwiched between the Skipsea and Withernsea tills, has been re-interpreted as signifying upper-beach-face gravels (Eyles *et al.,* 1994), hence re-opening the debate that arose a century ago over the origin of the Hunstanton esker.

Though it is clear that the esker in Hunstanton Park is a product of the Last Glaciation, available the amino acid assays suggest a Last Interglacial age for the derived fauna. Allan Straw has long maintained that the Last Glacial Stage in eastern England is divisible into two distinct glaciations, one forming the outer limits of the Holderness Formation in the early Devensian, followed by a more restricted ice advance in the Last Glacial Maximum. This has been challenged (Worsley, 1991), and Straw (1991) conceded that it was not yet certain whether the earlier advance took place in the early Devensian or whether both advances took place in the Late Devensian, but he later asserted 'the case for two glacial stadials in east Lincolnshire is a compelling one' (Straw, 2008). The most plausible age interpretation in the opinion of the writer is that the Hunstanton esker was deposited by meltwater close to an ice margin during the Last Glacial Maximum just before 20 ka BP. This view is supported (Clark *et al.,* 2009; Chiverrell & Thomas, 2010). Curiously, doubts linger in the minds of some workers about the relative ages of the Hunstanton and Blakeney eskers since a map of Norfolk's Devensian glacial features shows the Blakeney esker outside the ice limit yet coloured the same as the Hunstanton esker (Moorlock *et al*., 2008).

Hunstanton Park undoubtedly contains an excellent example of a small esker. The only other similar landform nearby is the Blakeney esker, but this has been damaged by quarrying and is certainly related to a glaciation that pre-dates the Last Glacial Maximum.

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Former workings in Jurassic ironstone near Grantham

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Abstract: The Lower Jurassic Marlstone Rock Formation was formerly worked for ironstone near Denton (SE Lincolnshire), and the Middle Jurassic Northampton Sand Formation near Hungerton and Colsterworth (SE Lincolnshire) and Saltby (NE Leicestershire), southwest and south of Grantham. Two ammonites from the Northampton Sand Formation at Hungerton are illustrated.

Four ironstone quarries near Grantham (Fig. 1) were visited during an excursion from the British Association meeting in Nottingham in 1966. One, at Denton Park in SE Lincolnshire, was worked for the Marlstone Rock Formation (Upper Pliensbachian – Toarcian; formerly the Marlstone Rock Bed). The others, at Colsterworth and Hungerton in SE Lincolnshire and Saltby in NE Leicestershire, were worked for the Northampton Sand Formation (Aalenian; formerly the Northampton Sand Ironstone Formation). The lithostratigraphic nomenclature follows Cox *et al*. (1999) and Carney *et al*. (2004), with equivalents used in older literature given in parenthesis at the first mention.

The Denton and Hungerton sites are now infilled, but exposures remained at Colsterworth and Saltby in 2008. Photographs taken in 1966 record a once-important extractive industry in its last years. (All grid references cited below are [SK]).

Denton Park Pit, in Marlstone Rock

The history of working at Denton Park [857317], the most easterly of the quarries in this formation in the Woolsthorpe area, was documented by Tonks (1992). In 1966 this quarry was worked by Stewarts & Lloyds Minerals Ltd. About 3 m of the Marlstone Rock was exposed in the lowest part of the excavations (Fig. 2), below the Whitby Mudstone Formation (formerly Upper Lias). The ironstone, a slightly calcareous sideritic ore, was greenish-black when unweathered, and whitish or grey-brown when weathered. Cross-bedding indicated an easterly transport direction, similar to that recorded

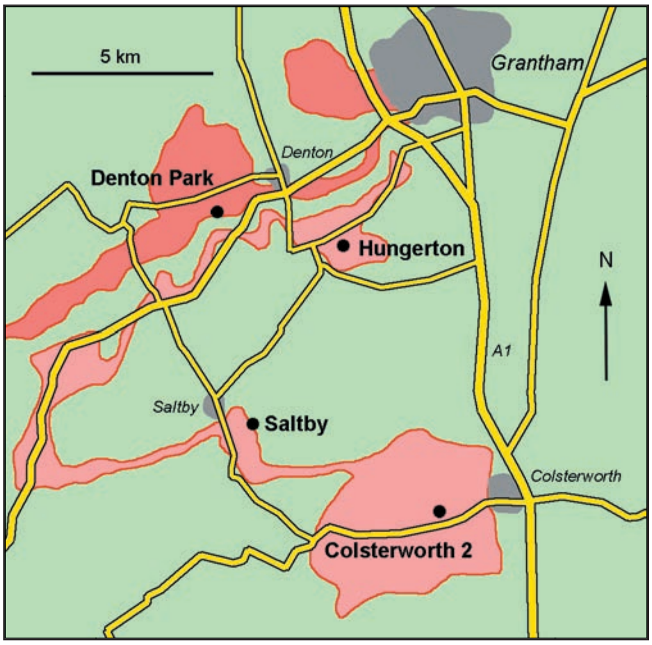

Figure 1. Locations of the four ironstone quarries and the outcrops of the two ironstone beds (generalised, and including sub-economic material); the darker red is the Marlstone Rock Formation and the paler red is the Northampton Sand Formation.

Figure 2. Two views of Denton Park Pit in 1966, with the Marlstone Rock Formation overlain by the Whitby Mudstone Formation

in the formation near Holwell, c.14 km SW of Denton Park (Carney *et al*., 2004, fig.21). The only fossils seen in profusion in the Marlstone Rock were belemnites (*Passaloteuthis*). Brachiopods, including *Lobothyris punctata* (J. Sowerby) and *Tetrarhynchia tetrahedra* (J. Sowerby), and bivalves were seen but were more randomly scattered in the formation. Hallam (1955) gave an account of the stratigraphy and palaeontology of the Marlstone Rock in Leicestershire and later he interpreted clusters of *L. punctata* and *T. tetrahedra* present in that unit in quarries at Branston, c.5 km WSW of Denton Park, as biocoenoses (Hallam, 1962); an example was illustrated by Carney *et al*. (2004, pl.11). The Whitby Mudstone at Denton Park contained brachiopods, bivalves, ammonites, including *Dactylioceras* and *Harpoceras*, and belemnites.

Whitehead *et al*. (1952) noted that the Marlstone Rock worked on the western side of Denton Park and south of Denton between 1916 and 1930 comprised c.3 m of brown decalcified ironstone with some bluish-green bands, and, when dry, contained 37% iron, 12.3% silica and 2.3% lime. Later workings, in Denton Park Quarry, comprised an east-west face some 275 m long in which c.0.6 m of ironstone rubble rested on 1.5 to 2.1 m of "rather soft brown limy ironstone with much green stone and occasional shelly bands, notably towards the base" (Whitehead *et al*., 1952, 121). Analyses made in 1940 by the Stanton Ironworks Company showed the ironstone here to be a relatively high-grade ore with an iron content, when dry, of 36.62 to 38.4%, and with 13.65 to 14.2% silica and 2.0 to 3.6% lime. Trials in a large unworked area revealed an easterly-trending zone of "barren material" up to 185 m wide south of the Denton Park Quarry face. In the area as a whole the ironstone had a workable thickness of c.2.12 m, with an iron content of 26 to 35%; silica averaged 10% and lime 10 to 17%. Carney *et al*. (2004, pl. 9a, b) illustrated the petrography of the Marlstone Rock with photomicrographs of specimens from Brown's Hill Quarry, near Holwell, and from one near Branston.

Denton Park was one of the Woolsthorpe group of workings where Stewarts & Lloyds Minerals Ltd introduced the practice of laying rail tracks on the ironstone bed (Fig. 2), rather than on the floor of the quarry (Tonks, 1992). After temporary closure in 1962, activity continued until 14 February 1974, when the last loads of ironstone left the quarry and 91 years of quarrying in the Woolsthorpe area, and all working of the Marlstone Rock, came to an end.

5. Upper Chamosite – Kaolinite Group
4. Upper Siderite Mudstone – Limestone Group
3. Lower Chamosite – Kaolinite Group
2. Main Oolitic Ironstone Group
1. Lower Siderite Mudstone – Limestone Group

Table 1*. Sub-divisions of the Northampton Sand (after Taylor 1949, from Hollingworth).*

The Marlstone Rock is no longer visible at Denton but exposures have been documented nearby in Lincolnshire [at 871357] (Berridge, *et al*., 1999, pl.3), and at several sites in Leicestershire, including Brown's Hill Quarry SSSI [741234], near Holwell, the Tilton railway cutting SSSI [76160555] and quarries at Pickwell [78411157, 78951130] (Stevenson, 1964; Clements, 1989; Cox *et al*., 1999; Carney *et al*., 2002, 2004, 2009; Ambrose, 2006). Whitehead *et al*. (1952, pl.1B) and Carney *et al*. (2003, pl.17) illustrated workings near Eastwell, c.8.5 km SW of Denton Park. Others illustrated were farther SW, at Holwell (Whitehead *et al*., 1952, pl.1A) and near Wartnaby (Anon., 2000); the latter site was described as in 'Middle Lias Limestone'.

The Northampton Sand Formation

The other sites visited in 1966 were in this formation, the petrology of which was documented by Taylor (1949) and other aspects, including its distribution and stratigraphy, by Hollingworth and Taylor (1951). These sites all lie within areas affected by large-scale 'valley bulging' (Hollingworth *et al*., 1944, pl.III). Their history and working were documented by Tonks (1991). Two ammonites collected from the Northampton Sand Formation at Hungerton in 1966 are noted and illustrated because of their rarity in that formation.

Hungerton Pit

This was one of the Harlaxton group of workings and was known as Harlaxton No. 4 (Hungerton) quarry [883305 to 889309] (Tonks, 1991). In 1966, it was worked by Stewarts & Lloyds Minerals Ltd in a face that extended WSW-ENE for some 800 m. The quarry exposed Northampton Sand (c.6 m) overlain successively by the Grantham Formation (formerly the Lower Estuarine Series, c.5 m) and the Lincolnshire Limestone Formation. The Whitby Mudstone Formation was visible locally beneath the Northampton Sand (Stevenson, 1964).

Figure 3*. 'Boxstone' structure in the Northampton Sand Formation exposed at Hungerton Pit in 1966.*

The Northampton Sand was divided into five units (Table 1). Of these, units 3 to 5 had a relatively limited distribution (Taylor, 1949). Only units 1 to 3 were seen at Hungerton where Unit 1, up to 3 m thick, but averaging c.2.25 m, was largely unworkable; Unit 2 was up to 4.6 m thick but averaged c.2.25 m, and Unit 3, up to c.1.5 m thick, comprised unworkable beds that occupied channels. The Lincolnshire Limestone at Hungerton was highly cryoturbated, and the Northampton Sand, an oolitic sideritic ironstone with a kaolinite content of 23 to 28%, showed very distinct 'boxstone' structure (Fig. 3), a product of weathering (Taylor, 1949). In places, a thin sideritic mudstone, resting on a decalcified shell bed, was present at the top of the Northampton Sand but in others only the shell bed was present. This bed contained large pectinids and other bivalves, many of which had been bored, as indicated by ferruginous tubes that remained in relief after dissolution of the shell.

The Hungerton pit subsequently extended WSW-ENE for 1.6 km. Activity there around 1971, and on 14 February 1974 when the last ironstone left the quarry and working in the Northampton Sand north of the Welland valley ended, was illustrated by Tonks (1991). Kent (1975) referred to it as 'Harlaxton Main Face (No. 4 Mine)' and provided descriptions of the Northampton Sand (c.1.07 m seen), Grantham Formation (3.21 m) and basal Lincolnshire Limestone. Earlier observations on the Northampton Sand in this area were given by Hollingworth and Taylor (1951).

Saltby Pit

In 1966 this quarry [857263 to 860255] comprised a face c.1 km long that was being worked eastwards, down-dip, towards the west side of Saltby airfield. The workings exposed the upper 2.4 m of the Northampton Sand, overlain successively by the Grantham Formation and the Lincolnshire Limestone (Fig. 4), the latter more massive than at Hungerton, some 5 km to the NE. The Northampton Sand appeared as at Hungerton, with a shell bed present at the top. The Grantham Formation comprised grey to silver, silky-textured, silty mudstones and silty sandstones, and darker grey mudstones. In 1971 a section at [857262] exposed Northampton Sand (c.2.5 m seen), Grantham Formation (5.05 m) and Lincolnshire Limestone (6.0 m seen) (Kent, 1975). An exposure of the Lincolnshire Limestone remained in 2008 (Fig. 5).

This site is slightly NW of quarries [865254 to 865249] c.1 km NE of Sproxton, Leicestershire, where the Northampton Sand averaged 7.0 m in thickness, of which up to 5.2 m was worked by the Clay Cross Company Ltd (Richardson, 1939). The Park Gate Iron & Steel Co. subsequently worked some 3.35-4.27 m of "brown weathered ironstone" beneath up to c.10.7 m of overburden (Hollingworth & Taylor, 1951) until a glacial channel was encountered along c.270 m of the working face; operations ceased around 1961 but the excavation remained open until 1965 (Stevenson, 1967). Descriptions of the channel, with illustrations of

Figure 5. *The Saltby Pit site in 2008, looking northeast across the former worked area, with Lincolnshire Limestone exposed in what was the overburden face.*

Figure 4. *Two views of Saltby Pit in 1966, with Northampton Sand Formation overlain successively by the Grantham Formation and the Lincolnshire Limestone.*

***Figure 6**. Colsterworth Pit No.2 in 1966, looking east, with Northampton Sand Formation overlain successively by the Grantham Formation and the Lincolnshire Limestone; compare this photograph with Plate 1A in Hollingworth and Taylor, 1951.*

the workings in 1959 and 1961, were given by Wyatt *et al*. (1971) and Stevenson (1967) respectively. In 1969 a section at [867248] in 'South Top Quarry', Sproxton, exposed Northampton Sand (c.4.5 m seen), Grantham Formation (3.35 m) and Lincolnshire Limestone (12.8 m seen) (Kent, 1975).

Colsterworth Pit No.2

Extensive workings at this site [914233] in 1966 (Fig. 6) exposed a section similar to that at Saltby, c.6 km to the WNW, with the Northampton Sand (c.2.5 m seen) succeeded by the Grantham Formation and Lincolnshire Limestone. In this area the thickness of the Northampton Sand varied from 3.7 to 4.6 m, of which c.3.0 to 3.7 m was worked (Richardson, 1939).

In June 1970 a section near the western end of the face exposed Northampton Sand (2.7 m seen), Grantham Formation (3.59 m) and Lincolnshire Limestone (5.8 m seen) (Kent, 1975). In this area the Grantham Formation showed considerable variations in thickness, with 2.4 m present at Stainby Glebe mine [904230], 1 km WSW, but only 1.83 m in Woolsthorpe Face, Colsterworth [920242], c.1.2 km NE (Kent, 1975) and near Woolsthorpe Manor House, the birthplace of Isaac Newton. The Northampton Sand was visible beneath the Grantham Formation in these and three other sections in the area (Kent, 1975; Robinson, 1979). In 2008 exposures of the Lincolnshire Limestone remained near the western end of the Colsterworth Pit No.2 site [910232].

Tonks (1991) illustrated activity in this quarry in 1945. Hollingworth and Taylor (1951) also illustrated this pit when active and described the method of working the Northampton Sand Formation. This involved shot holes being drilled into the beds above the Northampton Sand. After blasting, the overburden debris was transferred back to the area of worked ground by a large excavator, creating a bench on the Northampton Sand (Fig. 6), the top c.2.5 m of which were then removed by a smaller excavator.

The Hungerton ammonites

In the Northampton Sand Formation, fossils are localised but may be abundant; "… they include numerous bivalves, brachiopods, notably *Lobothyris trilineata* …. and rare ammonites, including several specimens of *Leioceras opalinum* found at Harlaxton near Grantham…" (Kent, 1980, 47). This reference to ammonites concerns two specimens collected from the upper part of the formation in the Hungerton quarry, one by Kent and the second by the writer. Both specimens

***Figure** 7. Leioceras sp., showing external ornament; Northampton Sand Formation, Hungerton Pit (BGS #Zm9530; collected by P.E. Kent, 1966). Bar scale is 3 cm long.*

Figure 8*. Leioceras sp., showing internal structure and septa; Northampton Sand Formation, Hungerton Pit (BGS # Zm9530a; collected by G. Warrington, 1966). Bar scale is 3 cm long.*

are in the British Geological Survey collections at Keyworth, and are registered as Zm9530 and Zm9530a respectively.

Kent (1975) recorded his specimen (Fig. 7) as *Lioceras* cf. *opalinum* [Reinecke] but it was subsequently figured simply as *Leioceras sp*. (Kent, 1980, pl.9, fig.10). Parsons (1980, 15) referred to it as *Lioceras*, and noted that it provided confirmation of an early Aalenian age for the 'Northampton Formation'. The specimen is involute, compressed and possibly keeled, and shows weak falcoid striae. The writer's specimen is less well preserved but, because of the rarity of ammonites in the Northampton Sand, it is illustrated for the first time (Fig. 8). This specimen shows internal features, including septa, and weak ribbing on the remaining external surface. Dr Beris M. Cox examined both specimens but did "not wish to identify either specimen beyond *Leioceras sp*." (pers. comm.).

Acknowledgements

Mr Paul Shepherd (BGS) located the ammonites and facilitated their photography, Dr Beris Cox kindly examined the ammonites and commented on their identification, and, with Dr K. Ambrose (BGS), is thanked for helpful comments on an initial draft of this contribution.

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The Upper Greensand of the Haldon Hills and East Devon

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Abstract: When the Upper Greensand of the Haldon Hills was surveyed in the 1960s poor exposure made its subdivision impossible, but a seismic survey revealed a remarkable thickness variation from 16m to 84m. This variation was explained in terms of contemporaneous down-folding of the basement during deposition. Later excavations for the re-aligned A38 road across Great Haldon yielded good sections that enabled a succession to be compiled and aided correlation with the sections in East Devon. There remain major questions concerning the erosional history of the Upper Greensand, and there is no explanation either for the survival of the Haldon Hills themselves or for the absence of any Upper Greensand outliers between Haldon and the main outcrop of East Devon.

The Upper Greensand is the youngest formation of the British Cretaceous sequence beneath the Chalk Group, which overlies it unconformably. In south-east England it crops out extensively along the edge of the Chalk outcrop, and in East Devon, as far west as Sidmouth, there are several large outliers only locally overlain by the Chalk Group. There is then a 20-km gap from there to the outliers on the Haldon Hills and even farther west on the eastern side of the Bovey Basin (Fig. 1).

Between Exeter and Teignmouth, the Haldon Hills form an elongated plateau remnant, capped by the Palaeocene Haldon Gravels, which are underlain by the Upper Greensand and then the Permian Teignmouth Breccias. In the 19th century there were extensive quarries in the Greensand on Haldon, working chert for whetstones as well as working the sands (Ussher, 1913), and also building a profitable trade in silicified fossils for sale throughout Europe. By 1966 these excavations were overgrown, and exposures were restricted to streambeds and disused quarries in the Haldon Gravels. The latter have also since become overgrown, so the exposure is even worse now, and for anyone interested in the Upper Greensand (Gallois, 2004: Edwards and Gallois, 2004), the best place to start is on the coast sections of East Devon, between Sidmouth and Charmouth, where sections in the sea cliffs are kept fresh by continual landslips and marine erosion (Fig. 2).

During the Late Albian (topmost Lower Cretaceous), blankets of glauconitic sand were deposited throughout southern England beneath rising sea levels, and the resulting Upper Greensand consists of fine-, medium- and coarse-grained calcareous sandstones along with calcarenites with varying amounts of silica, glauconite, comminuted shell debris and broken shells. There is a rich shallow-water fauna of bivalves, brachiopods, gastropods and echinoids, with a very few ammonites that confirm a Late Albian age. Sedimentary structures including trough and planar cross-bedding, hummocky cross-stratification and ripple-drift bedding indicate current-agitated water throughout. The green mineral glauconite is indicative of tropical marine deposition, and accounts for the name Greensand, although at outcrop the glauconite has usually weathered to red or brown iron hydroxides or washed out completely,

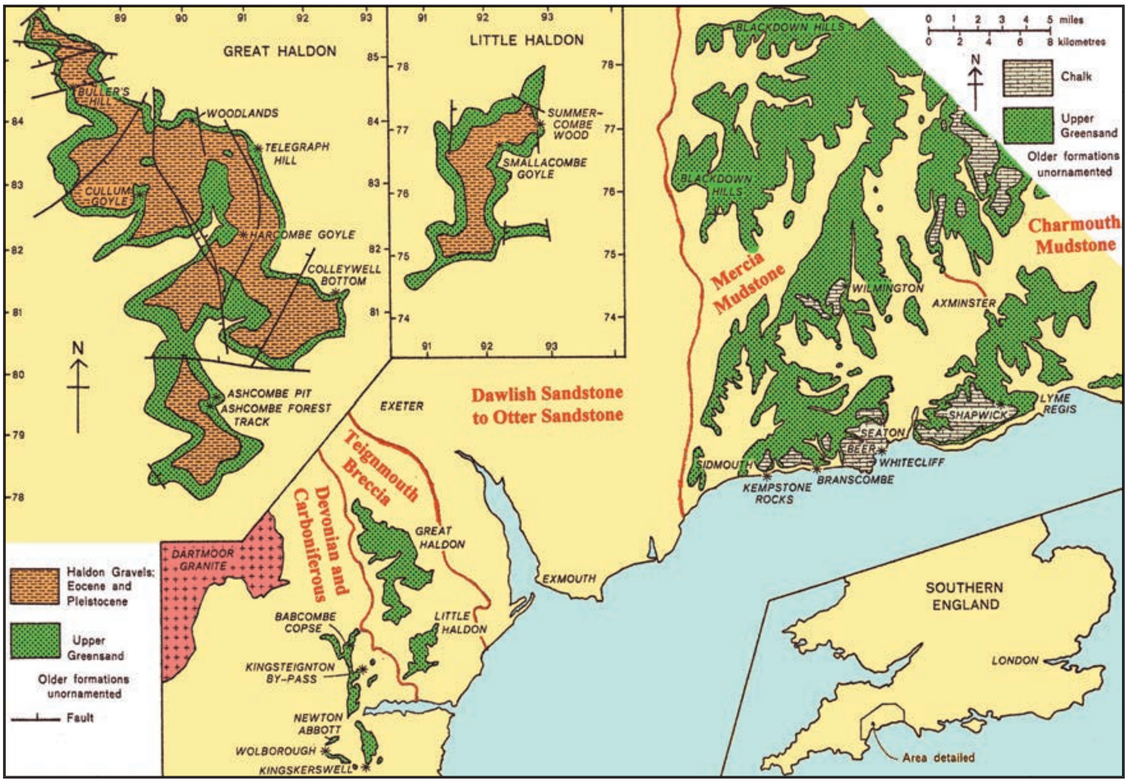

Figure 1. Cretaceous outcrops in Devon, with inset maps of Great Haldon and Little Haldon (after Hamblin and Wood, 1976). Limits of pre-Cretaceous strata are shown in red.

Figure 2*. Cliffs west of Branscombe exposing almost the complete Upper Greensand sequence overlain by white Lower Chalk. Foreground vegetation is on the landslip debris.*

so that the Upper Greensand is either shades of brown or pale yellow. In the Sidmouth-Beer district the formation is 45-55 m thick and is divided into three members, separated by mineralised erosion surfaces or hard-grounds (Table 1).

Mapping in the 1960s

In the Haldon Hills the Upper Greensand generally exhibits steep slopes with changes of slope, which are easily mapped, against the overlying Haldon Gravels and the underlying Teignmouth Breccia. Small exposures demonstrate that the Upper Greensand on Haldon is coarser and less clayey than that farther east, which is to be expected since during the deposition of the Upper Greensand, the Dartmoor massif would have been land and the coastline was only about 8 km west of Haldon. The presence of this land was confirmed by large quantities of Dartmoor-derived quartz and schorl (quartz-tourmaline rock) in the Greensand (Tresise, 1960). The Upper Greensand of Haldon is more deeply weathered than that in East Devon, possibly because the lack of clay made it more permeable, and the Haldon material is totally decalcified, falling thus in the 'Blackdown Facies' (Tresise, 1960). Little glauconite survives, although its previous widespread presence is commonly confirmed by red colouration of the sands, particularly in the lower parts of the sequence (Fig. 3). Fossils, particularly exogyrine oysters, are common, but wholly silicified to the mineral beekite.

Poor exposure then made it impossible to prove or disprove the presence of the three members known in the Upper Greensand of East Devon (Table 1). However, the Haldon sequence did appear to be divisible into three units, since a loose quartz conglomerate and coarse pebbly sands form a shelf roughly half way up the hillside (Selwood *et al*., 1984). However it was not possible to correlate this with the Whitecliff Chert Member (Table 1) since exposures in quarries for the Haldon Gravels indicated that the chert beds on Haldon occur in the top unit of the Upper Greensand (Fig. 4).

Bindon Sandstone Member (up to 8m): fine- to coarse-grained sandstone and calcarenite; chert horizons restricted to the lower part of the member east of Beer Head; slumped beds, contortions and festoon-bedding in the higher part.
Whitecliff Chert Member (up to 32m): fine- to coarse-grained sandstone and calcarenite with many horizons of nodular and tabular chert.
Foxmould Member (20-25m): finer grained and more siliceous than the overlying members, fine- to medium-grained sand with clay beds, calcareous cement and siliceous doggers. The high quantity of glauconite accounts for the common 'foxy red' colour of this member, which in turn accounts for its name.

Table 1*. The Upper Greensand in East Devon.*

The Upper Greensand is marked by steep slopes that were traced all around Haldon and made it easy to measure the thickness of the unit, which varied between 16m and 37m, but this degree of variation was surprisingly high. Since Haldon was so near to the coast during deposition of the Upper Greensand, it would be expected to be thinner there than farther east, where it is 45-55 m thick on the East Devon coast. Indeed, Dewey (1948) states 'The Greensand of Devon decreases in thickness from east to west. In East Devon it is 200 ft thick, at Beer, 156 ft, at Peak Hill, Sidmouth, 90 ft, whilst in the most westerly outliers of the Haldon Hills, near Exeter, the minimum thickness recorded is 75 ft'. Not only was Dewey wildly wrong with the thickness at Haldon, but Upper Greensand was not recognised farther west, in the Bovey Basin (Fig. 1). This most westerly Upper Greensand in Britain was shown by William Smith on his maps of 1815 and 1820.

Clearly the thickness of the Upper Greensand on Haldon needed further investigation, and the seismic survey system at Exeter University proved adequate for recording the depths of the bases of the Haldon Gravels and of the Upper Greensand (Durrance and Hamblin, 1969). Twenty seismic lines were run, and contour maps were produced for the base of the Upper Greensand (Fig. 5) and the base of the Haldon Gravels (Hamblin, 1972). Normal, dip-slip faults known from mapping around the hill were confirmed and could now also be plotted across the hill (Fig. 5). Throws ranged up to 20 m, and since they all cut the base of the Haldon

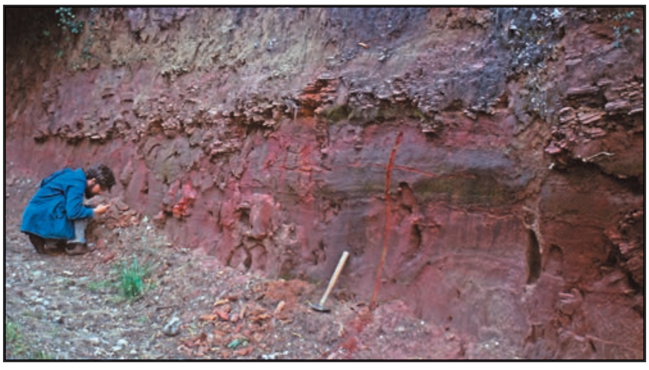

Figure 3*. 'Foxy red' fine- to medium-grained sands low in the Upper Greensand sequence on Haldon (Telegraph Hill Sands); the colour is due to glauconite oxidising to ferric hydroxides.*

Figure 4. Massive chert blocks worked from the top of the Upper Greensand sequence (Cullom Sands with Cherts Member) at Buller's Hill Quarry (see Figure 1).

Gravels as well as that of the Upper Greensand, they were clearly all post-Late Cretaceous. Thicknesses measured for the Upper Greensand not only confirmed the remarkable variation of thickness on Haldon, but also had maxima that were unexpectedly high compared with East Devon. Eight measured thicknesses exceeded the 55 m figure for East Devon, and the maximum was 75m, and since this was measured below the crest of the hill it must represent an original thickness of the Upper Greensand of 84 m, by far the thickest known anywhere in England.

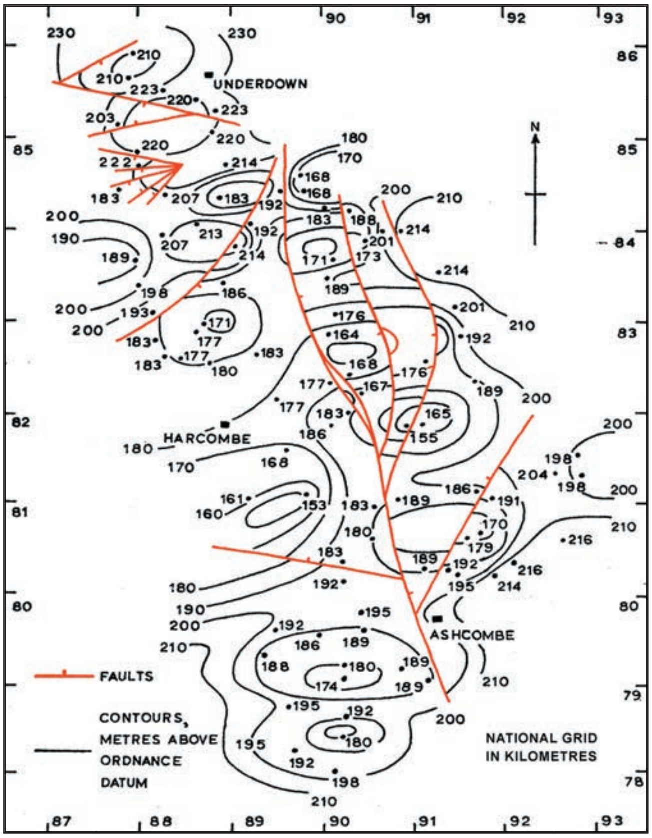

Figure 5. Contour map of the base of the Upper Greensand on Great Haldon, showing all post-Senonian faults known to cross the hill (after Durrance and Hamblin, 1969).

Structural interpretations

To produce a map of the base of the Upper Greensand as it would have been in immediately post-Upper Greensand times (Figure 6), the effects of these faults and also of the gentle folding found in the base of the Haldon Gravels were removed. The base of the Upper Greensand proved to be far more complex than expected, comprising a series of minor warps on a larger, shallow structure (Fig. 6). The minor warps take the form of inverted periclines, orientated east-west and separated by anticlinal areas: it proved impossible to interpret the data as forming upright periclines. The larger structure indicated by the contours at 200, 190 and 180 m, describing a roughly semi-circular arc around Harcombe (Fig. 6), could be interpreted as a trough plunging to the WSW or as the eastern half of a large basin - another inverted pericline (Fig. 7).

The shape of the surface between the Upper Greensand and the Teignmouth Breccia could not readily be interpreted as the results of fluvial erosion of the breccia before the Upper Greensand transgression, or as the result of tidal scouring during the transgression. It had to reflect tectonic folding (Durrance and Hamblin, 1969). Whereas all the faults detected are post-Late Cretaceous, this folding must be pre-Late Cretaceous, since the effects of folding of the Haldon Gravels have been removed from Figures 6 and 7. The question of whether this folding was contemporary with or after the period of formation of the Upper Greensand was

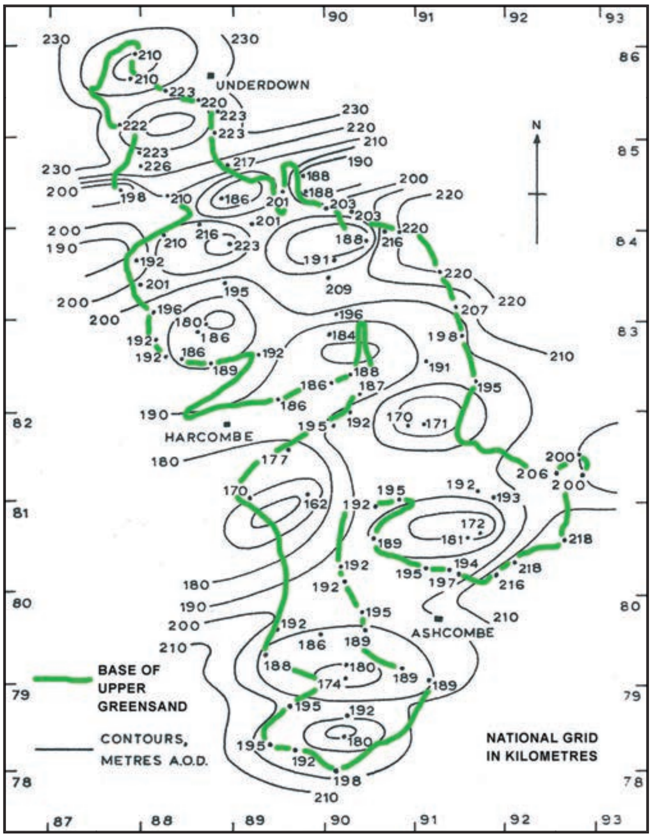

Figure 6. Contour map of the base of the Upper Greensand after removal of the effects of post-Senonian faulting (after Durrance and Hamblin, 1969).

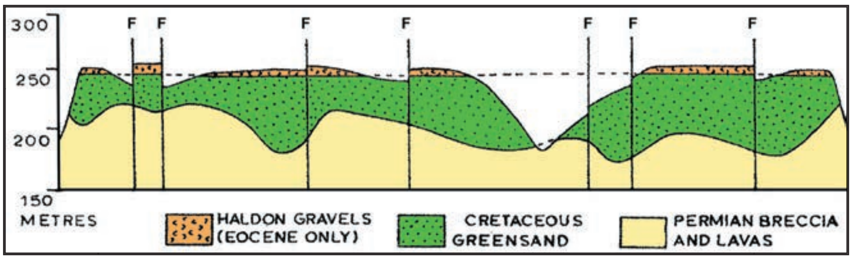

***Figure** 7. Diagrammatic section along the length of Great Haldon, with the effects of post-Senonian faulting removed in order to restore the base of the Upper Greensand to its pre-Chalk situation, the section extends over 7500 metres (after Durrance and Hamblin, 1969).*

debatable (Durrance and Hamblin, 1969). However, it must be contemporaneous, because if there had been no folding or subsidence during deposition, it is inconceivable that 84 m of Upper Greensand could be deposited within the Haldon area while only 45-55 m was deposited in East Devon. Support for this age of the folding was given by the loose quartz conglomerate being apparently restricted to areas of thinner Upper Greensand, where a shallower-water facies would be subjected to current winnowing. Also, boreholes southeast of Underdown (Figs. 5, 6) showed greater development of chert in the more tranquil conditions of the areas where thicker Upper Greensand was deposited. It was concluded that the folding resulted from simple north-south compresion, with deformation of the Permian-Cretaceous cover more or less independently of the Hercynian basement, comparable with more gentle folding in the Beer-Seaton district (Smith, 1965).

The survey also explained the shape of the Haldon Hills, since a comparison of the Upper Greensand outcrop with the position of the basins (Figs. 6, 7) demonstrates that the basins are largely contained within the hill and the outcrop follows the structural highs between the basins. This is due to the style of erosion of the Upper Greensand: rain-water soaks into the very permeable sand, travels freely down through it, and emerges at the base on the impermeable Teignmouth Breccia. Where the base of the Upper Greensand slopes outwards from the hill at the outcrop, water drains out and causes the sand face to retreat by spring-sapping. When this retreat reaches the ridge between the inverse periclines, the base of the Upper Greensand ceases to dip out of the hill, so the spring-sapping and back-wearing stops, and erosion proceeds elsewhere. Thus much of the outcrop of the base of the Upper Greensand follows the ridges between the basins. Erosion now takes place on the west side of the hills, where the westward plunge of the major trough causes the ridges between the periclines to be lower than on the east side of the hills and groundwater therefore emerges at the base of the sand.

Mapping in the 1970s

Excavation of cuttings for the re-aligned A380 (Exeter to Torquay) road in 1968 (Fig. 8) did not contribute to interpretations of the sequence, because the earth-scrapers smeared the exposures, though grass rapidly grew along the base of the Upper Greensand where water emerges. Excellent sections finally appeared in the Upper Greensand of Haldon in 1971, when torrential rain excavated deep gullies in cut faces along the re-aligned A38 (Exeter to Plymouth) road across the north end of Great Haldon (Fig. 9). The sections were logged in detail, and a formal lithostratigraphy could at last be created (Hamblin and Wood, 1976), based on a type section at Woodlands Goyle at NGR SX902840 (Fig. 10). Variations in thickness down to the level of individual beds were observed and these confirmed the concept of folding contemporaneous with deposition. In the Woodlands section, beds measured in the centre of the Bovey Basin totalled 21.4 m, of which Beds 6 to 21 totalled 14.8 m, whereas on the flanks of the basin (at NGR 901838) these beds are thinned to a total of only 7.3 m. The longest, continuous, measured section on Haldon, at the former quarry at Smallacombe Goyle (Jukes-Browne and Hill, 1900), totalled 28 m, and correlation of its description with the type section suggests expansion of individual beds rather than the addition of higher beds. Based on the Woodlands type section, four members were recognised within the Upper Greensand of Haldon (Table 2, Figs. 11, 12, 13).

Detailed palaeontology and sedimentology (Hamblin and Wood, 1976) enabled correlation of the Telegraph Hill Sands with the Foxmould of East Devon, the Woodlands Sands with the bulk of the Whitecliff Chert, and the Ashcombe Gravels with the remainder of the Whitecliff Chert (Beds 15 and 16 of the Ashcombe Gravels) and the Bindon Sandstone (Beds 17 to 19 of the Ashcombe Gravels). The Cullom Sands with Cherts are correlated with the Beer Head Limestone Formation of Cenomanian age. Whereas the latter is represented at Beer by a highly bioturbated, richly fossiliferous, porcellanous limestone (Edwards and Gallois, 2004), inland from Beer it includes the Wilmington Sand Member, a glauconitic calcareous sandstone. However, both chronostratigraphically and lithologically the Beer Head Limestone is a part of the

***Figure** 8. A cutting along the re-aligned A380 road exposing the boundary between the yellow-bown Upper Greensand and the underlying red Teignmouth Breccia.*

Cullom Sands with Cherts (Figure 11; Beds 20 to 23 on Figure 10, 6.71m thick at Woodlands). Green and brown, glauconitic, slightly pebbly sands with banded cherts and clay bands, horizons of quartz granules, tourmaline and kaolinised pebbles. Exogyrine oysters and abundant orbitoline foraminifera in the blocks of chert.
Ashcombe Gravels (Figure 11; Beds 15 to 19, 5.28m thick at Woodlands). Sandy quartz gravels and coarse gravelly quartz sands, with cross-bedding, iron cementation, kaolinised rock fragments. Fauna dominated by beekitised exogyrine oysters.
Woodlands Sands (Figure 12; Beds 7 to 14, 4.14m thick at Woodlands). Complex and variable succession of glauconitic clayey sands, shell drifts and sands with carious siliceous concretions and chertified sandstones. Coarser than the Telegraph Hill Sands, less well sorted and essentially clay-rich, with bands of green clay. Fauna has 27 species of coral, oysters and other bivalves, bryozoans, sponges and brachiopods, but no orbitolines. Corals prove a tropical shallow-water environment (Wells, 1967); pholadid borings in the corals confirm the near-littoral situation.
Telegraph Hill Sands (Figure 13; Beds 1 to 6; 5.26m thick at Woodlands). Sands, green and red with weathered glauconite; clay-free, well sorted, poorly consolidated. Glauconitic quartziferous sandstones and careous siliceous concretions (cherts). Fauna is dominated by molluscs, gastropods and very few ammonites. Small pebbles at the base. A massive basal conglomerate locally in depressions in the pre-Cretaceous floor, with a diverse oyster fauna, and fragmentary corals and orbitolines (the earliest occurrence of orbitoline foraminifera in the British Cretaceous).

***Table 2**. The Upper Greensand on the Haldon Hills.*

Grey Chalk Group, whereas the cherty sands of the Cullom Sands with Cherts are included in the Upper Greensand Formation. The presence of Cenomanian Upper Greensand on Haldon was not entirely unexpected, since fossils within the flints preserved in the Haldon Gravels are all Senonian and it is unlikely that the Cenomanian and Turonian were represented by a major hiatus on Haldon (Hamblin, 1968).

Survival of the Haldon Hills

By the mid-1970s the stratigraphy, structure and mode of erosion of the Upper Greensand of Haldon were reasonably well understood. But the problem remained as to why the Haldon Hills were still there at all. The main outcrop of the Upper Greensand of southern England extends as far west as Sidmouth (Fig. 1), and it is likely that erosion has steadily worked this western limit back eastwards from an original position on the

***Figure 9**. Excavation for a cutting along the re-aligned A38 (Exeter-Plymouth) road, after torrential rain created the gully in the cut slope to expose a complete section through the local sequence of the Upper Greensand.*

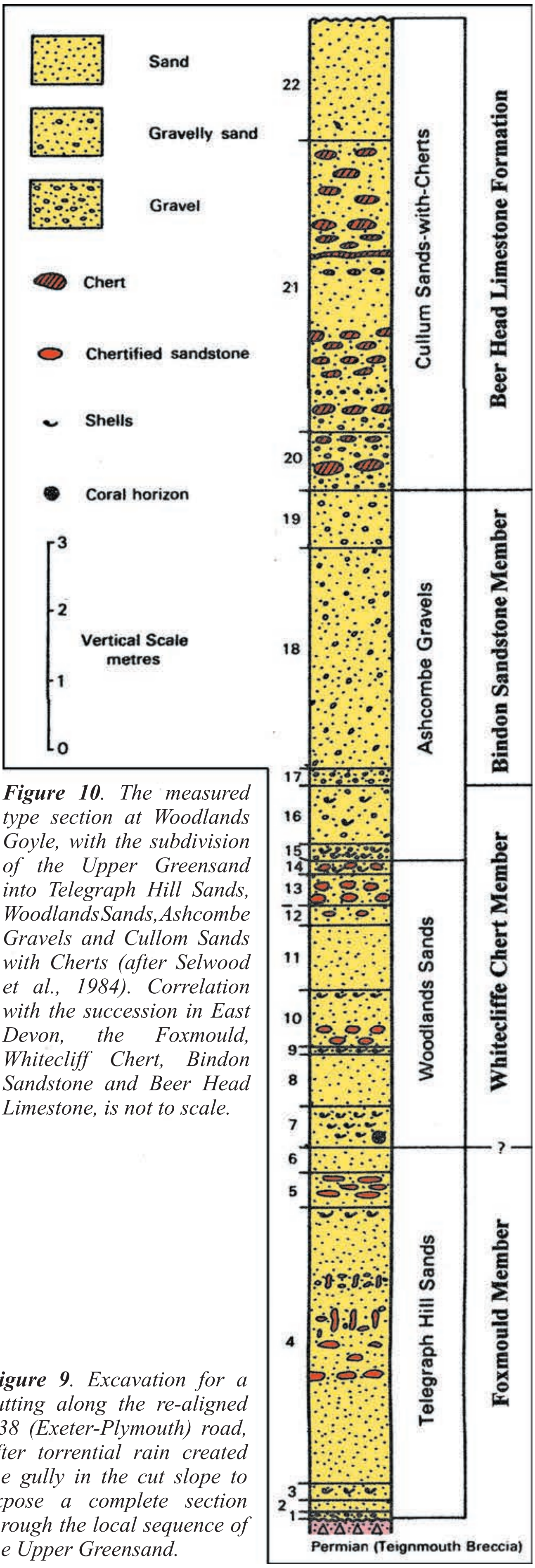

***Figure 10**. The measured type section at Woodlands Goyle, with the subdivision of the Upper Greensand into Telegraph Hill Sands, Woodlands Sands, Ashcombe Gravels and Cullom Sands with Cherts (after Selwood et al., 1984). Correlation with the succession in East Devon, the Foxmould, Whitecliff Chert, Bindon Sandstone and Beer Head Limestone, is not to scale.*

Figure 11. Ashcombe Gravels, coarse green and brown sands of Beds 18 and 19, and (level with Chris Wood's head) pale brown Beds 20-21 of the Cullom Sands with Cherts.

flanks of Dartmoor. Why has Haldon survived as an outlier, 20 km west of the main outcrop? The Bovey Basin, immediately west of Haldon and in which are found the down-faulted Upper Greensand outcrops from Babcombe Copse to Kingskerswell (Fig. 1), is a major structure of enormous depth, a pull-apart basin lying along the Sticklepath Fault. This is a major Tertiary wrench fault, and the Bovey Basin dropped down during the late Eocene (Selwood *et al*., 1984). Since the Tertiary deposits would never have filled the basin, Haldon must have stood as a hill ever since the Eocene. The Upper Greensand of Haldon is eroding on the west side of the hill, since the overall dip of the base is westward, so the hill should be retreating eastward. So why is it still sitting just above the Bovey Basin, where it must have stood from the Eocene to the present day?

This question is still unanswered, and a further complication has appeared. The Upper Greensand is seen to erode at its base where it rests on an impermeable substrate; it would be then expected that where the Upper Greensand rests on a permeable substrate, it should be stable, since percolation of groundwater freely down through the underlying sand would preclude spring development and the associated sapping and erosion at the base of the Greensand. Yet the exact opposite appears to be the case in Devon. Across most of its outcrop the Upper Greensand rests conformably upon the impermeable Gault clay, and beyond the western limit of the Gault it lies unconformably on similarly impermeable Jurassic Charmouth Mudstone and then Triassic Mercia Mudstone. However, across the 20 km gap between Sidmouth and Haldon, where the Upper Greensand is absent, the permeable Otter Sandstone, Exe Breccias and Dawlish Sandstone occur at the surface, and then the Upper Greensand of Haldon appears again resting on the impermeable (and ill-named) Teignmouth Breccia. This appears to be the wrong way round in terms of erosional susceptibility. Even if the rivers Exe, Otter and Axe can be blamed for a lot of erosion, why are there no Upper Greensand outliers resting upon the permeable Permian and Triassic formations between Exeter and Sidmouth? The Upper Greensand outlier on the Haldon Hills appears to be a complete anomaly, and by all logical reasoning should have been eroded away a long time ago. An explanation will be welcome.

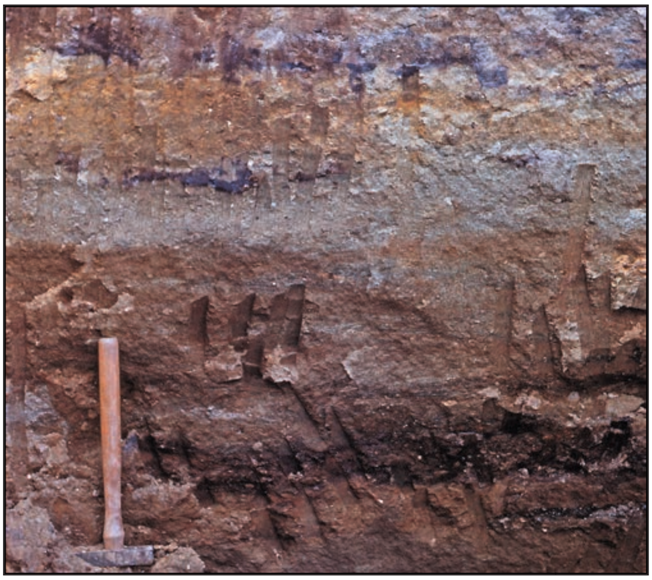

Figure 12. Woodlands Sands, Beds 8 to 11 at Woodlands: glauconitic clayey sands, shell drifts and sands with careous siliceous concretions, chertified sandstones and green clay.

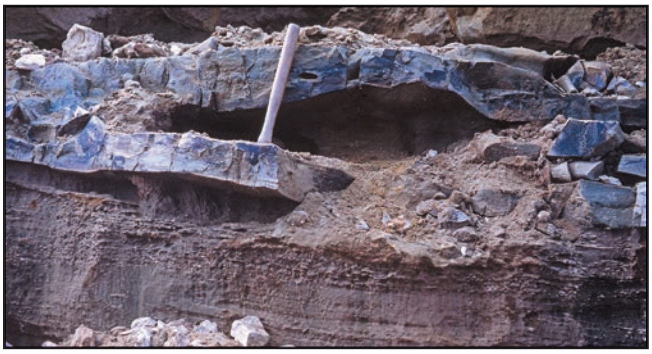

Figure 13. Telegraph Hills Sands, Beds 4 to 6 at Woodlands, green and brown sands and pebbly sands with cherts.

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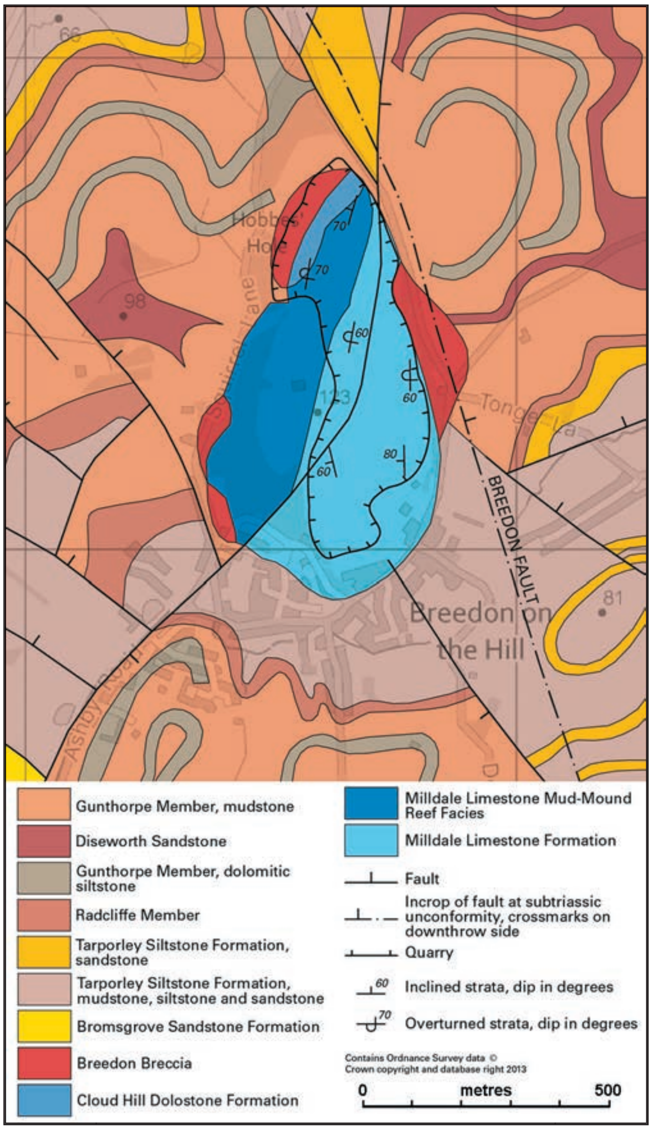
LANDMARK OF GEOLOGY IN THE EAST MIDLANDS

Breedon Hill

Breedon Hill forms one of the most prominent features in the landscape of north-west Leicestershire, standing up 50 m above the surrounding ground. That it has been a major landmark throughout recorded history is suggested by its name, which is derived from the Celtic ‘bre’ and the Anglo-Saxon ‘dun’, both words meaning ‘hill’. Viewed from the east, the rugged vertical western quarry face is crowned by the church that looks very precarious; it stands about 70 m behind the quarry face, but looks much closer from a distance. To see the quarry and its geology at relatively close quarters, the viewing platform at the north end of the quarry should be visited. There is also a footpath that follows the quarry’s eastern rim. Quarry visits are limited to organized groups, but a few small exposures are present along the footpath from Breedon village up the western slopes of the hill.



The geology of Breedon Hill (by British Geological Survey).

Breedon quarry seen from the viewing platform. The rocks in the right foreground are the massive mud-mound reef dolostones. On the left side of the quarry are well bedded, steeply dipping dolostones which, in the distance, show gentle folding. The cave with its red-brown Triassic fill can be seen to the left of the foreground tree in blossom.

Breedon Hill is one of six inliers of the Peak Limestone Group (informally known as the Carboniferous Limestone) in north west Leicestershire. The others are at Cloud Hill, Barrow Hill, Osgathorpe and Grace Dieu; all have been quarried in the past but the only other operating quarry is at Cloud Hill, just over a kilometre south of Breedon Hill. Cloud Hill is the larger quarry and is currently the only producer of aggregate. All these inliers are surrounded by rocks of Triassic age, with Precambrian Charnian rocks also abutting on the south side of the Grace Dieu inlier. Other inliers of these limestones occur 3-4 km to the west, around Ticknall, Calke Abbey and Dimminsdale in south Derbyshire.

The Breedon carbonates

The geology of Breedon Hill has been summarised in several publications, including Fox Strangways (1905), Parsons (1918), Mitchell and Stubblefield (1941), Ambrose and Carney (1997) and Carney *et al.* (2001, 2002). The Breedon story starts in the early Carboniferous, in Early Chadian times, when much of England was enveloped in a warm tropical sea close to the equator, where carbonates were deposited to form the Peak Limestone Group. Breedon Hill and Cloud Hill, lay on the Hathern Shelf, just south of the Widmerpool half-graben (or ‘gulf’), a deep, fault-bounded Carboniferous basin. Its location and evidence from sediments in the quarry suggest that Breedon was just on the flanks of the half-graben, in deeper water than most of the shelf area, and in water slightly deeper than that at Cloud Hill. But deposition at both quarry sites followed the same general pattern. The earliest rocks are the Milldale Limestone Formation, which consists mostly of the well-bedded, generally fine-grained carbonates, now dolostones, deposited by storms, possibly with some turbidite development. In quiet periods, fine muds and silts settled out from suspension to form partings between the carbonates. These storm deposits in Breedon quarry generally yield

The northern end of the quarry with red-brown Triassic sediments lying unconformably over the steeply dipping Carboniferous carbonates. The red colour of the limestone on the left side of the upper bench is the result of groundwater re-depositing iron oxide carried down from the overlying Triassic rocks.

only a few crinoids and brachiopods, but the paucity of fossils may be due to the later dolomitisation process that has affected all the rocks in Breedon, and may have destroyed fossil remains. The thickness of the Milldale Limestone at Breedon is around 400 m.

The rock that indicates water depth occurs on the west face of the quarry, where a very fine-grained, massive dolostone has no internal bedding structures. It is also more fossiliferous than the storm carbonates, additionally yielding corals, nautiloids, and ammonoids. This unbedded dolostone has been interpreted as a mud-mound reef, which formed by micro-organisms secreting a carbonate mud that built up into a mound (or reef). The reef at Breedon has been likened to those in Derbyshire, where all the Early Chadian reefs are of a Waulsortian reef facies, known to occur in water depths of 220-280 m (Bridges and Chapman, 1988). On the northern face of the quarry, similar well-bedded dolostones with the same fauna are interpreted as the reef flank, with debris cascading off the reef and building up in beds. Found in this part of the sequence, the ammonoid *Fascipericyclus fasciculatus* indicates an Early Chadian age. The only other age-diagnostic fossils found in Breedon quarry are the brachiopod *Levitusa humerosus* and a microfauna in layers of chert nodules within the storm carbonates. These nodules were unaffected by the dolomitisation and the microfauna has been preserved. Both indicate the same Early Chadian age. Cloud Hill quarry is the type locality for the brachiopod *Levitusa humerosus.* Other mud-mound reefs are seen in Cloud Hill quarry but these formed in shallower water of probably around 100 m depth, as fringing reefs on the Hathern Shelf.

The quarries of Breedon Hill and Cloud Hill, either side of the curving M42 motorway (from Google Earth).

Two important features occurs on the north face of Breedon quarry. An unconformity lies within the Peak Limestone, although the position of it is not precisely known. It represents a time gap of around 10 million years, separating the Early Chadian Milldale Limestone from the Holkerian-Asbian Cloud Hill Dolostone Formation. The latter is known from a fallen block that contained a coral of this age. A bedding plane crowded with the trace fossil *Thallasinoides*, which indicates a prolonged period of bioturbation, has provisionally been taken as the unconformity base in Breedon quarry. These younger beds and the unconformity are well exposed in Cloud Hill quarry, where a pronounced angular unconformity has been well exposed over time and has been named the ‘Main Breedon discontinuity’ (Carney *et al*., 2001). At the top of the north face of Breedon quarry, there is a major unconformity with the younger Triassic rocks exposed. This represents a time gap of around 100 million years.

Dolomitisation and mineralisation

The carbonate rocks at Breedon have been pervasively altered by the conversion of the original calcite to the magnesium-rich dolomite and the rocks are now referred to as dolostones. The timing of this process is not fully known, though an early, pene-contemporaneous stage and a later stage of Triassic age have been suggested (Parsons, 1918). Evidence from mapping the quarries showed that the dolomitisation occurred before the Triassic, as fragments of dolostone occur within caves and voids infilled with Triassic sediments. It is very likely that the dolomitisation occurred in the latest Carboniferous times, when the area was subjected to higher temperatures, pressures and mineralisation associated with the Variscan orogeny.

Mineralisation has occurred in two phases in these rocks. The earlier, in the Late Carboniferous (King, 1968, 1980, 1982, 1983), resulted in the deposition of calcite as a gangue mineral along with a variety of other minerals of which the most common is galena. Others found include wulfenite and cinnabar. The second phase occurred in the Triassic, associated with fluids moving along the unconformity. These left mainly copper minerals; none has been seen at Breedon because the unconformity is inaccessible, but they are common at Cloud Hill.

Cavity in the limestone infilled with dog-tooth spar calcite, indicating that the caves pre-date the late Carboniferous mineralisation.

Karst and cave development

Karst development in the form of caves and small voids is another feature of the rocks in Breedon quarry. Again, the timing of their formation is not known precisely but there are several clues. The 15% volume reduction of the rock resulting from the dolomitisation process may have played a significant part. Many of the smaller voids are lined with dog-tooth spar calcite associated with the end-Carboniferous mineralisation, so they formed probably quite soon after deposition of the carbonates and probably in response to circulating ground waters. Widening of some of the larger caves could have occurred throughout the Permian. Many were formed by Early Triassic times at the latest, as some are infilled with sediments of Mercia Mudstone Group age. Further cave enlargement may be attributed to groundwater flow during the Quaternary.

Perhaps the most striking karstic feature lies in the east face of Breedon quarry, where a large cave has been completely infilled with Triassic sediments. It is about 60 m wide and 10 m high, and the roof slopes into the quarry at around 40º. The sediments infilling the cave are dominantly massive red-brown siltstones, with some included clasts of finer and commonly laminated mudstones. These represent rapid deposition from water flowing into the cave. The uppermost deposit in the cave is a thin finely laminated, waterlain bed of sandstone-siltstone/mudstone couplets. The most likely timing for the infilling of the cave is during deposition of the Tarporley Siltstone Formation, the basal unit of the Mercia Mudstone Group. Laminated mudstone forming the cave deposit clasts commonly occurs in this formation, and the depositional environment is a flat alluvial plain washed by streams, so there was abundant water that could wash into the cave. Indeterminate bone fragments have been found in the cave fill (Fraser, 1994).

Development of the Breedon landscape

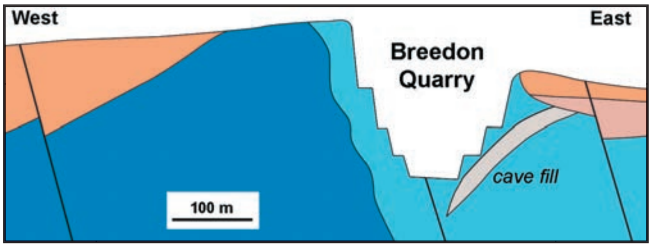
The landscape of Breedon Hill has its origins dating back some 300 million years to the late Carboniferous Variscan orogeny, when earth movements in the

The cave exposed in the quarry, before it was more overgrown, with its Triassic fill of red-brown siltstones of the Mercia Mudstone Group.

Midlands microcraton, pushed the Early Carboniferous limestones up into their near vertical aspect now exposed in Breedon and Cloud Hill quarries. The regional dip is to the west but the rocks are commonly overturned at Breedon and dip to the east. Erosion during the Permian removed younger Carboniferous rocks of the Millstone Grit and Pennine Coal Measures groups, leaving low hills of the Peak Limestone. Breedon Hill was probably somewhat higher than it is today. About 250 million years ago, in the Triassic, Breedon Hill was surrounded by the river system that deposited the Sherwood Sandstone Group, with the river flowing from northern France across much of England. This river had two courses, with a divergence somewhere in the English Midlands. It flowed north along the western side of England through the Staffordshire and Cheshire basins and into the East Irish Sea Basin, and also along the eastern side, through Nottinghamshire and Yorkshire and out into the North Sea, but it is unlikely that it occupied both courses at the same time.

About 10 million years later, the river ceased flowing, leaving a broad flat alluvial plane that was washed by river channels and contained many lakes; its deposits are the Tarporley Siltstone Formation at the base of the Mercia Mudstone Group. Following this, desert conditions set in. Much of England was a low-lying and flat landscape, with hills like Breedon and Mountsorrel standing up as inselbergs. Charnwood Forest formed a range of low, craggy hills that were probably mountains in the earliest Triassic. The desert was not a sandy desert like parts of the modern day Sahara, but a pelleted clay particles or ‘dust’ desert. Modern day analogues include the *parna* of southern Australia (Jefferson *et al.,* 2002). Clouds of dust blew across the flat plain and accretion occurred because of a high water table and frequently damp ground surface. This also resulted in the precipitation of gypsum close to the ground surface.

As the layers of sediment built up, Breedon Hill was gradually buried. The heavy rains that resulted in the deposition of the fine sandstones and siltstones on the desert plains had their impact on Breedon Hill. Screes that built up on the hillside were mobilised and flowed down the hill as debris flows. These survive in the quarry as fallen blocks of dolostone breccias. They are all matrix-supported, indicating deposition in debris flows, as opposed to clast-supported screes. The infilled cave now exposed in the quarry face had an opening on the surface of the hill. When the sediment accumulation on the plains reached its level, surface water washed sediment into the cave.



Profile through Breedon Hill; colour keys as on the map; vertical scale is double the horizontal scale.

A block of Breedon Breccia with matrix-supported clasts, which formed as debris flows on the side of the Triassic hill.

Eventually, towards the end of the Triassic, Breedon Hill, Cloud Hill, Mountsorrel and Charnwood Forest were completely buried. A prerequisite for this burial was continued regional subsidence (Carney, 2007) which favoured preservation of the soft desert muds. But this was not the end of sedimentation. Regional subsidence continued throughout the Jurassic and Cretaceous; Breedon Hill was under the sea and a great thickness of marine sediments accumulated on top of the Triassic strata. When the sea finally retreated at the end of the Cretaceous, the area was uplifted and tilted, and a long period of erosion ensued throughout the Palaeogene and Neogene. All of the Cretaceous and Jurassic rocks were stripped off, together with some of the Triassic, leaving behind the more resistant dolostones. Breedon Hill’s Permo-Triassic expression as an inselberg is thus being revealed once again. What was left prior to the Quaternary glaciations is pure guess work, but the Breedon Hill of today was trimmed by the passage of glaciers particularly during the Anglian glaciations of around 440 000 years ago.

Quarrying at Breedon

Breedon quarry has been working since around the 1880s, and there is evidence of earlier quarrying going back hundreds of years. At the present time, quarrying activities are limited, with only a few thousand tons extracted each year, all for ornamental stone. In the past the limestone has been extensively used as roadstone, as is much of the current Cloud Hill output. The quarry has also produced agricultural lime, fluxing stone, rockery, walling and edging stone, flux for blast furnaces and foundries, tarred and bituminous aggregate, foundation stone and top-dressing for tennis courts. In the past, the variety of colours of the stone at Breedon and Cloud Hill quarries have been used for surfacing driveways and paths. Products have included the self-binding Breedon Golden Amber Gravel, which has been used for the garden pathways at Chatsworth House, in Derbyshire; this gravel is self-setting under treatment by water and roller. Much of the quarry overburden has been used around the village and to create the village green.

Planning permission has been granted for an eastward extension of the quarry into the neighbouring field, which will necessitate rerouting of the road from Breedon to Wilson. This should reveal more of the course of the cave that is infilled with Triassic sediments. There is a good possibility of finding animal bones on the cave floor as it is exposed, and these could even indicate what *Chirotherium* really looked like. This mysterious animal is, to date, only known from footprints, found mainly in the Sherwood Sandstone but also in the Mercia Mudstone Group, up until Late Triassic Carnian times.

Breedon Church

No visit to Breedon would be complete without a visit to the fine 12th century church of St. Mary and St. Hardulph, which crowns the hill, and constitutes another treasure trove of geological features. Surprisingly, it is built not of the local rock nor even of the Millstone Grit sandstones from the Melbourne area, but from Bromsgrove Sandstone, part of the Sherwood Sandstone Group. This crops out in many areas nearby but the precise source used is not known. A wide variety of rocks have been used for headstones in the graveyard, but most striking are the slates. Up to around the middle of the 19th century, the locally quarried Swithland Slate provided all the headstones, but improved transport links made the cheaper and better Welsh slate more accessible, and this led to the decline and eventual collapse of the Swithland industry. Apart from the dates on the graves, the two slates are readily distinguished; the Swithland Slate, because of its relatively poor cleavage, has a rough back surface, whereas the much better cleaved Welsh slates have smooth front and back surfaces.

Breedon Hill was home to an Anglo-Saxon monastery, founded in about AD 676. When this fell into disrepair, some of the carvings were rescued and placed in the church; they were carved in the Jurassic Lincolnshire Limestone, sourced from at least 40 km away to the east. Another geological gem inside the church is a tomb carved from local alabaster, a tough variety of gypsum, sourced locally, either from Fauld, Chellaston or Aston, and carved in Burton upon Trent where an alabaster industry was well established.

Breedon church, with its gravestones of rough-backed Swithland Slate and smooth-backed Welsh Slate.

Tomb carved from local alabaster within Breedon church.

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REPORT

British Triassic palaeontology: new literature supplement 35

Since the completion of previous supplement (No. 34; *Mercian Geologist*, **18**, 77) on British Triassic palaeontology, the following works on or relating to aspects of that subject have been published or have come to the compiler's notice.

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A tree stump in the Petrified Forest of Lesbos, which was encased in fine-grained pyroclastic sediment and overlain by a coarse debris flow that broke off its top.

HOLIDAY GEOLOGY

The Petrified Forest of Lesbos

Also known as Lesvos, Lesbos is the second largest Greek island after Crete. It is in the northern Aegean, just off the Turkish coast. Unlike on some Greek islands, the locals out-number the visitors, and there is agricultural and commercial activity outside tourism. Skala Eresou is a resort noted for its nightlife scene, whereas Skala Kallonis attracts the bird-watchers for the spring and autumn bird migrations. These resorts are far apart, and the geologist will not wish to be based at either, as there is much to see across the whole island.

In the 4th century BC, Lesbos was home to Aristotle when his biological investigations, involving the dissection of sea creatures, and his writings mark a shift in science from philosophising to towards experiment and investigation. Another resident was Theophrastus the Eresos who recognised the difference between rocks and minerals, and that the former were made of the latter, and also recognised the nature of fossils. A third luminary of Lesbos was the poet Sappio who wrote on feminist themes and is the reason for the well-known adoption of the island's name.

The eastern part of Lesbos has Carboniferous to Triassic metamorphic rocks that have been thrust over the younger Mesozoic metamorphic rocks of the central and western parts of the island. All are largely overlain by Tertiary volcanics, which also buried the island's main geological attraction, the petrified forests.

During the closure of the Tethys ocean by the northward drift of Africa, at 65-20 Ma, Lesbos and the other islands were part of an Aegean landmass attached to Laurasia and uplifted by under plating. Andesitic volcanic eruptions on what is now Lesbos date from 21-16 Ma. The main centre was the Vatousa volcano, whose caldera, 6 km across, now the eponymous village and is crossed by a good road with some roadside interpretation boards. After 16 Ma the subduction zone was further south, causing volcanism on Santorini, and subsidence of the Aegean has left Lesbos as an island

Road cuts expose lavas, lapili tuffs and ignimbrites, but mostly debris flows. It is these that buried the forests on the lower slopes of the volcano. There are five sites where the silicified trees can be seen, with the Petrified Forest Park 14 km from the small town of Sigri with its museum and nearby coastal sites. The Museum of Natural History is excellent, with its guides and presentations as well as petrified trees immediately outside.

The debris flows that buried the trees were cold, and consisted of ash mud supporting unsorted boulders that are both angular and rounded. The buried trees, which were pines, laurels and sequoias, were replaced by a cryptocrystalline form of quartz that shows clear preservation of the wood structure. Erosion of the debris flows has revealed the tops of many tree stumps. Where excavated down to the roots, it can be seen that these were growing on an earlier flow, indicating that there were many burial events and re-growths. Many trees are still standing to heights of more than two metres, buried in the fine-grained material with small matrix-supported boulders. Some stumps are broken off at the base of a coarser debris flow, with the fallen upper parts of the trees buried down-slope close to the stumps. The site guide claims that the visible trees are more numerous than those in its namesake in Arizona, and also has many more upright trees.

The petrified forest of Lesbos is well worth a visit, and there is much to see. If time is short, visit the Museum and its trees first, miss the coastal sites, and hurry 14 km inland to the Pertified Forest Park, which closes at 4pm. Numerous orchids in spring, and little owls perching on some trees, are added attractions. Lesbos has direct flights from England in the summer and there are plenty of places to stay.

Alan Filmer

Multiple silicified tree stumps in positions of growth in the Petrified Forest of Lesbos.

REPORT

An early geological map of part of Charnwood Forest

During salvage of part of the teaching collections of the defunct Geology Department of Wigan Mining and Technical College, a hand-drawn and hand-coloured geological map of the northwestern corner of Charnwood Forest has come to light and is reproduced here as a matter of historical record.

The area was mapped by Drs Bernard Stracey and Frederick Bennett before World War I. There is a pencilled note in the margin “from Dr Bennett January 1917”, presumably dating from when he donated it to the Wigan Mining College but it is not known why he did so. A much reduced black and white version was published in the report of a 1911 excursion in the Proceedings of the Geologists’ Association. The coloured map is 45 x 41 cm whereas the reduced version is only 12 x 10 cm.

Drs Stracey and Bennett may thus be deduced to have done their mapping before 1911. Watts had mapped Charnwood a few years earlier, c.1896-1900; he gave a short account of the geology in the Geologists Association Jubilee volume of 1910 (enlarged but not fully updated in his book of 1947). However, Stracey and Bennett’s details of the geology differ considerably from Watts’ map in that the shape of outcrops is different and there are many more faults, particularly in the Warren Hills area. The Whitwick Quarry is not shown on Stracey and Bennett’s map; only a small Carrs Quarry appears near Thringstone, within an outcrop of hornfelsed Woodhouse Beds.

Though not depicted on the map, the Peldar Tor quarry is mentioned in the Geologists’ Association excursion report, which is mainly concerned with the petrology and origin of the igneous rocks, then described as various types of “porphyroid”. The Association members seem to have been uncertain as to whether they were extrusive lavas or intrusive sills or both. Watts (1910) thought that the porphyroids had been intruded into agglomerates with resultant mixing. Bonney (1915) regarded the porphyroids as pyroclastic flow breccias, *i.e.* extrusive. Bennett, together with Lowe, Gregory and Jones, provided a somewhat different map of the whole of Charnwood Forest in 1928. Re-mapping by the British Geological Survey in the late 20th century indicated that Bardon Hill consisted of andesites and dacites, variably massive or intensely brecciated, sometimes porphyritic, interpreted as volcanic domes emplaced at a shallow depth (Worssam & Old, 1988). The volcanic processes forming a similar complex near Whitwick were described by Carney (2000). The Bardon Quarry is just off the southern edge of Stracey and Bennett’s map, and was not visited on the 1911 excursion. Both complexes are depicted on the Charnwood Forest Special Sheet (Ambrose *et al*., 2007).

Though shown on Stracey and Bennett’s map, the faults were barely mentioned in their excursion report. Local offsetting of the Slate Agglomerate by close-set faults was inferred from dislocations along the outcrop along the Warren Hills, but other faults were concealed by Triassic and Pleistocene deposits and were inferred by misaligned outcrops of distinctive rock types.

Stracey and Bennett were both medical men and geology was their hobby: they are not known to have had any formal training in the subject. Stracey (1874-1944) was born in Edinburgh and was in Leicester by 1899. His specialty was in psychiatry and he published on the subject as early as 1901. He was known as “the shell man” and contributed to the Journal of Molluscan Studies. He lived at 16 New Walk. During World War I he was Surgeon Lieutenant in the 5th Northern General Hospital, later the Fielding Johnson Building of the University of Leicester. As his name does not appear in any post-1918 literature he may have left the area. He died in Switzerland in 1944, presumably isolated there during World War II. Bennett (1862-1930) was born in Leicester and was a leading medical practitioner and surgeon in the city, living on Regent Road. Among the founders of the University of Leicester, his name is perpetuated in the Bennett Building and Chair of Geology. As noted above Bennett and colleagues published their own map in 1928. Both Stracey and Bennett made numerous thin sections of Charnwood rocks and some of these were donated to Leicester City Museum where they remain to this day.

Stracey and Bennett published other notes on Charnwood geology, some jointly (1906-7) and some independently. Both their mapping and that by Watts were done long before the development of the modern Bardon Quarry which would have thrown light on their problems.

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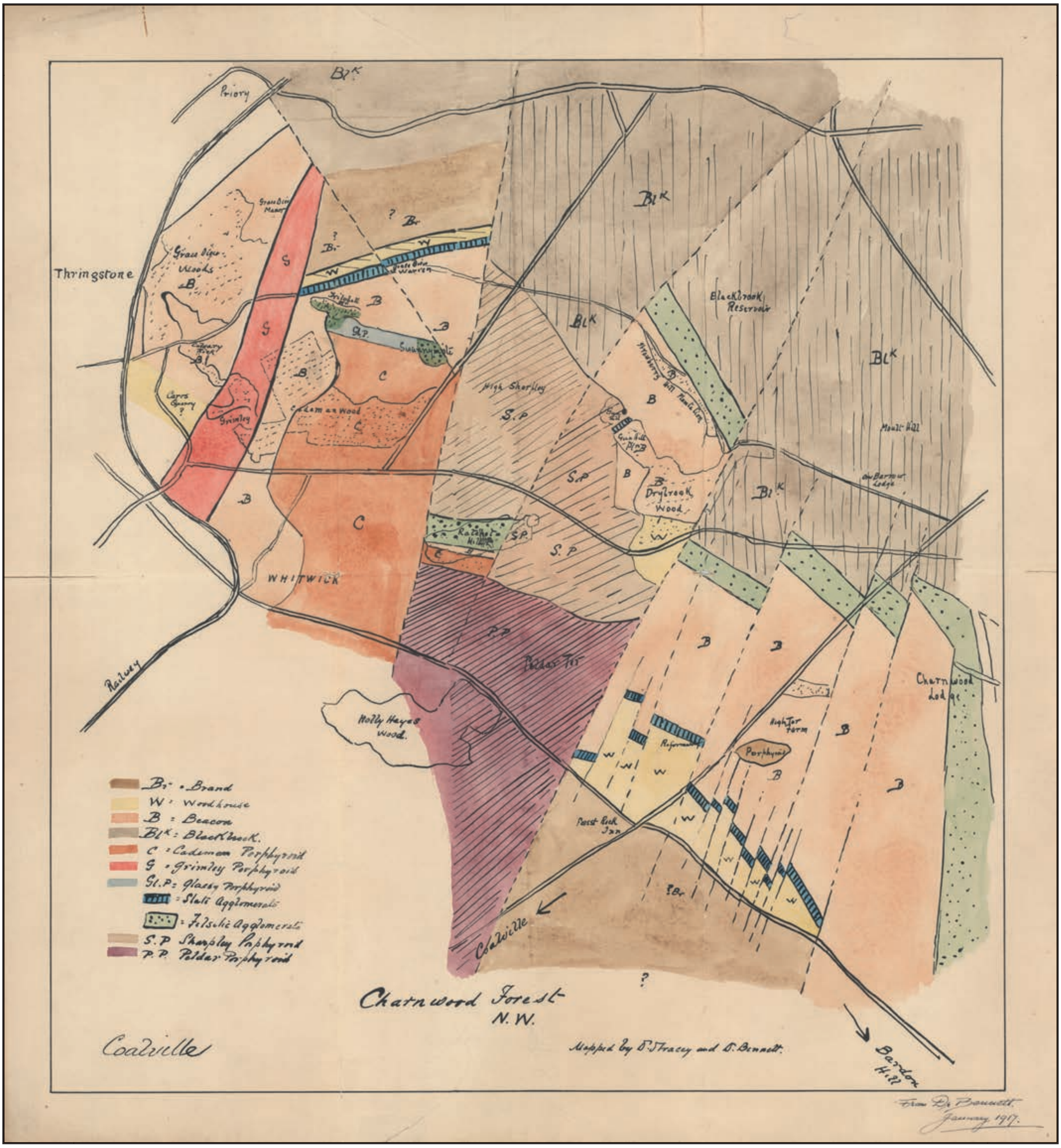


The geological map of the northwestern part of Charnwood Forest, prepared by Bernard Stracey and Frederick Bennett in the early 1900s.

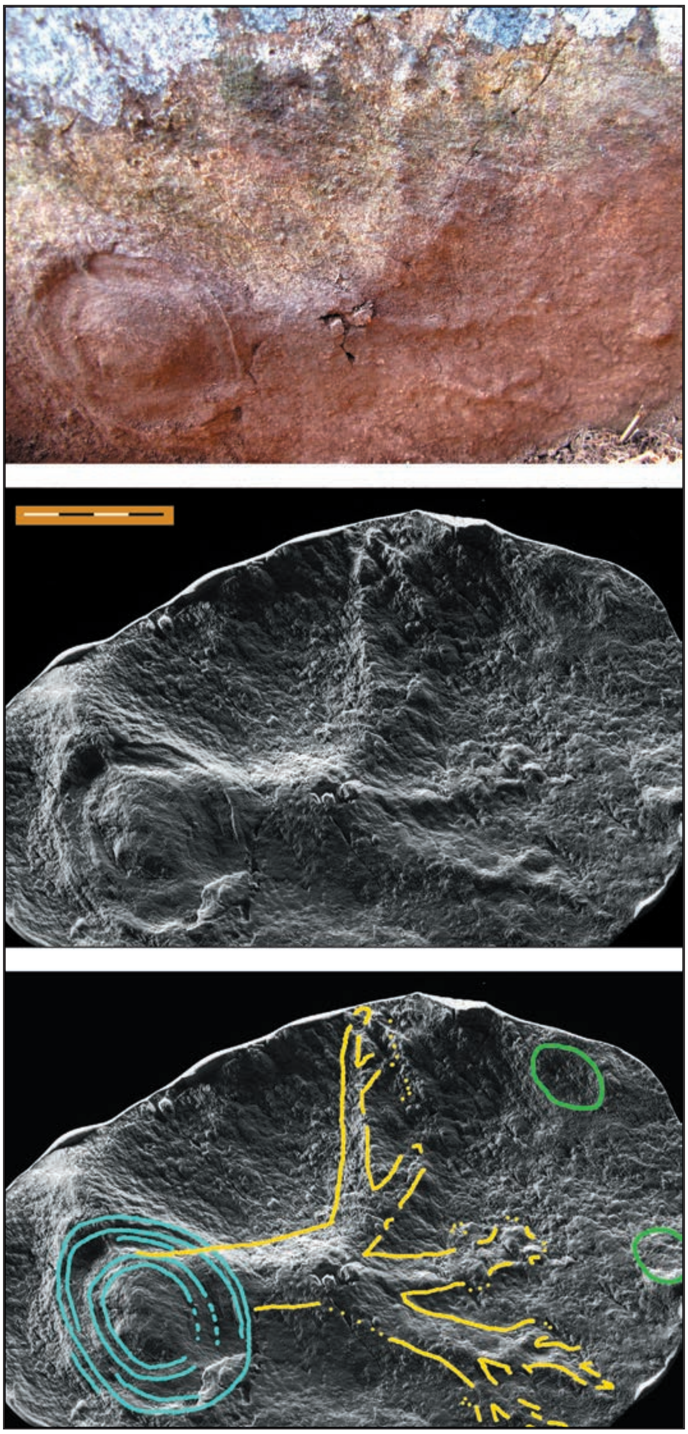
REPORT

An Ediacaran fossil from a new bedding plane in Charnwood Forest

Bedding planes at a number of localities in Charnwood Forest have been examined over the last two years, and in May 2012 a new fossil-bearing bedding plane was found. It occurs within the Bradgate Formation on the eastern limb of the Charnwood anticline, at a stratigraphical horizon comparable to the Memorial Crags locality, in Bradgate Park, from which the frondose form *Bradgatia linfordensis* was first described (Boynton and Ford, 1995). The volcaniclastic sediments that form this small outcrop show the same type of layering between fine-grained and coarser beds as occurs at the Memorial Crags horizon, consistent with deposition from distal-facies turbidites.

The specimen consists of a multi-ringed ovoid disc with an emerging robust stem that divides into a fan of four distinct, asymmetrically-distributed branches. Further distal branching can also be seen, though this is clearer in some parts of the specimen than in others. Were the specimen orientated in presumed life position with the disc at the bottom, the branches would take the overall form of an inverted triangle. The disc, which is assumed to represent the holdfast of the organism, measures 57x 48 mm. The outermost ring of the disc is distinctly prominent and the interior shows further concentric rings with the central portion of the disc being raised in a three-dimensional effect. The stem, whose lower border is indistinct, has a width of about 13 mm and extends some 25 mm beyond the holdfast margin before the branches emerge from it. The four first-order branches range between about 25 and 40 mm in length. Overall, the specimen has a length of 142 mm and its fan of branches reaches a width of 124 mm measured perpendicular to the stem. The immediate surrounding area of the bedding plane has a coarse lumpy appearance that is probably due to co-existent microbial matting, the presence of which is thought to bind together and thus preserve this organism. Beyond the reaches of the branches there are a further two poorly-preserved discoid specimens, each 20 mm across (on the right in the images).

When compared to other recorded Ediacaran fossils, this specimen bears most similarity to those of the *Primocandelabrum* genus first described from the Bonavista Peninsula, Newfoundland (Hofmann *et al*., 2004). Their species, *P. hiemaloranum*, includes ray-like appendages radiating from the disc, which the new specimen does not have; it is notable that this is also the case for other specimens from Charnwood Forest (Wilby *et al*., 2011). Other specimens related to *P. hiemaloranum* are distinguished by their lack of radiating structures from the disc; these were referred to collectively as *Primocandelabrum* sp., and were noted to have a higher ratio of frond width to frond length than *P. hiemaloranum* (Hofmann *et al*., 2004). The present specimen's relative dimensions are suggestive of this category too. Its branches show higher-order subdivisions but do not attain the frondose appearance seen in some *Primocandelabrum* specimens; this appears to be a reflection of the degree of preservation.



Images of the fossil, all at the same scale.
Top: Field photograph of the fossil.
Middle: Enhanced image of cast, created from two images lit from different directions, with bar scale in centimetres.
Bottom: Annotated image with sketched outline to pick out the main features and also the two adjacent discoid forms.

On-going work by the British Geological Survey has already demonstrated a range of different forms from Charnwood Forest, all showing degrees of resemblance to *Primocandelabrum* but with enough variety within them to suggest an underlying range of as-yet-undescribed taxa (Wilby *et al*., 2011). This work may, in time, clarify the taxonomic status of the current fossil find.

Time of year, day and light conditions are everything when it comes to locating the low-relief fossil specimens in Charnwood Forest; strong, low-angle sunlight striking obliquely across the bedding plane is ideal. Depending on the orientation of the outcrop, this may occur at both extremes of the day and what is revealed may well show significant differences between dusk and dawn. As this new example shows only too clearly, there may be other impressive specimens waiting to be found. Furthermore, surfaces that have been examined many times but not formally moulded could still be worthy of further research. Since the discovery of this fossil, the author has located two faint multi-ringed discs in excess of 90 mm diameter on a nearby older bedding plane. The surface had previously been examined repeatedly, but, under optimum lighting conditions one day, a disc became obvious from some distance. Later that day, the same specimen became almost impossible to identify at close range under a different angle of the sun.

Acknowledgements

The author is gratefully indebted to Dr Helen Boynton, whose knowledge, advice, support and encouragement has been so generously given. Thanks go also to Dr Phil Wilby for helpful discussions surrounding this specimen and allowing me to view some of the as-yet-undescribed finds from Charnwood Forest. The cast was made by Aron Bowers and the studio photography of it was undertaken by William Stone. I am grateful to them both for their skill and time. Thanks are also due to Dr Trevor Ford and Tina Negus.

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REVIEWS

Delving ever deeper: the Ecton mines through time by John Barnatt, 2013. Peak District National Park Authority, 382 pages, 160 illustrations, 978-0-901428-26-4, £21 at Matlock Mining Museum.

This beautifully produced A4-size paperback volume is the culmination of many years of painstaking and detailed archaeological research and physical survey work by John Barnatt and co-workers around the Ecton copper mine complex in the Manifold valley of north Staffordshire. It is copiously illustrated with many superb colour underground photographs by Paul Deakin complemented by numerous surface views and historic black and white images. There are also many clearly drawn sketches of mine levels and detailed section of workings as well as reproductions of the few remaining historic mine plans and sections.

The Ecton area is unusual from many aspects. It has dated Bronze Age workings. It was one of the first English mines to have the recorded use of gunpowder for mining. It was at its peak during the late 18th Century when it was amongst the deepest mines in Britain working an unusual (unique for the Peak District) semi-vertical pipe-like and very rich calcite-chalcopyrite orebody. It combined many unusual mining techniques, including the use of large underground water and steam engines for pumping and an underground canal for ore transport. It had an early Boulton and Watt steam winding engine housed in what is now the oldest remaining purpose-built engine house, which is in the process of stabilisation and conservation by the National Trust. This employed an early use of tapered ropes due to the great depth of the shaft. It also contains some excellent and accessible examples of the strongly folded and faulted Carboniferous limestone host-rock, though not of the high-grade mineralisation which sadly has all been removed by generations of miners. The area is now a centre for education and industrial archaeology.

The book is divided into a number of sections; each of these describes features associated with the individual mines, especially the two main mines, Deep Ecton and Clayton. The sections deal with the current surface and accessible underground features of the area and then describe the major phases of activity, such as Prehistoric mining, the main productive period under the Dukes of Devonshire and the latter stages of the area from the 1820s to the 1880s under several very hopeful companies. There are also sections on the mining and processing methods through the ages, the Boulton and Watt engine and decay and development since final closure in the late 1880s. The archaeological surveys could only cover the accessible parts of the mines above river level. Much remains hidden in the flooded depths of Deep Ecton and Clayton mines which extend to 300 m below river level. These were pumped out several times up to the end of their lives in the 1880s; perhaps we may see this done again and be able to explore the undoubted treasures concealed in their extensive workings.

There is a comprehensive bibliography and references to the numerous published and unpublished sources used in the project including the Chatsworth and Birmingham City Archives, county record offices and Mining Journal extracts. There is also a glossary of mining terms and reference to the large numbers of unpublished papers deposited by the project team in the Ecton Mines Project Archive at Bakewell.

This is not a book for a quick read, though the stunning underground photographs encourage page turning. It deserves careful study and every page has interesting facts and opinions. The numerous headings, separating details of each mine or section of mine, make navigation simple. It places on record an enormous amount of information gleaned from years of careful survey and observation by the author and his co-workers (Simon Timberlake, Bill Whitehead and Rhodri Thomas) at Ecton and in the archives noted above. It does not describe the social history of the mine workers or their families or delve into the details of the geology of the ores (Porter, 2004; Ford, 2000). I would have liked a fuller explanation, perhaps with diagrams, of how the Boulton and Watt engine worked and transferred its motion to the vertical shaft. There is also little on the calcining and smelting of ores, though most of the smelting was done elsewhere; the lack of surface and written evidence may be the reason. Overall this is a very comprehensive study of this fascinating area.

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Tim Colman

The Goldilocks Planet; the four billion year story of Earth's climate by Jan Zalasiewicz and Mark Williams, 2012. Oxford University Press, 303 pages, 29 illustrations, 978-0-19-959357-6, £16.99 (hardback).

This book is truly spectacular – not visually, but in the wealth of its data and the perspectives in which it places such a long and complex geological story. It takes a succession of geological events with which we are all familiar and relates each to climate changes, and ultimately leads to implications, debate and questions about the current phase of global warming.

Archaean banded iron formations, the Great Oxygenation Event, Snowball Earth and the role of limestones. The grey or black of Welsh slates related to Ordovician glaciations. The evolution of Pangaea followed by the Carboniferous coal-forming forests and glaciations related to carbon burial. The Permian impact of Siberian flood basalts, and the roles of carbon, methane and Whitby jet through the hyper-warm climatic interlude of the Lower Jurassic. And then the Oligocene growth of the Antarctic ice sheet related to carbon dioxide lost from the atmosphere as it was used in rock weathering. Suggestions and questions abound, there is too much to review, and the evidence for all these geo-events is massively diverse; the book is highly thought-provoking, and it just has to be read.

The quality and breadth of the research in this volume are exemplified by the treatment (occupying half the book's pages) given to the Pliocene epoch onwards, a crucial period that is of direct relevance to today's climate debate. The authors chart the subsequent climatic deterioration following the early Pliocene warmth by drawing attention to chemical variations in organisms from the layers encountered in deep-sea cores, and this evidence is evaluated in conjunction with other factors, such as the rise of mountain belts and the opening or closure of major oceanic gateways. In their typically objective assessment, the authors acknowledge the bewildering array of possibilities that may influence the geologically abrupt changes in the Earth's climate, but draw attention to the Pacific snowgun effect, where warm summer oceanic waters cause an increase in atmospheric moisture which then falls as snow in Polar regions, triggering the expansion of ice caps.

Moving into the glacial world, borehole evidence is again given prominence in relation to the astronomically-induced Milankovitch cycles. The authors are to be congratulated for painstakingly explaining these complex patterns, while at the same time enlivening their account be interleaving biographical details of the principal scientists involved. Arguably the most tantalizing aspect is the graph of temperature against time of Lisicki and Raymo, showing that just over a million years ago the frequency of climatic fluctuations changed, from 40,000-year cycles to 100,000-year cycles. This also marks the start of the current Ice Age, but the authors note that it is also a complete mystery.

The final sections present a state-of-the-science discussion of the highly complex data used to chart the planet's most recent climates – for example, the message imprinted in snowfall layers at the ice caps, which gives the Dansgaard-Oeschger pattern and Heinrich events; if explanations are not always forthcoming then the various alternative possibilities are expertly evaluated. Biological evolution is emphasised here, as it is throughout the book, and justifiably so since hominid evolution was directly influenced by Pliocene-Holocene climatic changes. Some remarkably abrupt climate triggers are discussed, such as the emptying of Lake Agassiz 8200 years ago, which caused a virtually instantaneous global sea-level rise of 1 m.

An assessment of Holocene climate patterns is also vital to the on-going debate about human influences, and the book succinctly discusses all available evidence, even down to studies of long-lasting nests made by packrats in the USA! The last 50 pages of the book deal with the last 1000 years of climate change and the various complementary influences that may be in play, such as the sun's fluctuating output, the El Niño effect, and others. And so to the latest culprits – ourselves and how our burgeoning need for power generation may be influencing the climate of the newly-named Anthropocene Period (see *Geobrowser* for 2011). Highlighted here is the progressive carbon rise, dramatically demonstrated by the Keeling curve for the last 50 years.

The authors do not hold back on their prognosis for the future for, as the 'hockey stick' global temperature curve of Michael Mann shows, it is now possible to assign many recent changes (for example sea-level rise) to atmospheric warming. The debate about extrapolating these effects into the future is still controversial, but the book concludes that it is "...likely....indeed very likely that climate has already started to change towards greater global warmth", with carbon dioxide levels possibly tripling, and methane levels doubling, within the next 100 years. Reliance on previous climatic events to chart our future may be problematic, however, since our present climate regime is, uniquely, influenced by artificial (human) factors rather than by the natural checks and balances that existed in the geological past. The authors quote the oceanographer Wallace Broecker, who suggested that "climate is an angry beast", to which he cautioned that we are currently poking it with a stick. The book concludes with evidence-based assessments of how the planet is increasingly likely to be affected by our activities. Our planet is a 'Goldilocks world', perhaps unique in the Universe in being just right for human habitation. But constrained as human societies now are within rigid and jealously-guarded borders, how can we as a species adequately respond to the major environmental changes that we are blithely perpetrating?

John Carney

Lead mining in Derbyshire: history, development and drainage by J H Rieuwerts; **v1 Castleton to the River Wye,** Landmark, 2007, 192pp, 978-1-84306-343-8; **v2 Millers Dale to Alport and Dovedale,** Horizon**,** 2008, 142pp, 978-1-84306-344-5; **v3 Elton to the Via Gellia,** Horizon, **2**010, 208pp, 978-1-84306-345-2; **v4 The area south of the Via Gellia**, PDMHS, 150pp, 978-0-904334-02-09; £25 each from Matlock Mining Museum.

A difficulty in any mining is water flowing into the workings, and the lead miners of Derbyshire were no exception to this problem; their many drainage levels are known as soughs. In 1987 Dr Rieuwerts privately published a limited-edition compilation bringing together some 30 years of research into widely distributed archives. His review covered the 200 soughs then known, and is difficult to obtain today. A further 25 years of research in the Derbyshire Record Office, Sheffield Archives (formerly the Reference Library), in the Duke of Devonshire's archives in Chatsworth House, the Duchy of Lancaster Archives at Chatsworth and in London, the Rutland Archives at Haddon Hall and in the National Archives (Public Record Office) at Kew and several other collections, has uncovered much more material. In particular the number of known soughs has increased to well over 300; thus Dr Rieuwerts has found it necessary to expand his 1987 book into a four volume set. A great quantity of data on the history of mining, investment and drainage is now accessible and Jim Rieuwerts has done us a service in analyzing the numerous and often vague or conflicting references. Many of the historical details have been revealed by frequent disputes between mine owners and sough-driving companies, resulting in court cases with consequent legal records.

Jim Rieuwerts has taken the opportunity to describe the industry as a whole, with accounts of who worked which mines and when, and how much lead ore was produced, where figures survive. Much of the history discussed relates to the 17th and 18th centuries when production was at its peak and demonstrates that the miners knew about the geological relationships of the Carboniferous Limestone, the inter-layered toadstones and the overlying shales long before geology as a science was born. Indeed their observations provided John Whitehurst with his early concept of Derbyshire stratigraphy in 1778. The miners knew that the interleaved lavas (toadstones) rarely yielded much lead ore and they could often predict where they might be met. However, their knowledge had its limitations and these books show that they still ran into many problems, particularly where the lavas extended further or were thicker than expected. The miners also found what appear to be volcanic vents and feeders where the toadstone could not be bottomed. Thus some soughs were abandoned or diverted when they met toadstone.

The traditional categorization of the mineral deposits into rakes, scrins, pipes and flats has been followed. Rakes and scrins are more or less vertical fracture fillings, whereas pipes and flats were largely controlled by favourable beds or, more widely, by bedding planes. It is noted that the pipes were mineral-lined caves where roof beds locally collapsed into the voids, and some later filled with sediments containing detached lumps of ore, referred to by the miners as gravel ore. He also includes comments on the 'plumbs' and 'hadings' of Longstone Edge where the fissure veins are in steeply dipping limestone beds on the south side of the Longstone Edge monocline.

Several important mines are discussed in detail, e.g. Magpie Mine at Sheldon, the Hillocks and Knotlow Mines near Monyash, Golconda Mine near Brassington, and Millclose Mine at Darley Dale. Many other mines are currently inaccessible, e.g. Hubbadale Mines at Flagg where it is to be hoped that mine explorers will soon gain access. The last major lead and zinc mine at Mill Close is covered in volume 3 (not in volume 4 as implied by the map on the title page). The lead and baryte Golconda Mine is covered in volume 4, as are the mines of the Ashover and Crich inliers.

The books are illustrated with sections of the Old Series 6-inch and 25-inch Ordnance Survey maps with mining details superimposed. There are scattered references in the text to plans and diagrams in archives but few of these have been reproduced: they would have made it easier to follow the historical details and would have helped future studies.

Each volume is illustrated with photographs by Paul Deakin and others, mostly in colour. Volume 4 includes a survey of mining activities and trials outside the orefield at Baslow, Ashley Hay, Whitwell and Whaley Bridge. It also includes 15 pages of appendices to volumes 1 and 2.

I have not seen many of the archives, so I cannot criticize the detail. However, a few improvements could have been made. The mining enterprise using boat haulage in the Speedwell Mine at Castleton gets rather brief treatment in volume 1; boat haulage there has been said to be unique but in fact boats were used at several other mines and soughs. I found it difficult to work out some of the Mining Liberty boundaries: they could have been shown on a separate map or added to the existing maps. The important Stoney Middleton area is split between several maps: an extra map would have been helped, though a map of Morewood Sough at Stoney Middleton is in vol. 4. References cited in the text are not always listed, as in the Ashover chapter in vol. 4 where Stuart Band's articles are not listed.

The volumes have bibliographies and list of archives consulted. I did not notice many spelling or type-setting mistakes, but "Astleton" in the contents list of volume 1 stands out. Also the BSA (British Speleological Association) documents are now in the British Caving Association library at Glutton Bridge near Buxton, not Litchfield as stated in the appendix to volume 1.

Jim Rieuwerts is to be congratulated for bringing together so much information on what is in effect a defunct industry, but one which has left many traces of lead mining activities both on the surface and underground throughout the Peak District. All these volumes should be on the shelves of anyone interested in the lead mining industry in the Peak District.

Trevor Ford

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.

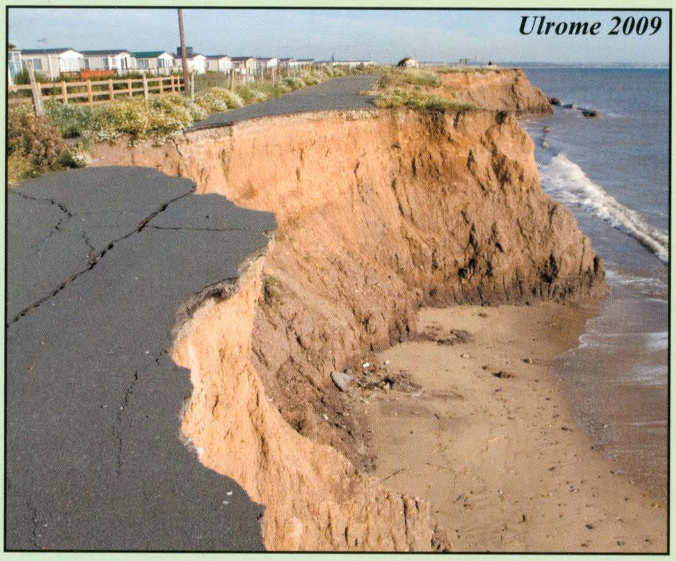
Caves and Karst of the Yorkshire Dales edited by Tony Waltham and David Lowe, 2013. British Cave Research Association: Buxton. 264 pages, 165 maps and graphics, 354 photos, 978-0-900265-46-4, £25 from www.bcra.org.uk/bookshop or BGS shop at Keyworth.

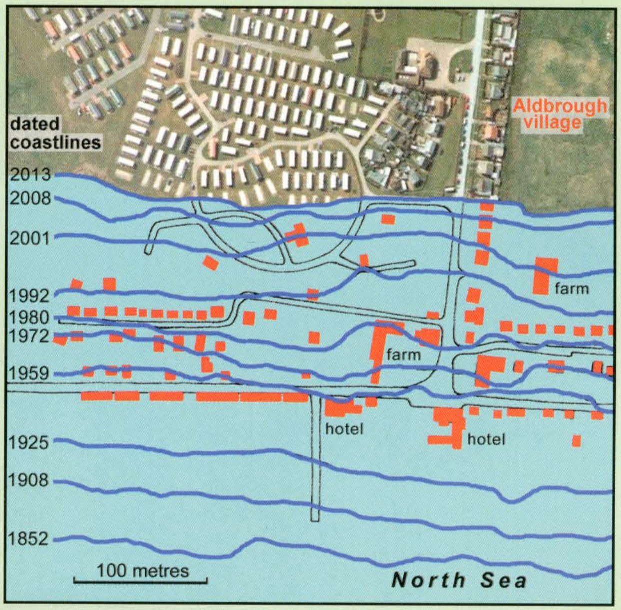
This book offers just about everything you ever wanted to know about the geology, geomorphology and landscape chronology of the Yorkshire Dales, with 16 chapters written by an impressive group of cognoscenti. It replaces a book published in 1974 that has long been essential reading for anyone interested in the Dales and especially in its limestone landscapes, and it has greatly benefited from the huge extent of both scientific techniques and underground discoveries made since then.

Two chapters in particular encompass major scientific strides that have been made in understanding the geomorphology of the Dales. That addressing the chronology of the caves draws on the hundreds of radiometric and other dates that have been published for the region since the late 1970s, enabling them to be placed in the broader context of landscape evolution, which is addressed in the chapter on glaciation and Quaternary evolution. The latter provides an excellent summary of global events through the Quaternary as well as summarising an extensive body of local field evidence amassed particularly in the past two decades. A short chapter examines the palaeoclimate record preserved in just a single stalagmite, little else having been published for the area, and suggests where future developments linking past environments with chronologies may lie, while a chapter on Holocene environments provides a link between the landscape, the flora and the influence of people over the past few thousand years.

For anyone with even a passing interest in the Yorkshire Dales this book is a must, but its value and interest extends far beyond the limits of the region it encompasses and it should prove equally attractive to anyone with an interest in the diverse facets of limestone landscapes. By setting the subject of each chapter in a broader chronological and/or environmental framework, the authors provide us with admirably readable, concise and current summaries of the state of knowledge in their respective fields. The book as a whole is clearly laid out, with the detailed breakdown of subheadings listed on the contents pages making it easy to home in on a particular aspect despite the absence of a comprehensive index (although there is an index to localities). There is a plethora of illustrative material - photographs, maps, diagrams and tables – and at just £25 for the paperback, this beautifully presented and highly informative book represents extremely good value. This is definitely not the sort of book to sit gathering dust on a shelf and I have little doubt that those who purchase a copy will find themselves consulting it frequently for years to come.

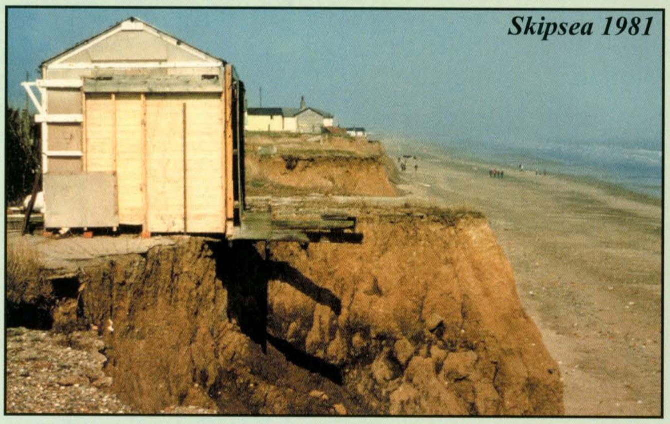
Michael Simms

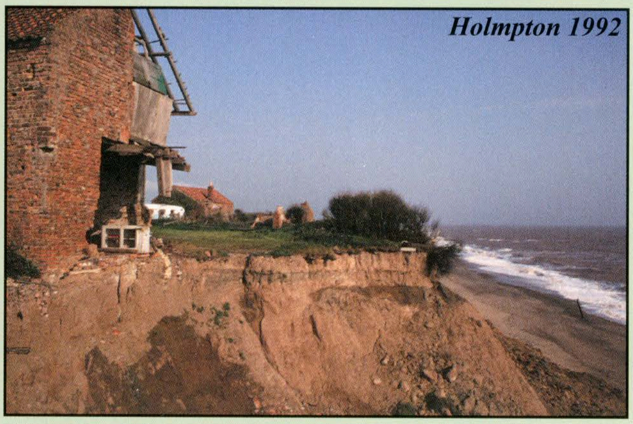


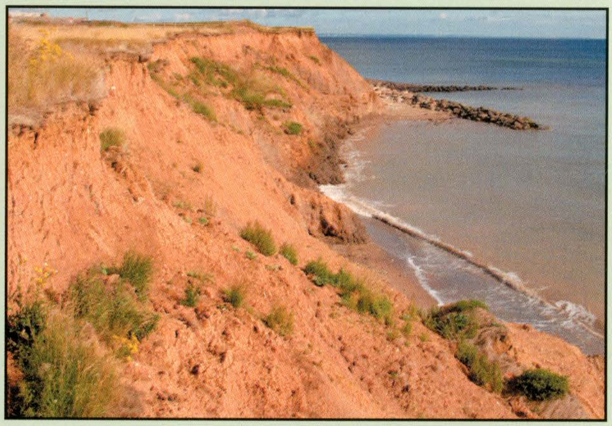


Coast erosion at Holderness, Yorkshire

Mapped coastlines at Aldbrough, with cliff retreat at mean rate of 1.75 m/y; most of the village is long gone, and new development is just a caravan site.







Mappleton, 2013, with accelerated erosion down-drift of the hard point created with armour stone in 1991.