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East Midlands Geological Society

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Cover photograph: East side of the Derwent Gorge just below Matlock, seen from the slopes of Masson Hill. The white limestone cliff bisects the High Tor reef (see landmark on page 235), while Riber Castle stands on the Ashover Grit, and Chatsworth Grit forms the skyline [photo: Tony Waltham].

Contents

PROFILE

Ian Thomas

Ian, our new president, was born and brought up in Mansfield Woodhouse, Nottinghamshire, where two generations earlier his grandfather had worked the Parliament Quarry, on Vale Road (in the 1840's the quarry was one of a number which supplied stone to rebuild the Houses of Parliament after a major fire). In 1957, his family moved to Aberystwyth (where great grandfather had sailed ships laden with lead ore). So geology was in the family blood. Ian's interest in geology stemmed from a fascination for industrial history of the lead mines in Wales that he explored as a school boy.

He read geology, biology, physics and geography at University of Swansea, graduating in geology in 1968 (having also taken a course in cartography).

For four years he worked at the Institute of Geological Sciences (later to become BGS) in Exhibition Road, London – advising British and foreign governments and industry, on a portfolio of refractory, ceramic, carbonate and strontium minerals worldwide. Had BGS decided to move out to Keyworth at that stage, he would probably have still been working for them. Instead, in 1972 he joined Derbyshire County Council's Strategic Planning Division to work on minerals policies for Britain's largest mineral producing county.

The following year, he set up the first Regional Aggregates Working Party (RAWP) (i.e. for the East Midlands) and continues as its Technical Secretary. In 1979 he became the Convenor of the RAWP Secretaries for England and Wales, which again he continues under contract to the Office of the Deputy Prime Minister. He also became involved in adult education, teaching applied geology in various Derbyshire centres.

In the 1980s, he promoted the idea of the National Stone Centre (NSC) and gradually gained seconded time from the County Council to this end, becoming the Centre's full time Director in late 1988. The Centre opened to the public in 1990, and now attracts hundreds of school groups and thousands of family visitors. In 1989, he was also appointed to BGS's first Programme Board.

Two thirds of the work at the Stone Centre is unrelated to visitors. It includes the design of interpretative panels for leading quarry companies in Britain, collecting and publishing data on minerals planning, and advisory services relating to Earth Science education for English Nature and the Countryside Council for Wales.

Much of Ian's work is now involved with developing national policies for both the English and Welsh governments for balancing the need to provide for aggregates with the need to protect the environment. In the last few years, the NSC has been more involved in Wales, including assessing the scope for a Welsh Stone Centre.

At the Stone Centre, Ian is able to combine his passions for the history of quarrying, geology and design. Ten years ago, nineteen members of the Thomas family staged an art and design exhibition ranging from Jaguar car designs to apples made from applewood, and Ian still undertakes freelance design work.

Apart from involvement in various local and national committees, covering the arts, tourism, regeneration of Wirksworth, mining history and building stone, Ian has just completed a two-year term as chairman of ESTA (Earth Science Teachers' Association). In 2002 he chaired the Standing Joint Committee on Natural Stones, a group linking key professional and government organisations concerned with building stones.

During this period, he became concerned that ESTA was focused on catering for those teaching the few thousand school students studying geology per se. Not adequately addressed were the needs of the 8-10 million pupils being taught a more limited amount of Earth Science (often poorly), through mainstream National Curriculum science. As a result, a small group approached the main professional institutions concerned with chemistry, physics, biology and science teaching, successfully engaging them in the Joint Earth Science Education Initiative which Ian now Chairs – readers should visit www.jesei.org to see some of the results.

GEOBROWSER

Warm times

The recent succession of years with anomalous climatic conditions, either excessively warm and dry, or stormy, or both, has stimulated interest not only in predicting future trends, but also in reconstructing past climatic regimes. Two major global warming events are particularly well documented, but can we draw any lessons from these examples, that may help us to anticipate or even regulate future climate trends?

Cretaceous warming: Probably one of the most important discoveries of the past 20 years has been the recognition that the Polar landmasses of Gondwana were warm, forested regions throughout the Mesozoic and into early Tertiary times. A recent review (*Journal of the Geol. Soc. 2001, p.709*) notes that the global thermal maximum occurring in the Cretaceous Period, between 112-88 Ma (late Albian-Turonian), was characterised by broad-leafed and conifer forests of warm-temperate aspect in Kamchatka and Russia (up to at least 82°N) and Antarctica (up to at least 75°S). Fossil tree-ring structures indicate that the forests (with their specialised dinosaur fauna) were adapted to long, dark winters with average temperatures between 0°C and -4°C, and long, light summers with temperatures of 20-24°C.

These proposals are difficult to reconcile with suggestions that Cretaceous global sea-level fluctuations were caused by temporary continental ice sheets in Antarctica (*Geol Soc. America Bulletin, 2000, p.308*). Strontium and oxygen isotope data supported the glacio-eustatic models, but better information has recently been made available from the more continuous drill cores recovered from the Atlantic by the Ocean Drilling Project. Oxygen isotopic analysis of fossil foram carapaces in the cores indicates that bottom-waters were very warm in the Cretaceous oceans, ranging from 9ºC to 20ºC (*Geology, 2002, p.123*). Such conditions, coupled with warm high-latitude surface water temperatures, rules out the possibility that ice sheets could have existed then.

The general global warmth of the Cretaceous has usually been attributed to elevated levels of atmospheric CO_2 due to the vigorous volcanic and tectonic regime of ocean creation that then prevailed. Expansion of the oceanic ridge systems would, incidentally, also account for the Cretaceous sea level fluctuations. It appears, however, that CO2 outgassing reached its peak during the Aptian-early Albian (120-110 Ma) – before the Albian-Turonian thermal maximum. The latter must therefore have been caused by a mechanism of regional climate change additional to the flux of CO2 to the atmosphere. This mechanism, it is now suggested, was the particular phase of oceanic spreading that occurred during Albian times (*Geology, 2003, p.115*). It changed the configuration of the landmasses, opening up a deep-sea gateway between the (equatorial) north and south Atlantic basins, each of which was formerly characterised by very different water temperatures and salinity. The ensuing vigorous circulation and mixing of waters between the two former basins would have been sufficient to bring about rapid and substantial changes in temperature and salinity throughout the newly-enlarged proto-Atlantic ocean.

Tertiary warming: Global warming that occurred in Palaeocene times, about 55 Ma ago, was of a similar intensity to that in the Cretaceous, but its causes were radically different. It was characterised by a massive and rapid (within a few thousand years) addition of isotopically light carbon to the oceans and atmosphere. In this global 'greenhouse', sea-surfaces had warmed by 4-8°C, to around 16°C off Antarctica, and the deep oceans by 5°C. The thermal maximum then continued for a further 210,000 years (*Geology, 2000, p.927*), before recovery to more normal temperatures. Three possible explanations have been proposed to account for this change, and its rapidity: enhanced CO_2 outgassing during emplacement of the North Atlantic volcanic province (of which the Tertiary volcanics of north-western Scotland are part); dissociation of massive quantities of methane hydrates along continental slopes; and a carbonaceous bolide impact. The stable isotope records of Southern Ocean deep-sea cores had pointed to either seafloor methane outgassing or the bolide impactor explanations as being the most likely, but one line of evidence was missing.

Vital to discrimination between these two models is the answer to the question of which came first - global warming or carbon inputs to the sea or atmosphere. This problem has now been resolved, thanks again to the Ocean Drilling Program. The latest isotopic results (*Geology 2002, p.1067*) confirm that the outgassing event was geologically instantaneous and that, most importantly, it was preceded by a brief period of gradual surface-water warming. Possibly this warming was a consequence of the Tertiary volcanism mentioned earlier; it is unlikely to have been caused by a bolide impact. Whatever its causes, however, this initial surface warming provided the trigger for the whole event since it penetrated downwards, bringing about the rapid thermal dissociation of methane hydrates locked in oceanic sediments. The dissociated methane was then liberated into the atmosphere-surface water zone and the global 'greenhouse' proceeded apace.

If a lesson were to be learnt from these Cretaceous and Tertiary thermal events it is probably to be drawn from the latter, since in Tertiary times the oceanic areas closely resembled those of today. The Tertiary experience demonstrates the sensitive nature of the linkage between atmosphere and ocean, and it shows that the balance between these two systems can suddenly change without any particularly catastrophic trigger being applied. It seems that modern anthropogenic carbon emissions have caused a gradual atmospheric warming trend that is strikingly similar to the one that preceded the Tertiary thermal event (*Geology 2002, p.1067*). This has caused the modern atmospheric and surface-ocean carbon reservoirs to be altered. There is no cause for alarm just yet, but if the warming trend were allowed to continue downwards, to the deep ocean, liberating methane from the hydrate layers, there would be little to prevent a rapid, Tertiary-style thermal event from being re-enacted.

Proof of Life

In a previous 'Geobrowser' (*Mercian, 2001*), the possibility of life originating as simple cells hosted within Archaean mid-ocean ridge hydrothermal systems was reviewed. But is the mere presence of organic compounds indicative of life, and if not, what then constitutes proof of life? In this debate, philosophy and pedantry both enter the ring, as an article in the *New Scientist* (*22 Feb. 2003, p.28*) explains. Up till a couple of years ago, the received wisdom was that the existence of 'Life' had been demonstrated in rocks as old as the early Archaean. The burden of proof relied either on chemistry (carbon molecule structures and isotopic signatures in rocks) or on findings of cyanobacteria-like microfossils, the latter from the 3.5 billion years-old Apex Chert of Western Australia. Now, however, doubt has been cast on the organic nature of the Apex Chert structures, which Martin Brasier has concluded could equally well be of abiogenic origin. Even the famous Archaean stromatolites can be generated abiogenically, he maintains; for example by precipitation around hydrothermal springs or vents. The chemists have replied with the suggestion that Raman spectroscopy could distinguish biogenic carbon molecules in Archaean rocks, but it is now thought that this technique alone cannot provide evidence that the material was once alive. Brasier does suspect that life was under way 3.5 billion years ago, but concludes that the earliest *unequivocal* evidence of life, in the form of definite microfossils, comes from the Gunflint Chert of Ontario, Canada. At 1.9 billion years old, however, these microfossils are more than a billion years younger than the problematic structures found in the Apex Chert.

So what chance of detecting life on Mars?

Answers to this question will very soon be sought, when the European Space Agency's Beagle 2 probe lands at the end of this year, and again in 2004 when NASA's Mars Exploration Rover arrives. It was hoped that the sensors with which these probes are equipped will find proof of the former existence of life, perhaps in the form of organic residues or isotopic fractionation that will discriminate between organic and inorganic phases; possibly even cell-like shapes will be found. We have seen, however, that the case for early life on Earth, if based solely on the interpretation of such evidence, may be flawed; at the very least it has not found universal acceptance within the scientific community. In view of this, the *New Scientist* (*22 Feb. 2003*) suggests, there is a strong chance that only controversy will emerge from the results of the Martian investigations – unless we can resolve this debate here on Earth, and come up with criteria for the unequivocal confirmation of life that all can agree on.

REVIEW

Geology of the Loughborough district, by J N Carney, K Ambrose and A Brandon, 2002, Sheet Explanation of Loughborough, England & Wales Sheet 141, Solid & Drift Geology 1:50,000, British Geological Survey. 34 pages A5, ISBN 0 85272 411 X, £9. (Map is £11 alone, or £18 with its Sheet Explanation). Also - Geology of the country between Loughborough, Burton and Derby, by same authors, 2001, Sheet Description, BGS; 92 pages A4, ISBN 0 85272 388 1, £25.

If this is the new format for our Geological Survey publications then it is a great and very welcome leap forward. The explanation booklet is an excellent, concise, authoritative, well-illustrated and very readable account of the area north and west of Loughborough (as covered by map 141). It contains everything that the local resident or amateur geologist is going to need, and is a valuable summary for any professional land-user or researcher.

Almost half the booklet describes the solid geology, while the other half is split into equal thirds on the Quaternary, applied geology aspects and references. A series of whole-page tables that summarise the coal seams, Triassic lithostratigraphy, Quaternary events and deposits, mineral resources and geotechnical data are especially useful and make the data so accessible. Also welcome is the map of the buried palaeochannels that show early stages in the evolution of the Trent valley. The Quaternary correlation chart meets the inevitable problem of the Wolstonian's existence by downgrading stages 8 and 6 to periglacial. But the chart then defines the Upper Devensian as glacial, when it was only periglacial within the area covered by this publication (and glaciation did occur in outside areas during at least some of the Wolstonian stages marked here as periglacial). A reviewer usually feels obliged to pick on some detail (in order to prove that he has read the item completely and critically), and the Loughborough Explanation must be good if the Wolstonian provides its biggest bug.

The accompanying new addition of the map contains a staggering wealth of detail that makes it undeniable value. Slightly irking that a big slice of the Charnian appears as almost exactly the same colour as the Upper Triassic - one wonders if this is going to be a recurring problem as "seamless" mapping is constrained to a universal set of stratigraphic colours for the entire country.

If more detail is required, the Sheet Description is a much deeper database, covering the subjects in about the same proportions as does the Explanation. It approaches the detail of the old "sheet memoirs" with the benefit of a more readable writing style and less slavish devotion to stratigraphy. It is inexpensively produced by desk-top printing, so there are many more colour photos (of slightly reduced quality).

As Loughborough is local to many EMGS members, the package of the "Explanation plus Map" is going to be especially attractive, and will be welcomed too by many more members who live "off the sheet". It now appears to be BGS policy to keep the prices of the 50,000 maps and their Explanations low (and accessible) for the wider market, while charging high for the 10,000 maps and the detailed reports that are valuable to the professionals - and this makes sense. We eagerly await an Explanation of the Nottingham Sheet.

Tony Waltham

THE RECORD

The Secretary reported that since the last AGM, 21 new members had joined and membership now stood at nearly 377. Last year, the Society heard of the death of two long-standing members, W W Campbell and founder member W A Sarjeant.

The Society has had another successful year, and this review is used to record and thank the various individuals that have made that possible.

Indoor meetings.

The Society is very grateful to all the speakers, in a programme organised by Beris Cox.

In March 2002, John Martin gave the Foundation Lecture on bringing dinosaurs to life, at a meeting that also held the AGM and the Foundation Buffet.

In April, Prof. Ian Smalley described Wagga Wagga as a model for Nottingham in the Permo-Trias, as part of the successful weekend visit by the Geologists' Association to Nottingham

The new season opened in October, with Prof. Dixon Cunningham talking about his research on tectonic developments on the Southern Andes.

In October there was a successful and well-attended joint meeting with the Yorkshire Geological Society entitled Crinoids!, with lectures by Prof. Stephen Donovan, Dr Mike Simms and Dr Claire Milsom.

In November, Prof. David Keen revised some of the traditional views on Midlands glaciations.

In December, Dr Tony Waltham described geological treats in Central Asia on an overland journey from Aralsk to Huanglong, before Cheese and Wine arranged by Janet Slatter.

In January, Prof. David Siveter presented a very animated and informative lecture on soft-bodied sensations from the Silurian.

In February, Dr Paul Wignal enlarged on his BBC Horizon appearance to talk on new developments of the end-Permian extinction.

Field meetings

The Society is very grateful to all the leaders, and again the programme was organised by Ian Sutton.

In May 2002 Keith Ambrose repeated his trip to the Millstone Grit of South Derbyshire Melbourne.

In June, Colin Bagshaw took members to the mineralised limestone of Bonsal Moor.

In July, Peter Gutteridge led a trip to Monyash.

In September, Vice-President Richard Hamblin led a weekend to the East Devon and Dorset coast.

In October, Neil Aitkenhead led on Ilkley Moor.

Events

The Society was represented at the Geologists' Association Earth Alert 2 in Scarborough, at the Creswell Crags Archaeology and Geology road show, and at the ESTA conference at BGS.

Publications

The EMGS Field Guide will be published in 2003 as Geology of the East Midlands, GA Guide 63, edited by Peter Gutteridge.

The booklet on Nottingham City Building Stones is in preparation, as well as a comparable guide on Leicester.

The Society's book on the Sandstone Caves of Nottingham, by Tony Waltham, has now sold nearly 7000 copies, and has been reprinted again.

The Society's website at www.emgs.org.uk now has a local geology section using material from Mercian Geologist and contributions from members, maintained by Rob Townsend.

This report ends on a personal note. After ten years on Council, with nine as Secretary, I am standing down. I would like to thank members for their consideration and courtesy in their dealings with me. It has been a pleasure to work with three presidents and I would like to particularly thank my predecessor secretary, Sue Miles, for her help notably on matters procedural and constitutional.

Alan Filmer, Secretary 2002

FROM THE ARCHIVES

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

Langwith Bone Cave

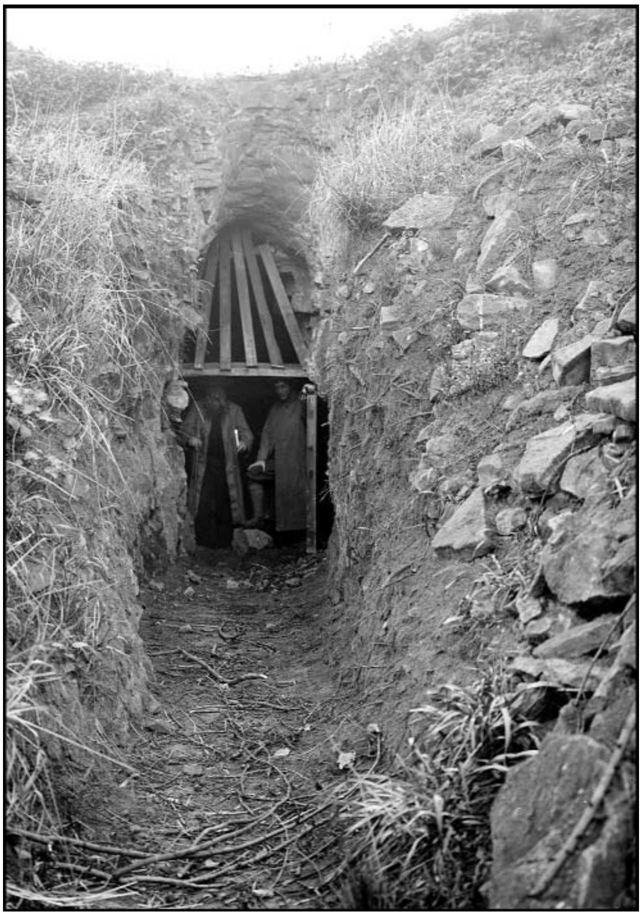
Like the more extensive and well-known cave systems at Creswell Crags, the Langwith Bone Cave is a natural cavern formed by groundwater solution within the Lower Magnesian Limestone. Formerly concealed by talus, its entrance was discovered by the local Rector of Upper Langwith, the Reverend Edwin Mullins. Between 1903 and 1912, Mullins led the excavation of the cave and carefully collected and identified the vertebrate remains and human artefacts he found inside. He published a list of his collection in 1913. Dorothy Garrod completed a later excavation and collection in 1927.

The photograph dates from 26 April 1911, during Mullins' excavation work, and was taken by the prolific Geological Survey photographer, Jack Rhodes. It was the last of a series of local geological photos he took on that day – the time was 6.40 pm and an exposure of 10 seconds was needed to counter the evening gloom, despite the feeble assistance of a candle held by one of the two shadowy figures in the cave entrance.

The cave lies near the small village of Upper Langwith, about 4 km east of Bolsover, on the northern valley side of the River Poulter, and its site is shown on 1:50,000 Ordnance Survey maps. The Lower Magnesian Limestone forms river bluffs about 13 m high. The cave entrance lies about 7 m above the flood plain of the Poulter, but parts of the cave are only 2-3 m above flood level. The Poulter valley was not incised to its present level until the end of the late Devensian ice age about 10,000 years ago, so any occupation of the cave by animals or humans is likely to post-date that period following fall of the local water table.

The vertebrate fauna collected by Mullins included bison, auroch, arctic fox, wolf, reindeer, horse, lynx, hyena, woolly rhinoceros, bear, water vole and numerous species of birds. Animals may have occupied the cave for shelter, but some may also have fallen in via fissures in the roof. The bones represent a mixture of cool and warm climate faunas, suggesting that vertebrate remains may have accumulated in the cave for an extended period following the end of the last ice age. Dorothy Garrod found that recent occupation by badgers had also mixed the fauna considerably.

Flint artefacts within the cave are thought to be Late Palaeolithic. By association, a human skull found in the cave was originally thought to be of the same age, and played its part in the Piltdown Man controversy as a 'control' specimen of Palaeolithic man. More recent radiocarbon dating has shown the Langwith skull to be only about 2300 years old, dating from the Iron Age.



The Langwith Bone Cave, during the excavations in April 1911 (BGS photograph # A1156, © NERC).

Though the entrance is overgrown, the cave remains accessible today, and is designated a Regionally Important Geological Site in Derbyshire. Much of Mullins' collection has unfortunately been lost, but the remaining material is distributed among the Cambridge Museum of Archaeology and Ethnography, Oxford University Museum, Derby Museum, Buxton Museum, and the Natural History Museum, London.

Literature

Garrod, D.A.E., 1927. Excavations at Langwith Cave, Derbyshire, April 11-27, 1927. *Reports of the British Association for the Advancement of Science, for 1927.*

Mullins, E.H. et al., 1913. The ossiferous cave at Langwith. *Derbyshire Archaeological Journal*, **35**, 137-158.

Andy Howard, British Geological Survey

Footnote - Hemlock Stone

The archive photograph on page 153 of the last *Mercian Geologist* showed a party of from the Leicester Literary and Philosophical Society on an excursion to Nottingham on June 15th 1882. Thank you to Andrew Swift of the Lit and Phil for solving the mystery on this one.

Consequences of a modest loess fall over southern and midland England

Ian Jefferson, Ian Smalley and Kevin Northmore

Abstract. Loess deposits that are invariably small are scattered over southern and midland England. They can be examined within a simple, speculative geomorphological model. This allows the concentration of loess material to be predicted and explained, and a distribution network relating to the whole system is produced. A complex series of events in the Weald loess trap causes a concentration of loess material by rivers flowing through various gaps in the Downs. The Thames provides loessic estuarine deposits, and the Pegwell Bay loess was a feature of the Stour. South coast accumulations are related to rivers flowing south through Downs gaps, such as the Adur and the Arun. The geomorphological model assumes a modest loess fall (say 200-500 mm, derived from the northeast) over southern and midland Britain, and develops loess accumulations by logical geomorphological processes from this starting point. Palaeoclimatic studies suggest that interest in the British loess is growing; some overall sedimentological studies might be useful. Loess in Britain should be seen as a major landscape material; it is not an obvious landscape component but it is of fundamental importance. The distribution tree within the geomorphological model accommodates all relevant loess deposits, with major deposits falling on the main line of significant events.

There is more loess material in southern and midland England than is immediately apparent. It has a major effect on landscapes and on economic activity. The soils of the midlands are productive soils largely because of a substantial loess admixture. This addition of fresh Quaternary rock material raises the silt content, and thus improves the texture and the nutrient status. But the presence of the loess is not obvious. We lack the large deposits that are a feature of Asian and American loess regions, and as a result the study of loess has been neglected, or at best disjointed. It should be possible to produce a conceptual model that describes the arrival of some aeolian loess into the region, and its subsequent reworking and re-deposition, to explain the deposits and landscapes that we currently observe. This is attempted in an outline and speculative version in this paper. Besides bringing great advantages to farmers and brick-makers, the loess does cause a few problems. The classic engineering problem is hydroconsolidation and subsidence (Rogers et al, 1994), and there are thicknesses of loess in certain places where this can be a problem. Problems were anticipated at the proposed airport in the northern part of the Thames estuary (classic brickearth country) and this initiated a serious study of the engineering geology of loess in Britain.

Northmore et al (1996), in their study of the loessic brickearth in south Essex, found a thickness of around 8 m - quite impressive loess deposits. Loess of this thickness could contain a palaeosol (or two) and perhaps contribute to Quaternary climatic reconstructions, or it might suffer from hydoconsolidation and subsidence and prove to be a hazard to construction. This is real loess, not just a sprinkling of brickearth, and a widespread unified study is required to give a complete overall picture of

Figure 1. Loess exposed in a shallow brick pit at Ospringe, near Faversham. About 2 m of leached brickearth is worked to make distinctive orange bricks, while 2 m of unleached material is left in place.

this hitherto relatively neglected loess region. In truth, loess has not been neglected in terms of the number of investigations and papers published (see Catt 1977, 1985, 1988), but until now there has been no unifying theme and no conceptual framework for the loess deposits of S E England.

A terminological problem needs to be tackled before progress can be made. We can use the term *loessic brickearth* (as recommended by Smalley, 1987) to refer to the material under investigation. When the Geological Survey mapped S E England in the nineteenth century, they used the local term *brickearth* to describe certain silty, loamy, superficial deposits, many of which now turn out to be loess. Unfortunately the term brickearth is not specific, and it does not fit in with international usage. However these deposits cannot simply now be called loess, because virtually all of the literature relating to them uses brickearth. So a compromise is called for, and the term *loessic brickearth* is used. Defined at length by Smalley (1987), this means deposits which we think are loess, which coincide with deposits called *brickearth* or *head brickearth* by the Geological Survey.

The loess fall considered is associated with the Devensian glaciation. We assume, like Fookes & Best (1969), that the ice sheet of this stage was responsible for the provision of the loess material. We will also assume that loess material was delivered to southern Britain by a loess fall that provided a modest overall cover of about 200-500 mm thickness. This is the starting event for our simple developmental model. The consequences of this modest loess fall might be predicted, and could be compared to the loess landscapes that we observe today. Some of the wider consequences are some thin primary loess deposits (like those on the South Downs which, despite much erosion, still provide farming livelihoods), some loess material added to soils (Catt et al, 1971) in Norfolk, the *Chalk Heath* soils of Perrin (1956), and larger deposits resulting from fluvial transportation and second phase aeolian deposition (Fig. 1). This loess also accounts for a modest brick industry, a few subsidence problems, some good-quality agricultural soil, some confusion because it was locally called brickearth, and some opportunities for British scholars to study loess.

Actually, it may be the case that the loess in southern and midland Britain is of much greater consequence than has been realised to date. It is not a spectacular deposit in any of its manifestations, but it has influenced land-use and a whole way of life since pre-Roman times. It has lacked appreciation and full-scale scientific investigation because it falls into a sort of conceptual and intellectual gap. The geologists were, by and large, dismissive of these loamy surficial deposits and it offered no stratigraphic data for the Quaternary investigators; it did not provide major problems for the engineers; and, in the region around London, much of it had been turned into bricks before scientific interest was kindled. Loess needs to be seen as a major influence on life in an interesting English region, it provides the soils on the chalk (that arrive from above, and not from below), it may provide much of the silt for the Fens and Wash region, and it is involved in some interesting fluvial processes in the Weald and the Hampshire Basin.

Loess in Britain

The loess literature is traditionally large, complex, difficult, written in many languages, and touching on many topics and regions - but it is fascinating in total and it repays study. Woldstedt said that it was *ungeheuer*, which is usually translated as monstrous, but we see it as a rich resource. There is literature on the British loess relating to geology, geomorphology, sedimentology, stratigraphy, archaeology, pedology and more.

It appears that the bulk of the scientific papers and journal contributions about the southeastern brickearths were published in the Proceedings of the Geologists' Association. As it happens, the area of interest demarcated by the Association, ie S E England, is the region where many interesting deposits of loessic brickearth are concentrated (Fig. 2). Some classic papers have appeared in the Proceedings, including Kennard (1944), Palmer & Cooke (1923), Bull (1942) and Burchell (1956), together with many others, including Lill & Smalley (1978).

Two local journals also carried important information - the Essex Naturalist and the South-Eastern Naturalist and Antiquary. They flourished in the golden age of the amateur naturalist and geologist, and much useful material was published in their pages - and subsequently was not appreciated as fully as it should have been. A thorough study of the collected volumes of these two publications would reveal some loessic treasures. Wooldridge (1932) published a classic paper in the

W1	Loam of N E Norfolk, in front of Cromer moraine
W2	Loam plateau of the Tendring Hundred in Essex
W3	Southend loam plateau
W4	Taplow terrace with its brickearth covering (in S W Essex, London and S Middlesex)
W5	Sussex levels
W6	The great Medway brickearth modifying heavy clay (in Medway valley from Tonbridge to Maidstone)
W7	High-level brickearth on Chiltern plateau (particularly at the eastern end in Hertfordshire)
W8	E Kent between Chatham and Thanet
W9	On the Thanet Sands
W10	On the Hythe Beds as far west as Sevenoaks
W11	On the Bargate and associated beds in W Surrey
W12	On parts of Hythe & Sandgate Beds (Rother Valley)

Table 1. Loess regions of England (Wooldridge, 1932).

latter on soil and civilization in S E England and produced what might be the definitive list of loess regions; these are be listed and numbered for reference purposes in Table 1. Wooldridge describes these as 'loamy soil regions' and suggested that they are associated with loess: "Much of the true loam and brickearth, both at high and low levels, compares closely, both in origin and character, with the 'loess' and 'limon' of the continent".

The three key papers in engineering geology are Fookes & Best (1969), Derbyshire & Mellors (1988) and Northmore et al (1996). Engineering interest was much stimulated by a proposal to build another London airport in southern Essex, and this provoked widespread investigations by the Geological Survey, many of which were eventually reported in Northmore et al (1996), a comprehensive and useful paper. A major airport in the Thames estuary would generate renewed interest in the loess/brickearth in the region, but this now seems unlikely. An interesting study has just been completed by Fall (2003) at Portsmouth which indicates the growing level of interest in loess/brickearth. He studied the heavy mineral information and found it to suggest a single distant source for the material, a result that should be compared to the investigations by Eden (1980).

The geomorphological model for loess

This model can operate either as a simple thought experiment or as a detailed GIS system, but it is really the former. It starts with a small, even loess fall covering all of southern and midland England, falling on various slopes and in a range of drainage basins. Post-depositional movement of this loess material can be predicted, as it is carried down slopes and into rivers, and into larger rivers, and on to flood plains, and is then blown inland and soliflucted back again.

Using the old PTD system (Smalley, 1966) we can follow two loess particles. One falls into the catchment of the Arun, in the Weald (Table 2). The other falls into the catchment of the Thames, up near the headwaters (Table 3). The so-called PTD system was simply a way of trying to sort out the significant processes and events that determine the dynamics of the loess deposit formation process. P actions were provenance actions, related to particle formation processes (e.g. glacial grinding); T actions were transport actions; and D actions were those related to deposition. The basic idea has been developed and much improved by Wright (2001).

For initial manipulation we assume that the D1 deposit is an even cover of perhaps 200-500 mm - a modest loess fall; farmers on the South Downs appear to operate with a soil cover of about this thickness, while deep erosion gullies expose the underlying chalk. This D1 deposit provides the silt material that was mapped by Perrin et al (1974), mostly falling into zones I and II (Fig. 2). The sequence of events in Table 2 leads to the formation of the loess deposits on the Sussex coast. The initial assumption of the modest loess fall, with a series of apparently reasonable subsequent events, produces a loess deposit where one is currently observed. Actions in the Weald will be further considered in a

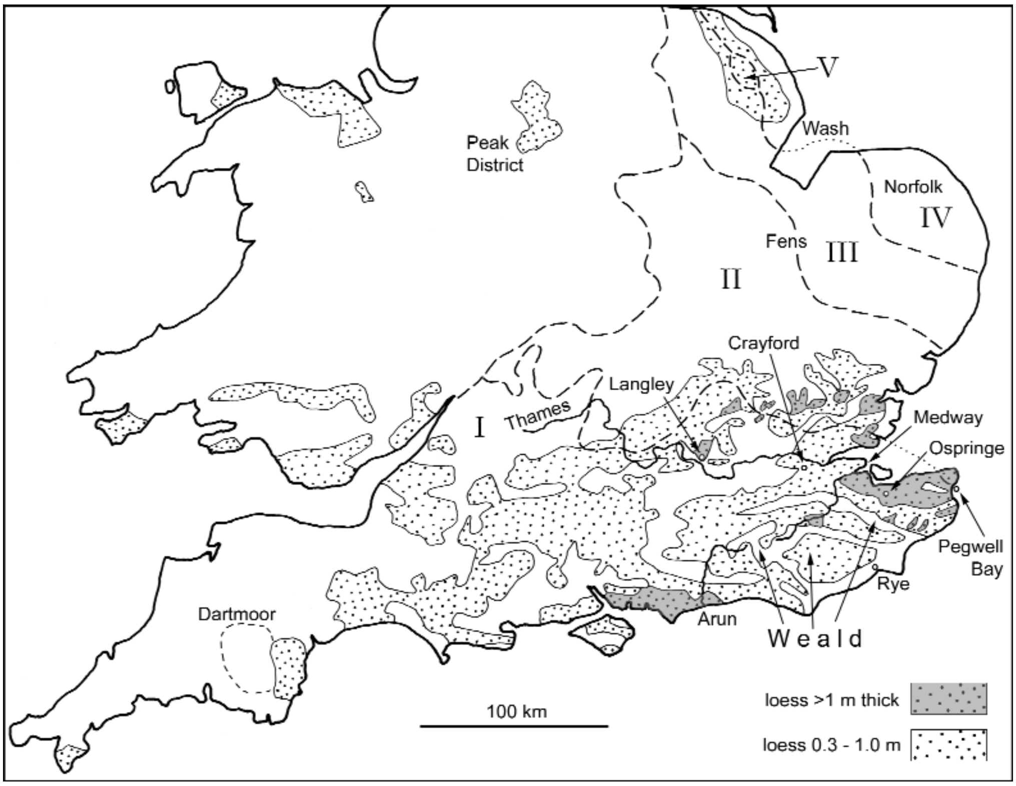


Figure 2. The distribution of loess across midland and southern England. The areas of thin and thick loess are taken from Catt (1988). The provinces of Perrin et al (1974) identify the aeolian deposits that formed away from the Devensian ice sheet; zones I and V have mainly loess, zone III has mainly cover sand, while zones II and IV contain both loess and the cover sand.

later section. The Weald makes a good region to study hypothetical loess activities because it represents an almost closed system, and is surrounded by what appear to be original D1 deposits.

The situation for the loess in the Thames catchment is more complex, and more speculative (Table 3). Its first three stages are the general case, and the same as in Table 2. The Thames might be seen as a classic loess providing river, but the associated deposits are too diffuse and ill-defined for this vision to be really convincing. If the modest loess fall occurred, the Thames has access to loess material in the same style as that of the great loess rivers like the Danube and the Mississippi, and can therefore produce similar downstream deposits. This idea is explored in a later section.

The geomorphological model distributes loess material over the map of southern and midland Britain, and the genetic processes can be outlined by a distribution tree diagram (Fig. 3). This is a simple speculative tree diagram that focuses on the main line of loess deposit development after the original modest fall. Various speculations grow from this distribution network. Loess material deposited in midland England, which avoids the Thames catchment, can be carried to the north and east by streams draining into the Wash, and can provide much of the silt material for that part of England. Loess falling into the Rother catchment can provide silt for the silting up of the port of Rye. Silt has to come from somewhere, and much of it is covered by this geomorhological model.

P1	particles are formed by cold phase glacial action; the actual formation mechanism is not important, all the model needs is a supply of loess material
T1	loess material is blown in a generally southwards (or south-west or even west) direction Hobbsean anti-cyclonic winds (Lill & Smalley, 1978)
D1	deposits over midland and southern England
D1a	material for the southern deposits; silt deposits in the Arun catchment, in the W Weald
T2a	carried into the River Arun by slope wash; small channel fluvial transport
T3a	carried by the River Arun in suspension, out through South Downs gap and into coastal region
D2a	deposited on coastal plain, near to the Arun mouth
T4a	blown into final position
D3a	loess deposit formed; it relates to the W5 deposit of Wooldridge (Table 1), and to part of the Sussex and Dorset coast deposits on the Catt map (Fig. 2)

Table 2. Progress of a loess particle that falls in the Arun catchment in the Weald.

The Thames, Mississippi and Danube

There is a huge difference in scale between the Mississippi-Missouri river system and the Thames, but there are some interesting similarities. The headwaters of both gather in a region associated with glacial cover, and, in each case, glacial sediments can be carried into the mainstream. The Missouri gathers loess material near the Canadian border and transports it south. It flows between Nebraska and Iowa and has provided loess for both states. It carries material further south, joins the Mississippi and delivers large quantities of material for the delta construction and the loess deposits of the lower valley (those described so provocatively by Russell, 1944). The main American loess system depends on the delivery of loess material into the Mississippi drainage basin, and its secondary redistribution by fluvial, and then aeolian means.

The Thames picks up loess material, provided by glacial action, and delivers it to the estuary, where it contributes to loess deposits in south Essex and north Kent. On the Kent side, the Thames material might be seen as augmenting Wealden material that has been collected by the Medway system and delivered into the Swale region (south of Sheppey). Essex and Kent act as small-scale versions of Nebraska and Iowa - the loess-carrying river flows between them, and it contributes loess to both regions, via the 'all directions' loess distribution mechanism of variable winds (Handy, 1976). With loess deposits 8 m thick in S Essex (Northmore et al, 1996), we need to allow for more than a tiny amount of material to be delivered into this loess zone.

The Mississippi-Missouri system provides the classic example of the interaction of a great river and a loess region (Smalley, 1972), but another notable example is the Danube (Smalley & Leach, 1978). The Danube is the great loess-transporter of eastern Europe. It picks up material from the Alps, the Carpathians and other mountainous regions in its basin, and supplies it to regions to the east. As it flows into the Black Sea it has delivered material to

P1	particles are formed by cold phase glacial action
T1	loess material is blown generally southwards
D1	deposits over midland and southern England
D1t	deposits in Thames catchment, headwaters region
T2t	carried into River Thames by slope wash and streams. Short transport may deliver it to the Langley silts
T3t	carried by River Thames into estuary region
D2t	deposited on northern bank as a floodplain deposit
T4t	blown inland to form loess
D3t	loess deposit formed, perhaps in S Essex

Table 3. Progress of a loess particle that falls in the headwater part of the Thames catchment.

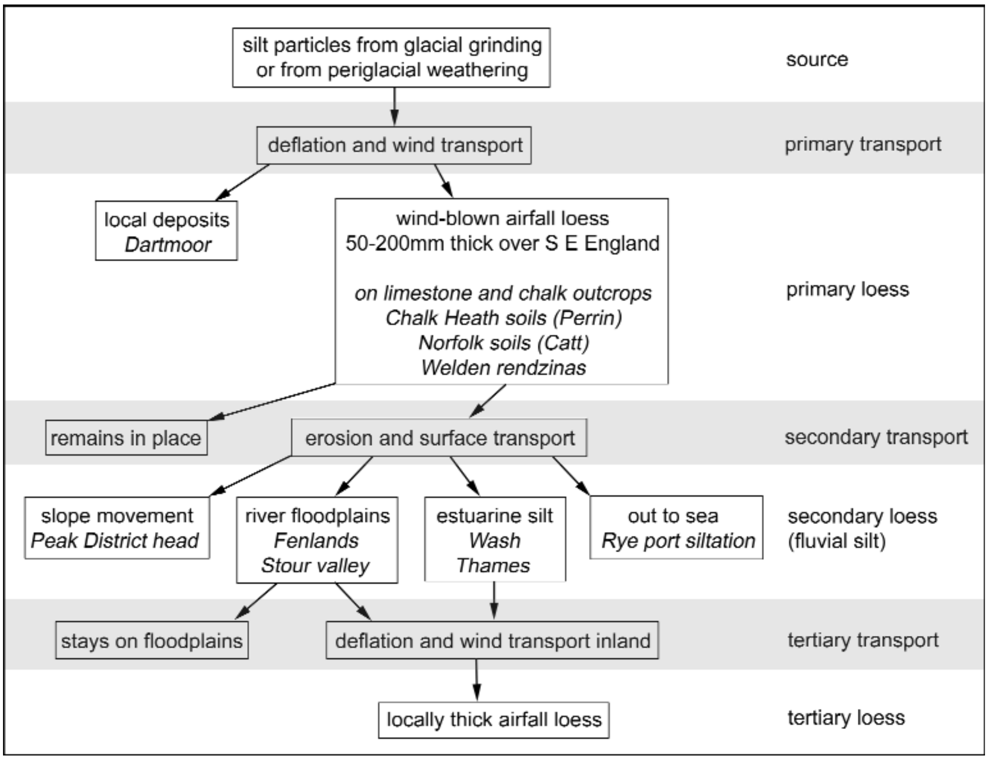


Figure 3. The geomorphological model for the loess of England, presented as a tree diagram that links processes and materials. Selected examples are in italic script.

Bulgaria and Romania, to loess zones north and south of its course. Bulgaria and Romania can serve as larger analogues for Kent and Essex.

It is clear that the Thames fits well into the classification of the world's great loess-carrying rivers; it is on a small scale, but this does not make it any less interesting or significant. If loess material is delivered into a particular catchment, the associated river serves to concentrate the material, to provide major intermediate transportation, and subsequently to lead to a downstream loess deposit. This is true for the Mississippi, the Danube and the Thames, and also for the River Dart, which carries silt from Dartmoor to provide a loess deposit in Torquay.

The Weald as a loess trap

The main line of the distribution network in our genetic model delivers material into the Thames basin. In the same initial modest loess fall, material accumulates in the Weald and on the chalk lands around the Weald. Burrin (1981) offered a study of loess in the Weald, but it had a fairly narrow focus and concentrated on the petrology of some of the southern sediments. The Weald offers a fascinating region for the study of loess deposition, transport and re-deposition. The loess, in its Wealden setting, provides the most interesting and challenging aspect of the study of loess in S E England, and is a good test for the geomorphological model.

The consequences of the initial modest loess fall into the Weald depend on the timing of the event. A fairly recent loess fall would yield widespread deposits of primary loess. A loess fall that occurred more than 10,000 years ago could leave a Weald virtually devoid of loess today but with concentrated deposits placed where fluvial movement had positioned the material for a final short aeolian re-deposition. In this longer-term vision, there should be deposits associated with rivers that flow out from the Wealden region. This is the genesis of the south coast deposits, associated with rivers such as the Adur and the Arun, and the north Kent deposits associated with the Darent and the Medway. The Medway provides a classic case of loess transportation; it dominates the drainage of the Weald and it is no surprise that near the mouth there are major accumulations of loessic material. The Medway augments deposits that might have been formed by the Thames, and provides one of the best known and most commercially viable brickearth regions. Loess falling into the Darent and Cray catchments may also have provided material for the famous Crayford Brickearths (Kennard, 1944; Smalley, 1984).

The Pegwell Bay deposit is the most famous loess deposit in Britain (Fig. 4). Some classic papers refer to it (Pitcher et al, 1954; Weir et al, 1971; Dalrymple, 1969; Fookes & Best, 1969). We perceive it as a Stour deposit, fitting neatly into the geomorphological model. The concentration of material at the coast occurs because the Stour delivers material out of the Weald trap, into Pegwell Bay. Material is blown into position from the seaward side; Shearman (pers.comm.) reported that

Figure 4. Exposure of brickearth at Pegwell Bay, with the darker decalcified horizon overlying the paler unleached material that has the calcite needles bridging between the silt particles.

marine organisms have been observed in the Pegwell Bay deposit. A distinctive feature of the Pegwell Bay loess is the diagenetic variation within its structure (Fig. 5).

The soils of the Weald were described by McRae & Burnham (1975), but, from the loess point of view, the most interesting soils are perhaps just outside the Weald proper. Rendzina soils are indicated on the McRrae & Burnham soil map all around the fringe of the Weald. These are classically formed by aeolian deposition of silty material. They are A-C soils where the A horizon sits directly on the chalk C horizon. Perrin (1956) observed the same situation with the Chalk Heath soils of East and West Sussex. These are remnants of the original modest loess fall, and they sit high in the geomorphological model (Fig. 3). In the Weald trap the loess has been extensively moved and redeposited. Burrin (1981) quoted Catt (1978) to the effect that reconnaissance of large areas of the Weald, especially the Weald Clay outcrop, revealed insignificant amounts of loessic material. Within the geomorphological model, most of the initial Weald deposit that arrived at the same time as the rendzinas on the rim would be moved into rivers and carried away, while some was re-deposited, but some was carried into the estuaries and some out to sea.

The rendzina soils on the Weald rim, and the Chalk Heath soils of Perrin play an important role in the study of loess in S E England. Their presence establishes the occurrence of a widespread and significant loess fall, their silty nature is explained by the operation of this modest loess fall. “The commonest rendzinas have a brownish colour and a considerable silt content, attributed to loessial contamination” (McRae & Burnham, 1975). The deposition of the loess on calcareous materials allows a stabilising effect to develop. In the soil classification of Avery (1973), used by McRae and Burnham, the rendzinas are in the lithomorphic soil section, with a topsoil resting directly on bedrock or on a C horizon. In the USDA Soil Taxonomy system, they fit uncomfortably into the mollisol order. The rendzinas are difficult to classify because of their carbonate content (Fig. 5) - which caused problems in early attempts to define loess. Most are the result of airfall material arriving on a rocky substrate. The lack of mineral soil material derived by weathering of pure carbonate rocks leaves airfall loess as the major soil material - accounting for the obvious correlation of loess distribution (Fig. 2) with the outcrops of the Carboniferous limestone and the Chalk. The loess is not a contamination, but is the key ingredient in the formation of these soils.

Crayford and the fossil collectors

In his definitive study of the Crayford brickearths, Kennard (1944) concentrated on the vertebrate and mollusca fossils, and rather neglected the interesting material in which they were embedded. The collectors worked over the Crayford region at the end of the 19th century. Two factors worked together here - a golden age for fossil collectors and amateur geologists, and the widespread exploitation of the N W Kent brickearths to build the London suburbs. When this region was mapped by the Geological Survey in the 1890s some of the pits were already worked out. The underlying strata are shown as visible on some maps because all of the superficial Pleistocene material has been removed.

Upper Brickearth, including the ‘trail’ up to 6m thick
Lower Brickearth (up to 9 m thick)
including the Corbicula Bed (up to 1.5 m thick)
Basal sands and gravels: the ‘Crayford Gravel’ up to 4m

Table 4. The brickearth sequence at Crayford (after Kennard, 1944).

Kennard collected at Crayford between 1892 and 1900, until his attention was diverted by the reopening of the brickpit at Grays in Essex, the opening of the sections in London Wall and Dierden's Pit at Swanscombe, Kent, as well as excavations for the new reservoirs at Tottenham. Leach (1905) reported a GA excursion to Crayford and Erith and described five new sections; the deposits at Crayford were well described by Whitaker (1889). Chandler and Leach (1912) described another GA excursion, and later Chandler (1914) described the whole Crayford brickearth environment.

Kennard described the Crayford series, with three well-marked divisions (Table 4). The mollusca from the Lower Brickearth were very largely freshwater species with *Sphaerium corneum* and *Psidium ammicum* predominating. The Upper Brickearth has yielded few fossils, but has been the subject of much speculation. It was proposed that the Upper Brickearth was "probably a weathered and decalcified loess" (Bull, 1942) and this is essentially the position that we adopt. But there are questions that need to be asked. Was the Crayford brickearth part of a large spread of brickearth that covered much of the land adjacent to the Thames estuary? Is the deposit essentially a Thames deposit, or is there a significant contribution in the Crayford region from material deposited in the Cray and Darent catchments? Given the modest loess fall, where did the thick Crayford material originate? Comparison with the lower reaches of the Danube suggests that this is a true loess. Arguing by analogy, the Kent loess relates well to the Bulgarian loess. The Thames, like the Danube, is a river with terraces; we might reasonably expect loess on several terraces.

The Langley Silts

West of London's Heathrow Airport, the Langley Silt Complex overlies the Taplow Gravels (as do the Crayford Brickearths). This silt is probably largely primary loess (Fig. 3). It was studied by Rose et al (2000) who suggested that, as it overlies a Last Interglacial (Ipswichian) soil, it could provide evidence for sedimentation and soil formation during parts of the Last Glacial. The material provides new evidence for depositional and periglacial processes that occurred over this period of time in low-relief, valley-floor locations in southern England. The airport site also provides evidence of soil formation during the Devensian Late-glacial, reinforcing existing proposals for the development of an argillic soil horizon during the Late-glacial and Windermere Interstadial. Rose et al (2000) propose that there is indirect evidence for loess formation in the region during the Late-glacial Younger Dryas.

The silts are part of the sedimentary unit defined by Gibbard (1985, p57) as the Langley Silt Complex, which is interpreted as being formed by a

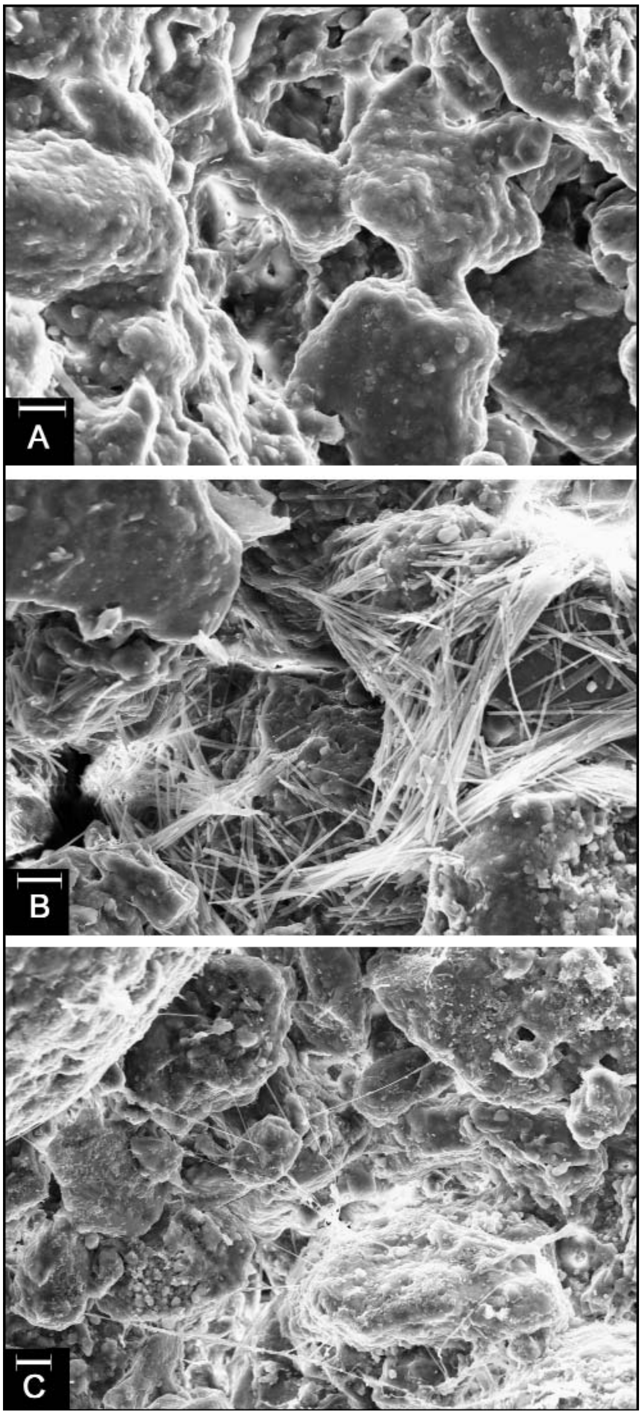


Figure 5. Scanning electron micrsocope (SEM) images of brickearth from Pegwell Bay. On each image the white scale bar is 10 microns long.

A: 6 Brickearth with well-developed clay bridges linking adjacent quartz silt grains. The grains are heavily coated with a gelatinous film of clay similar to, and contiguous with, the clay forming the grain-bridging fabric.

B: 2 Brickearth with needles and fibres of calcite cement forming a coating on clay-coated silt grain surfaces, and bridging pore throats.

C: 4 Brickearth with very fine and delicate fibres of secondary authigenic calcite. These rest on the surface of, and bridge between, clay-coated silt grains on the face of a large void (possibly a root cavity).

variety of processes including direct wind action, slope wash and fluvial reworking. The material has been regarded variously as loess, colluvium and overbank sediment, or mixtures of each (Gibbard et al, 1987). These silts comprise classic brickearth, and are around 2-3 m thick. The location of the Langley silts is north of the Thames, 5-6 km from the river (Fig. 2). The Wey and the Mole, after traversing the North Downs in their respective gaps, join the Thames on either side of the Heathrow site.

How do the Langley silts fit into our model? Here is a relatively substantial brickearth deposit, subjected to wide-ranging and careful investigations. Yet in some ways the Crayford question remains - is it largely aeolian or fluvial? How loessic is it? In terms of particle size distribution it compares well to western European loesses. It looks like primary loess material, within zone 1 of Perrin et al (1974). Its presence and nature will doubtless attract further investigations but it looks as though, in a simple overall sense, it fits our geomorphological model. The silt in the Thames valley, like the silt in the Chalk Heath soils, should be loessic.

Figure 6. Blocky joints distinguish the weakly cohesive brickearth in a sample 600 mm high from the face of the Ospringe brick pit.

Discussion and conclusions

From all the writings on loess in southern Britain, it is possible to assemble a rough overview of a possible deposition scenario. There are enough indications of the observation of loess for it to be fairly obvious that there was a substantial, but fairly thin, cover of loess material delivered in the later phases of the Pleistocene period. The geomorphological model assumes that the development of the deposition environments after the last significant loess fall can account for most of the deposits in S E England. Some material is still in its original position as primary loess (Figure 3); evidence for this is found in the rendzina soils on the Weald rim, and in Perrin's Chalk Heath soils. The thick, substantial deposits on the Catt map (1988) are the result of subsequent sedimentological events.

Interesting events focus on the Weald. It is possible that the Wealden loess operations are unique, that nothing similar is observed elsewhere in the world of loess. The modest British loess deposits may have something unexpected and significant to offer the world of loess scholarship. The idea of the loess trap in which material is initially deposited, to be later moved and re-deposited to form thicker deposits, is a development of most loess deposition scenarios. It has a certain similarity to the proposals for the North China deposits by Smalley and Krinsley (1978). They proposed that the northern deserts acted as loess material reservoirs that supplied material for downwind deposits. The particles did not form in the deserts, they were simply stored there (a conjecture whose validity was subsequently proved by Sun Jimin, 2002). Here we have the Weald as a loess store, but only a short-term loess store, as the material from the modest fall is quickly concentrated by the Wealden rivers and delivered through Weald river gaps to form coastal deposits. The Chinese deserts are part of a dynamic system in which silt material is delivered from mountains to deserts fairly continuously; in the Weald the system is more or less closed and the one-off modest fall has not been repeated. Thus much of the loess has disappeared from the Weald interior (Burrin, 1981) and now forms the Dorset coast deposits and the Pegwell Bay deposits, and perhaps contributes to the North Kent deposits.

There is a benevolent excess of silt in southern and midland Britain, which contributes to the agricultural excellence of the soils. It also provides good bricks and may have affected the concentration of ancient brick buildings in the south-east part of England (Smalley, 1987). In recent geomorphological terms it may have contributed to the nature of the ground in the lowlands near the Wash, and the silting up of Rye Harbour may have happened because of the abundance of silt in the Rother catchment of the Weald: silt must come from somewhere.

Bull (1942) made some interesting observations over sixty years ago - "During the early and middle parts of this last glaciation, brickearths were spread over the country to the south of the ice-sheets. These brickearths have received much attention at Crayford, where they overlie the Taplow gravels. At Crayford the lower brickearth is about 20 feet thick and contains *Elephas primigenius*, *Rhinoceros antiqitatis*, and *Ovibos moschaties* indicative of a cold steppe climate." Bull describes the setting for the primary loess deposition, and he points to Crayford as a significant site. Two years earlier, Bull was involved in what was probably an even more significant observation on the primary loess. Kircaldy and Bull (1940) stated that "A further complication, whose widespread occurrence does not appear to have been previously recognized, is that the whole country is mantled with a sheet of fine grained unstratified brown loam of a loess-like character, which is commonly one to three feet in thickness and occurs at all levels over the area to the north of the Downs." Here is a clear statement about the existence of widespread loess; strange that it did not provoke systematic and widespread study of loess in southern Britain, but it did not. The sixty years since Kirkaldy and Bull have yielded all sorts of isolated studies, some of great scholastic and scientific virtue, but providing no overall sedimentological and geomorphological picture of the formation and reformation of the main parts of the British loess. The geomorphological model is an initial step towards providing a framework for study; all loesses should have a position on the tree diagram (Fig. 3), and the mainline of the tree leads to the major deposits, those marked solidly on the Catt map of 1977.

Using the Langley silts, Rose et al (2000) contrived a reconstruction of climate and environmental change in southern Britain from the Last Interglacial (Ipswichian or Eemian, Oxygen Isotope Stage OIS 5e, 132-123 ka BP) through to Holocene (OIS 1, 11.5 ka BP to present). By using the brickearths rather than successions in river sediments a considerable step forward in Quaternary palaeoclimatology and sedimentology has been achieved, and the Rose et al paper represents significant progress in loess research in southern Britain. It is a matter of regret that the Crayford Brickearths, which could have yielded similar data, are lost under a collection of playing fields and housing estates. Those with a responsibility to the geology in southern and midland England need to encourage the location and preservation of major sites with brickearth and loess - now that their potential has been realised, sixty years after Kirkaldy and Bull (1940). As the palaeoclimatic significance begins to be appreciated, there is now a need for an overall sedimentological model to provide a framework for further studies.

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Warwickshire's Jurassic geology: past, present and future

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Abstract. Jurassic strata were extensively quarried in Warwickshire, during the 19th and early to mid 20th centuries, but much of the succession is now poorly exposed. Selected sites are afforded statutory and non-statutory protection as Sites of Special Scientific Interest and Regionally Important Geological and Geomorphological Sites. Warwickshire's Jurassic history is outlined, demonstrating the value and purpose of the currently protected sites as repositories of stratigraphic, palaeontological and palaeoenvironmental data.

The fields, hills and villages of southern and eastern Warwickshire, central England, conceal a marine sedimentary succession of Lower and Middle Jurassic age (Figs 1 and 2). This is at least 400 metres thick (Williams & Whittaker, 1974) and spans about 40 million years of Earth history. The beds demonstrate a gentle regional dip towards the south-east and are affected by numerous normal faults (Institute of Geological Sciences, 1983), as well as cambering, landslipping and periglacial cryoturbation (Fig. 3). Unconsolidated Quaternary deposits locally cover the Jurassic sediments, notably in the Dunsmore area of eastern Warwickshire (British Geological Survey, 1984).

The latest Triassic-early Jurassic Wilmcote Limestone Member (Blue Lias Formation, Fig. 2) locally forms a well-marked dip slope in the south-west of the county. The widespread early Jurassic Saltford Shale Member, Rugby Limestone Member and Charmouth Mudstone Formation give rise to the clay lowland agricultural region of the Warwickshire Feldon. Siltstones and sandstones of the Dyrham Formation form the gorse-clad slopes of prominent hills and escarpments, principally within the so-called Cotswold and ironstone fringes, south and east of the clay lowlands (Warwickshire County Council, 1993). Many of these are capped by the Marlstone Rock Formation - an ironstone still quarried at Edge Hill (Fig. 1) as 'Hornton Stone'. Edge Hill reaches a height of around 200 metres above sea level. In the south, a number of hills are capped by Middle Jurassic sandstones and limestones and reach around 250 metres above sea level (Fig. 4). These fringe the northern Oxfordshire uplands to the south and south-east, and the Gloucestershire Cotswolds to the south-west. The most picturesque villages in southern Warwickshire owe much of their character to the use of locally quarried Jurassic building stone, notably the rusty brown ironstone of the Marlstone Rock Formation.

The Vale of Moreton Axis is mapped as a north-south line running through the south-western part of the county (Sumbler, 1996; Fig. 1) and coincides with well-marked lateral facies and thickness changes in the Jurassic succession. The Axis is thought to be underlain at depth by a zone of steeply dipping basement faults that must have formed a structural hinge throughout much of Lower and Middle Jurassic time (Horton *et al.*, 1987). This separated the London Platform and East Midlands Shelf in the east from the Severn (or 'Worcester') Basin in the west (Sumbler, 1996). West of the Axis, in south-western Warwickshire, the Lower Jurassic succession features a laminated, calcilutite-dominated Hettangian development (Wilmcote Limestone Member), a more arenaceous facies development of the Pliensbachian Marlstone Rock

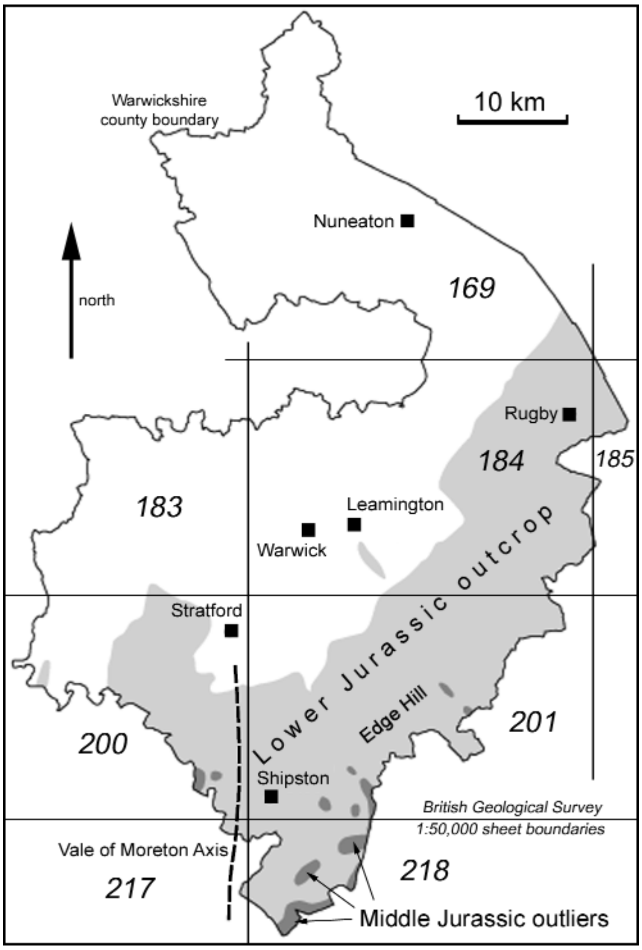

Figure 1. Outline map of Warwickshire, central England, showing Jurassic outcrop.

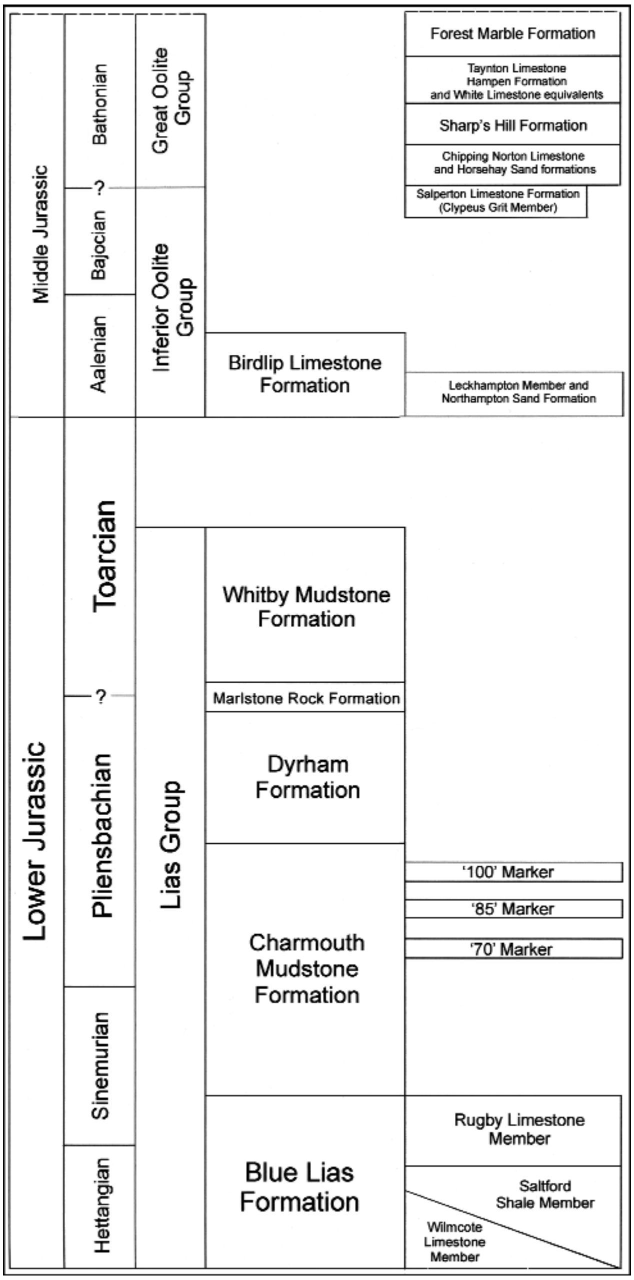

Figure 2. Outline of the Lower and Middle Jurassic succession in Warwickshire, central England (adapted from Sumbler, 1996; Barron *et al.*, 1997; Cox *et al.*, 1999; Ambrose, 2001 and Cox & Sumbler, 2002).

Formation, and sandstones forming the highest part of the Toarcian Whitby Mudstone Formation (Williams & Whittaker, 1974).

The Wilmcote Limestone is absent to the east of the Axis in southernmost and south-eastern Warwickshire (Ambrose, 2001). Here, a minor chronostratigraphic hiatus commonly separates latest Triassic from earliest Jurassic rocks that overstep onto the London Platform to the south-east (Donovan *et al.*, 1979; Old *et al.*, 1987). Where preserved in south-eastern Warwickshire, time equivalents of the Hettangian upper Wilmcote Limestone are developed largely as mudstones. Ambrose (2001) raised the possibility of localized fault control on their deposition (Princethorpe Fault north-east of Royal Leamington Spa). Higher in the succession, the Marlstone Rock Formation is developed here as a calcitic sideritic chamosite oolite (up to around 7.5 m thick), weathering to limonite. This was formerly quarried as iron ore within the Banbury ironstone field to the south-east (Whitehead *et al.*, 1952; Edmonds *et al.*, 1965). Nowadays it is quarried for ornamental and building purposes (as Hornton Stone), and as a source of aggregate.

The Middle Jurassic is represented to the west of the Axis by oolitic and bioclastic limestones of Aalenian age (Birdlip Limestone Formation; Barron *et al.*, 1997, 2002; Fig. 2). East of the Axis, the Aalenian strata are overstepped by the Clypeus Grit Member of the Upper Bajocian Salperton Limestone Formation (Cox & Sumbler, 2002) that ultimately rests on the Whitby Mudstone. There, the basal, arenaceous, Leckhampton Member of the Birdlip Limestone Formation is preserved, replaced further east by the Northampton Sand Formation (Horton *et al.*, 1987; Barron *et al.*, 1997). The Clypeus Grit is overlain by Warwickshire's youngest 'solid' geology - a Bathonian (Great Oolite Group) carbonate-dominated succession ranging from the Chipping Norton Limestone Formation possibly up into the Forest Marble Formation (Edmonds *et al.*, 1965; Horton *et al.*, 1987; Fig. 2). Warwickshire's Jurassic outcrop lies immediately north-west of Arkell's (1947) Oxfordshire Shallows that flank the

Figure 3. Rugby Limestone (Blue Lias Formation), periglacially cryoturbated in the Spiers's Farm excavation, Southam Cement Works (SP425635).

Figure 4. Aerial view of the Burton Dassett Hills RIGS (SP3952-3951). The hills are capped by the Pliensbachian up to Aalenian Marlstone, Whitby Mudstone and Northampton Sand formations. The old quarry workings are within Marlstone Rock Formation ironstones (photo: John Ball of Middlemarch Environmental).

London Platform to the south-east (also see Sylvester-Bradley, 1968).

At the broadest scale, the Lower and Middle Jurassic of Warwickshire comprises two overall upward-shallowing marine successions (Hallam & Sellwood, 1976; Holloway, 1985). These are superimposed upon a picture of general sea-level rise, following the earliest Jurassic eustatically driven marine transgression (Hallam, 2001). The succession comprises ammonite-rich mudstone facies (Blue Lias, Charmouth Mudstone and Whitby Mudstone formations), passing up into shallow-water sandstones, limestones and ironstones (Fig. 2). The earliest shallowing episode culminated in the Marlstone Rock Formation and is thought to be due to regional hinterland and/or sea-bed uplift. The second concluded with deposition of Middle Jurassic limestones in the Severn Basin, and the nearshore marine Northampton Sand and succeeding carbonate-rich strata on the adjacent shelf (Fig. 2). This has been attributed to upwarping of the central North Sea region (Hallam & Sellwood, 1976).

Southern Britain is thought to have lain about 10° south of its present latitude during the Jurassic (Hallam, 1993). Thick-shelled molluscs, corals, chamositic ironstones and oolitic limestones within the shallowest water facies show that prevailing climates were both warm and humid (Hallam, 1975). The diverse benthic faunas, shallow-water ichnofossils and tempestites that occur throughout much of the succession (Edmonds *et al.*, 1965; Clements, 1975; Horton *et al.*, 1987; Radley, 2002 and unpublished observations), suggest that central England's Jurassic seas were not much more than a few tens of metres in depth (Hallam, 1975, 1997).

The past

During the nineteenth and early twentieth centuries Warwickshire's Jurassic outcrop was riddled with quarries and pits, extracting rock as raw material for bricks, aggregate, building stone and ornamental stone. Additionally, freshly excavated railway cuttings provided some important sections (Woodward, 1893). This was the heyday of local Jurassic investigation. Many of the exposures and their palaeontology were documented by geologists such as the Rev. Peter Bellinger Brodie (*e.g.* 1868, 1874), Thomas Beesley (1877), John Judd (1875), Horace Woodward (1893), Edwin Walford (1899), Beeby Thompson (1898) and Linsdall Richardson (1922). Comprehensive bibliographies of the older works are provided by Arkell (1933), Edmonds *et al.* (1965), Williams & Whittaker (1974), Horton *et al.* (1987), Old *et al.* (1987, 1991).

Over the last fifty years, the larger quarries have attracted the attention of further workers who have continued to document and interpret their stratigraphy, palaeontology and palaeo-environments (Howarth, 1958; Hallam, 1968; Clements, 1975, 1977; Weedon, 1986; Old *et al.*, 1987 and Wignall & Hallam, 1991). The lithostratigraphic scheme in current use (Fig. 2) has been developed by the British Geological Survey (Old *et al.*, 1991; Barron *et al.*, 1997; Cox *et al.*, 1999; Ambrose, 2001). Ammonite biostratigraphy was established for the Lower Jurassic by Dean et al. (1961), Getty & Ivimey-Cook (1980) and Howarth (1980a,b) and for the Middle Jurassic by Parsons (1980) and Torrens (1980).

The present

Only a handful of quarries remain in work at the present day. Lower Jurassic (Blue Lias Formation) mudstone and limestone is still exploited for the Rugby Cement industry and the Marlstone is currently quarried at Edge Hill for aggregate, building and ornamental purposes (see above). Many disused quarries occur, but their rock exposures are frequently obscured by talus and vegetation, or are flooded. Exposure is otherwise poor and largely limited to shallow, partly overgrown road, lane and railway cuttings, stream and ditch sections, and shallow, weathered landslip scars. Temporary exposures and field brash remain an important source of new data.

Interest in Warwickshire's geology remains high, notably among amateur geologists, students, engineers and geoconservation specialists. Protection of the field evidence for Warwickshire's Jurassic succession lies partly with English Nature through their geological SSSI (Sites of Special Scientific Interest) network and the county's RIGS (Regionally Important Geological and Geomorphological Sites) Group. The SSSI list has been developed nationally to identify, document and conserve sites that demonstrate the key scientific elements of Britain's geodiversity (Ellis, 1996). Warwickshire currently (2003) has three sites that are afforded statutory protection for their Jurassic interest through SSSI status - Wilmcote Quarry, NGR SP151594; Napton Hill Quarry, SP457613; Cross Hands Quarry, SP269290 (Cox & Sumbler, 2002; Simms *et al.*, in press).

Warwickshire's RIGS Group was established in the early 1990's to enable county-wide, non-statutory, geological and geomorphological site conservation (Harley, 1994). Up to March 2003, 80 RIGS have been documented, roughly a quarter of them for their Jurassic interest. RIGS selection is a dynamic process; new sites are constantly being appraised for their educational, scientific, historic and aesthetic importance, and it is likely that further Jurassic RIGS will be identified. This paper demonstrates the value and purpose of protected sites as a framework for interpreting Warwickshire's Jurassic history - which is summarised below with reference to the SSSIs and RIGS.

Lower Jurassic

The oldest beds are still exposed at Wilmcote Quarry SSSI (SP151594) and Temple Grafton Quarry RIGS (SP121539). These sites still expose several metres of mudstone interbedded with fine-grained laminated limestone (Wilmcote Limestone Member; late Rhaetian - early Hettangian; planorbis Zone). The beds were deposited predominantly as poorly oxygenated muds during the earliest phase of the Jurassic marine transgression (Wignall & Hallam, 1991). When in work, the quarries yielded beautifully preserved fossils including crustaceans, insects, fish, marine reptiles and land plants (Brodie, 1868, 1897), mainly from lower beds than those currently exposed (Simms *et al.*, in press). Some are housed within the Warwickshire Museum (Fig. 5). Basal mudstones of the Wilmcote Limestone were formerly exposed at Round Hill road cutting RIGS, near Wootton Wawen (SP143618). They are thought to lie within the planorbis Zone, suggesting local attenuation in the vicinity of the Vale of Moreton Axis (Old *et al.*, 1991).

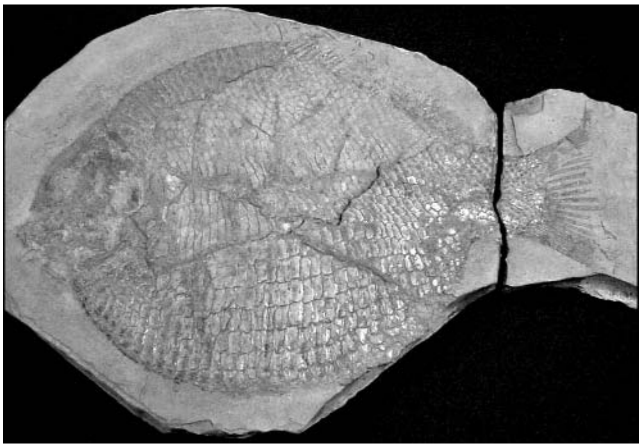

Figure 5. Fossil fish (*Dapedium* cf. *angulifer* (Agassiz)) from the Rhaetian up to Hettangian Wilmcote Limestone Member (Blue Lias Formation) of Wilmcote, near Stratford-upon-Avon, Warwickshire. Warwickshire Museum specimen G384. The slab is 450 mm long.

On the shelf area to the east, earliest Jurassic (planorbis Zone) sediments are either absent or represented by mudstones (Old *et al.*, 1987; Ambrose, 2001). Southam Cement Works Quarry RIGS, Long Itchington (SP418630), exposes the Saltford Shale and Rugby Limestone members above latest Triassic (Rhaetian) Langport Member limestones (Fig. 6). The Saltford Shale (approximately 15 m thick) is dominated by dark-coloured mudstones enclosing limestone nodules and thin, laterally persistent limestone beds. Some nodules preserve concentrations of well-preserved schlotheimiid ammonites (Fig. 7; indicating the liasicus and angulata Zones) and fish debris, as well as sporadic bivalves, nautiloids and marine reptile remains. The ammonites are commonly imbricated, suggesting that the skeletal debris accumulated under the influence of weak currents. Wignall & Hallam (1991) and Radley (2002) invoked an essentially dysaerobic setting for the Saltford Shale at Southam, given the scarcity of macrobenthos and the abundant lamination. However, boreholes drilled nearby by the British Geological Survey (Harbury Quarry Borehole, SP392589; Stockton Locks Borehole, SP430648; Old *et al.*, 1987) have revealed a number of sedimentary cycles within the unweathered strata. These comprise fissile mudstones that pass up into blocky calcareous mudstones and limestones. The presence of relatively massive, calcareous beds suggests that the seafloor became periodically oxygenated (K. Ambrose, *pers comm*).

The lower part of the overlying Rugby Limestone Member (angulata up to bucklandi Zone; about 25 m seen at Southam Cement Works) is also exposed at the Southam by-pass RIGS (SP419627). This comprises the well-known 'Blue Lias' facies of rapidly alternating mudstones, calcareous mudstones and argillaceous limestones (Fig. 6). The Rugby limestones differ from those of the Saltford Shale in their relatively bioturbated and fossiliferous character, suggesting greater overall oxygenation. The fossils include large bivalves, pleurotomariid gastropods, rhynchonellid brachiopods and echinoderms. Relative shallowing during the late Hettangian is supported by the cessation of sediment onlap onto the London Platform at this time (Donovan *et al.*, 1979).

Weedon (1986) presented evidence to suggest that the cyclic alternations of argillaceous and relatively calcareous beds within the Rugby Limestone resulted from changes in orbital precession and obliquity, affecting prevailing climate ('Milankovitch' cyclicity). He took the fissile, argillaceous intervals to signify wetter phases and increased runoff from nearby land, 'drowning' carbonate deposition (also see Radley, 2002). This model has gained considerable popularity, although elsewhere at least, certain Blue Lias limestones are probably wholly diagenetic in origin.

The Rugby Limestone is overlain by the Charmouth Mudstone Formation. This is developed in Warwickshire as a thick (up to around 170 m), poorly exposed succession of fossiliferous grey mudstones, calcareous mudstones and thin limestones, spanning much of the Sinemurian-Pliensbachian interval (bucklandi up to davoei Zone). Field mapping (Geological Survey of Great Britain (England and Wales), 1982) suggests that the lower part of the formation might be represented at the Ettington road cutting RIGS (SP264492). Here, pale, weathered, sparsely fossiliferous mudstones appear to be underlain by, or faulted against, darker mudstones containing common *Gryphaea arcuata* Lamarck.

Figure 6. Northern end of Southam Cement Works Quarry RIGS (SP420633). The face exposes alternating mudstones and limestones of the Rugby Limestone Member (Hettangian-Sinemurian; approximately 8 m preserved), underlain by mudstone-dominated strata of the Saltford Shale Member (Hettangian).

Figure 7. Limestone nodule enclosing a concentration of schlotheimiid ammonites. Hettangian Saltford Shale Member (Blue Lias Formation), Southam Cement Works Quarry RIGS (SP419629). Warwickshire Museum specimen G15588/1. The nodule is 213 mm long.

In recent decades, field and subsurface investigations by the British Geological Survey have established the presence of calcareous, shelly, marker horizons within the higher, Pliensbachian part of the central English Charmouth Mudstone. These include Horton & Poole's (1977) '70', '85' and '100' Marker members (Fig. 2). They form topographic benches in southern Warwickshire, in part formerly interpreted as remnants of a pro-glacial lake margin (Dury, 1951; Ambrose & Brewster, 1982). Fenny Compton RIGS (SP4352) comprises one such feature.

Several metres of the Charmouth Mudstone are still exposed at Napton Industrial Estate RIGS (SP455616), below the site of the former Napton brickworks (partly preserved as Napton Hill Quarry SSSI). Mudstone and limestone nodules have yielded a rich macrofauna of brachiopods, gastropods, bivalves, ammonites, belemnites and crinoids. Amongst the ammonites, *Liparoceras cheltiense* (Murchison), *Acanthopleuroceras valdani* (d'Orbigny) and *Tragophylloceras ibex* (Quenstedt) prove the presence of the valdani Subzone (M. Howarth, personal communication). A bioclastic limestone bed crops out at the top of the section, packed with *Gryphaea* cf. *gigantea* J. de C. Sowerby, *Hippopodium ponderosum* J. Sowerby and other thick-shelled bivalves. This might represent the '85' Marker of Horton & Poole (1977) which lies at the top of the valdani Subzone (Howarth, 1980a).

The rich benthic fauna of the Charmouth Mudstone at Napton indicates that it was deposited in a relatively shallow, well-oxygenated sea. The bioclastic limestone seems to mark a phase of heightened winnowing, possibly due to shallowing (Old *et al.*, 1987). The resulting coarser-grained shelly substrates allowed establishment of the *Gryphaea*-dominated community. In this way the sediment became progressively enriched in shell debris, facilitating further epifaunal colonisation.

Overlying the Charmouth Mudstone, the Dyrham Formation (margaritatus Zone, up to around 65 m thick; Williams & Whittaker, 1974) marks significant late Pliensbachian regional environmental change. General shallowing is indicated by the increased silt and sand content. Parts of the Dyrham Formation are seen at Avonhill Quarry RIGS (SP417507), near Avon Dassett. Here, about 6 m of mudstones, siltstones and sandstones yield a rich invertebrate fauna including the sub-zonal ammonite *Amaltheus subnodosus* (Young and Bird) (Martill & Blake, 1984). Sawn sandstone blocks provide an opportunity to study the internal sedimentary fabrics. A diverse ichnofossil assemblage occurs, as well as scours filled with shell debris. The latter suggest storm current influence in shallow water (Sellwood, 1972; Howard, 1984).

The top of the Dyrham Formation is seen at the Edgehill Quarry and nearby A422 (Starveall Barn) RIGS (SP372468 and SP378454). The highest metre comprises shelly mudstone, cross-bedded bioclastic limestone and a layer packed with worn belemnite rostra (Fig. 8). The latter is a good example of a 'belemnite battlefield' and proves a phase of reduced sedimentation, allowing concentration of skeletal remains (Doyle & Macdonald, 1993). The base of the succeeding Marlstone Rock Formation is marked by a widespread pebble bed (Walford, 1899; Edmonds *et al.*, 1965), well exposed at the Edge Hill quarries (see above) and the nearby Burton Dassett Hills RIGS (SP3952-3931). It is partly made up of cobbles and worn slabs of shelly ironstone and sandstone, derived from the underlying strata. The coarse-grained oolitic and bioclastic matrix yields a rich fauna of thick-shelled epifaunal bivalves (mainly oysters and pectinids) and spiriferid, rhynchonellid and terebratulid brachiopods and belemnite rostra. The more worn fossils display a range of invertebrate borings and grazing traces. The latter indicate a former cover of algae and cyanobacteria on shallow, photic substrates (Radley & Barker, 2001).

Figure 8. 'Belemnite battlefield'. An accumulation of belemnite rostra, uppermost Dyrham Formation (Pliensbachian), Edgehill Quarry RIGS (SP372468). Scale is provided by pen.

Figure 9. Sawn slab of 'Hornton Stone' (Pliensbachian possibly up to Toarcian Marlstone Rock Formation) at Edgehill Quarry RIGS (SP372468). Note the 'nest' of predominantly fully articulated terebratulid brachiopods. Scale is provided by pen.

Overlying the pebble bed, the Marlstone Rock Formation (Pliensbachian spinatum Zone, possibly up to Toarcian tenuicostatum Zone) shows subtle differences when traced through the Warwickshire outcrop. Close to the Vale of Moreton Axis, Ilmington (Dairy Ground) RIGS (SP207429) exposes richly fossiliferous flaggy, sandy, ironstone. At Edge Hill (SP3747) the Marlstone reaches its maximum local thickness of approximately 7.5 m and is developed as an unusually pure chamositic oolitic ironstone, weathering to limonite (Whitehead *et al.*, 1952). Here it yields brachiopods, bivalves, belemnite rostra and wood fragments (Fig. 9). Cross bedding is especially evident at the Burton Dassett Hills and Avonhill sites.The Marlstone gains an appreciable sand content to the north-east, as at Napton Hill Quarry SSSI.

The Marlstone signifies a greater overall rate of sediment accumulation, following the strongly erosive phase represented by its basal pebble bed. It has been central to the controversy concerning the origin of oolitic ironstones. It is now generally thought that the iron was derived from terrestrial laterite soils, implying a warm, humid early Jurassic climate (Hallam & Bradshaw, 1979). The pure, relatively thick ironstone development seen at Edge Hill suggests that it was deposited in a semi-isolated depocentre (Edmonds *et al.*, 1965; Chidlaw, 1987).

The overlying Whitby Mudstone Formation is poorly exposed and spans part of the Toarcian Stage (falciferum possibly up to variabilis Zone). It is thickest to the west of the Axis (up to 60 m) where the highest part is arenaceous (Williams & Whittaker, 1974 and above). The basal beds are seen at Avonhill Quarry RIGS, resting sharply on the Marlstone (Fig. 10). They comprise weathered brown mudstone (about 2 m preserved) enclosing beds of fine-grained ammonite-rich limestone (Cephalopod limestones; Edmonds *et al.*, 1965). Amongst the ammonites, *Harpoceras* spp. within the lower part of the succession indicate the exaratum and falciferum Subzones of the falciferum Zone. The highest layers yield *Dactylioceras commune* (J. Sowerby) and *Hildoceras sublevisoni* Fucini, indicating the commune Subzone of the bifrons Zone (Martill & Blake, 1984). The abrupt reappearance of fine-grained ammonite-rich strata indicates early Toarcian deepening (Hallam, 1997). This widely recognised event is thought to have had an underlying tectono-eustatic cause (Hallam, 2001).

Middle Jurassic

West of the Vale of Moreton Axis, Toarcian sands foreshadow the development of lower Aalenian shallow-water oolitic and bioclastic limestones (Birdlip Limestone Formation). The limestones were formerly quarried on Ebrington Hill (SP188427) near Ilmington. Only the basal, Leckhampton Member (='Scissum Beds') is preserved east of the Axis, lying on an eroded surface of the Whitby Mudstone. The Leckhampton Member passes eastwards into the Northampton Sand Formation (Horton *et al.*, 1987; Barron *et al.*, 1997). The transitional region of southern Warwickshire has attracted the attention of numerous workers including Judd (1875) and Richardson (1922). The lithologies present include arenaceous limestones ('Scissum Beds' facies), yielding a shallow water fauna of corals and serpulids at Brailes Hill RIGS (a ploughed field; SP294392). Ferruginous sandstone is seen at Winderton road cutting RIGS (SP341408). Fine-grained, calcareous sandstone (Astarte elegans Bed; Richardson, 1922; Edmonds *et al.*, 1965) occurs at Windmill Hill Quarry RIGS, Tysoe (SP332426).

Superimposed upon the overall Middle Jurassic shallowing trend, the transgressive Upper Bajocian Clypeus Grit (parkinsoni Zone) crosses the Vale of Moreton Axis onto the shelf, where it rests on units as old as the Whitby Mudstone (Horton *et al.*, 1987). Several metres of the Grit are exposed at Cross Hands Quarry SSSI, on high ground near Little Compton (Fig. 11). It consists of pale-coloured oolitic and pisolitic micrites, capped by a richly fossiliferous muddy layer (Cox & Sumbler, 2002). The latter yields serpulids, corals, bryozoans, brachiopods, gastropods, bivalves, echinoids (including *Clypeus ploti* Salter, Fig. 12) and many other fossils. The fauna signifies colonisation of stabilised shallow water substrates. The Clypeus Grit thins to the east and north as it passes into marginal ferruginous and conglomeratic facies (Horton *et al.*, 1987).

The overlying Great Oolite Group (Chipping Norton Limestone possibly up to Forest Marble Formation; zigzag up to ?discus Zone) continues the pattern of shallow water deposition across the Vale of Moreton Axis (Sellwood & McKerrow, 1974; Horton *et al.*, 1987; Sumbler, 1996). The Warwickshire Great Oolite represents part of a mosaic of shallow-water carbonate-dominated settings that spread to cover much of central and southern England at this time (Bradshaw & Cripps, 1992; Cox & Sumbler, 2002). The succession is dominated by oolitic and bioclastic limestones, interspersed with mudstones and finer-grained, micritic limestones (Edmonds *et al.*, 1965; Sellwood & McKerrow, 1974; Horton *et al.*, 1987).

The Chipping Norton Limestone is well exposed at Cross Hands Quarry SSSI and Weston Park Lodge Quarry RIGS (SP285340), resting erosively on the Clypeus Grit at the former (Fig. 11). It comprises fine-grained, flaggy bedded, oolitic limestone, penetrated by *Diplocraterion* burrows and containing plant debris. Farther east into Oxfordshire, onto the general region of the London

Figure 10. Basal Whitby Mudstone (Toarcian) overlying Marlstone Rock Formation (Pliensbachian possibly up to Toarcian) at Avonhill Quarry RIGS (SP417507). Quarry face is about 5 m high.

Figure 11. Basal Chipping Norton Limestone Formation (Bathonian) that is overlying the Clypeus Grit Member (Bajocian) at Cross Hands Quarry SSSI (SP269290).

Platform, it passes into marginal facies (Horsehay Sand Formation) and oversteps the Clypeus Grit to rest on the Northampton Sand Formation (Cox & Sumbler, 2002).

In southern Warwickshire, patches of relatively pale sand locally overlie the Northampton Sand. The British Geological Survey mapped these as 'Lower Estuarine Series' (Edmonds *et al.*, 1965; Horton *et al.*, 1987). However, it seems likely that they represent decalcified Chipping Norton Limestone, and/or Horsehay Sand (M.G. Sumbler, *pers comm*).

A couple of metres of shelly mudstone and limestone are seen above the Chipping Norton Limestone Formation at Rollright Quarry RIGS, just over the Oxfordshire border (SP282307). These represent the lower part of the Sharp's Hill Formation and yield corals, brachiopods, oysters, nerineid gastropods and irregular echinoids. A similar thickness of weathered Great Oolite limestone (possibly representing the Taynton Limestone) is seen at Traitor's Ford Quarry RIGS, close to the Oxfordshire border (SP336362). Warwickshire's Jurassic story concludes at Broomhill Farm, near Epwell (SP342413) where the British Geological Survey mapped the Forest Marble Formation (Edmonds *et al.*, 1965). This is not currently exposed but deserves renewed reinvestigation.

The future

Southern Warwickshire's protected geological sites demonstrate key lines of evidence for Lower-Middle Jurassic palaeoenvironmental change. This body of information will be augmented by future selection of Jurassic sites as RIGS or SSSIs, and documentation of temporary exposures, subsurface records and museum collections. Above all, the detailed stratigraphy, sedimentology and overall palaeoenvironments of the mudstone formations remain poorly understood. The Charmouth Mudstone Formation in particular, is poorly documented, potentially concealing evidence for Sinemurian-Pliensbachian sea-level fluctuation and palaeoecological response (Sellwood, 1972; Hesselbo & Jenkyns, 1998). Taphonomic and isotopic studies, clay mineral analyses, micropalaeontology and ichnology are a largely untapped source of palaeoenvironmental data, potentially applicable to many protected and currently unprotected sites. The prospects for palaeobiological study are similarly good, given the recognition of spectacular fossil concentrations (Fig. 7) and also the wealth of unresearched fossil material from local sites retained in museum collections. Progress will rely partly upon ongoing mineral extraction, exposure documentation, public awareness, education and funding. A number of the most fossiliferous nineteenth century sites still exist, albeit in an overgrown and/or partly filled state. They deserve re-excavation, detailed documentation, protection, and planned management as resources for education and research.

Figure 12. Irregular echinoid (*Clypeus ploti* Salter; partly an internal mould) from the Clypeus Grit Member (Salperton Limestone Formation; Bajocian) of Cross Hands Quarry SSSI (SP269290). Warwickshire Museum specimen G8839. Specimen is 97 mm in diameter.

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A record of the Brigantian limestone succession in the partly infilled Dale Quarry, Wirksworth

Peter Gutteridge

Abstract. The now partly infilled Dale Quarry exposes a section from the upper part of the Asbian Bee Low Limestones to the Brigantian Monsal Dale and Eyam Limestones. With other quarries in the Wirksworth area, it provides a three dimensional view of the transition from the Derbyshire carbonate platform southwards down the platform margin slope that passes into basinal facies of the Widmerpool Gulf. This paper provides a permanent record of the sedimentary facies and large-scale slump structures in the Brigantian Monsal Dale Limestones in Dale Quarry. The platform margin slope is dominated by bioturbated argillaceous wackestone that was deposited below wave base and derived from carbonate mud and comminuted bioclasts reworked from shallow carbonate platform environments. It also displays a range of soft sediment deformation structures, including both the compressional and extensional parts of slump sheets and an eroded syn-sedimentary thrust. An additional aim of this paper is to make a case for re-exposing these features in the event of any re-development or landscaping of the Dale Quarry site.

Dale Quarry (SK283452) is one of a number of disused quarries in the Wirksworth area that provide excellent exposures of the late Dinantian succession. These can be used to re-construct the three-dimensional facies geometry and evolution of the southern margin of the Derbyshire carbonate platform during the Asbian and Brigantian (Fig. 1). The Wirksworth area also demonstrates the transition from the Derbyshire carbonate platform to the Widmerpool Gulf to the south. The succession in Dale Quarry can be traced into cyclic shallowing-upwards limestones deposited in shallow water on top of the Derbyshire carbonate platform exposed in Middle Peak Quarry 500 m to the north (Walkden, 1982; Vanstone, 1996). The succession in that quarry contains palaeokarstic surfaces that are not represented in Dale Quarry, suggesting the succession in Dale Quarry represents a setting deeper down the palaeoslope. Seismic lines shot across the southern margin of the Derbyshire carbonate platform along strike to the east show that this part of the platform was progradational, building out southwards into the Widmerpool Gulf (Fraser *et al*, 1990).

The succession in Dale Quarry includes the upper part of the Asbian Bee Low Limestones (still exposed), a complete section through the Brigantian Monsal Dale Limestones (now mainly obscured) and the lower few metres of the Eyam Limestones (Shirley, 1959; Frost & Smart, 1979; Walkden, 1982; Oakman, 1986). Unfortunately Dale Quarry has been infilled and much of the sedimentary succession together with the large-scale slump structures has been buried. This paper records the succession of Dale Quarry before infilling, concentrating on the facies types and slump structures in the Monsal Dale Limestones.

The Bee Low Limestones, still exposed in the lower eastern part of Dale Quarry, comprise about 25 m of thickly bedded, bioclast, peloid, grainstone/packstone, with bedding planes marked by palaeokarstic surfaces overlain by thin volcanic derived soils. The Bee Low Limestones are capped by a karstic surface that has removed a few metres of the uppermost Asbian (Walkden, 1982). The Monsal Dale and Eyam Limestones were formerly exposed in the main southern and southwestern quarry face and in the limestone pillar left behind by quarrying in the central part of Dale Quarry (Fig. 1). This pillar was not quarried because it contains shafts and chambers associated with Burton's Lead Vein that left it in an unstable state (Frost & Smart, 1979). The southern and southwestern faces of the

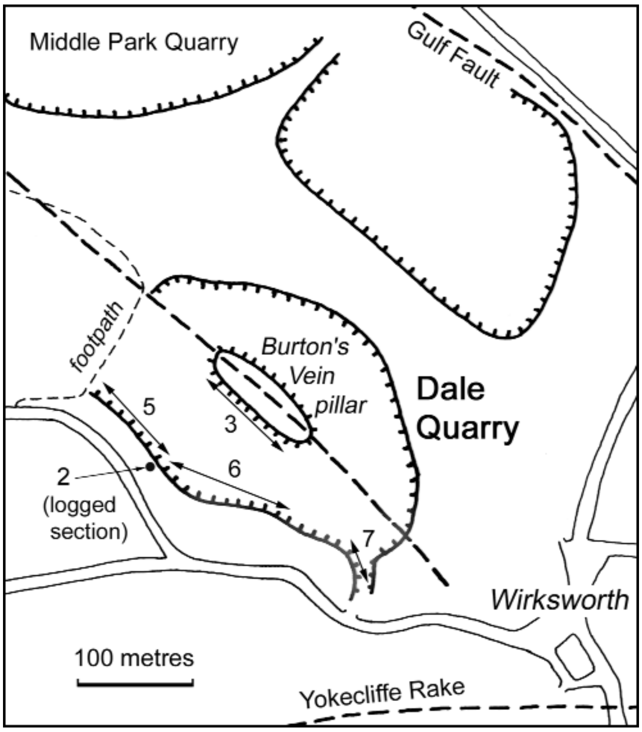


Figure 1. The location of Dale Quarry and other quarries close to Wirksworth. Positions of the logged and measured sections are identified by their figure numbers in this paper.

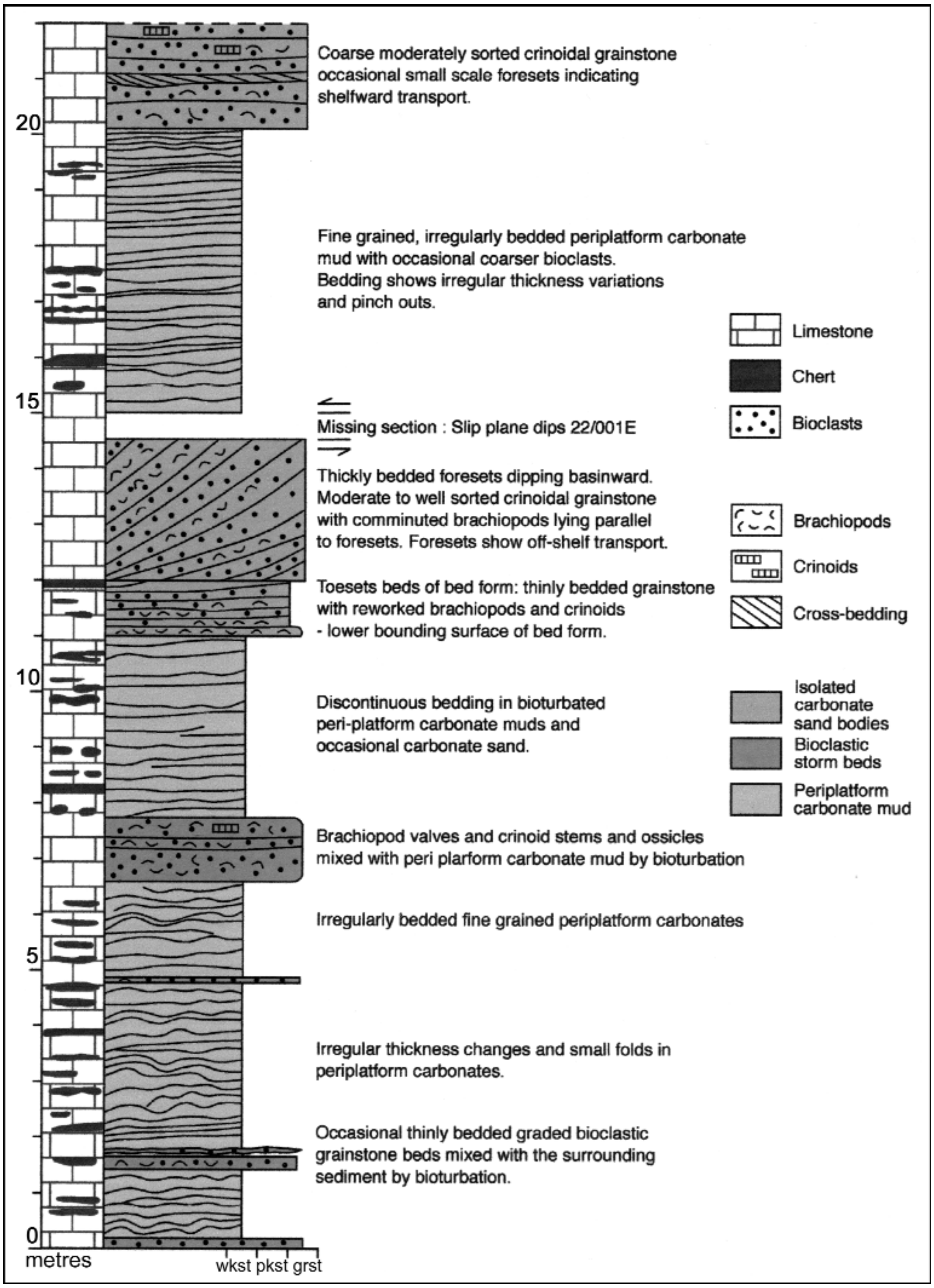


Figure 2. Sedimentological log of the southwest face of Dale Quarry; the position of the log is also shown on Figures 1, 5 and 6. All but the top 2-3 m of the logged section is now obscured.

quarry were measured and logged before it was infilled. The surviving faces of Dale Quarry can be viewed from a public footpath that leaves the Wirksworth-Hopton road at SK281541. Access to the lower part of Dale Quarry is possible from a point next to a garage entrance at SK284540. The face on the west side of this lower entrance was also measured, although this has not been infilled; it is becoming overgrown and filling up with other debris.

Sedimentology

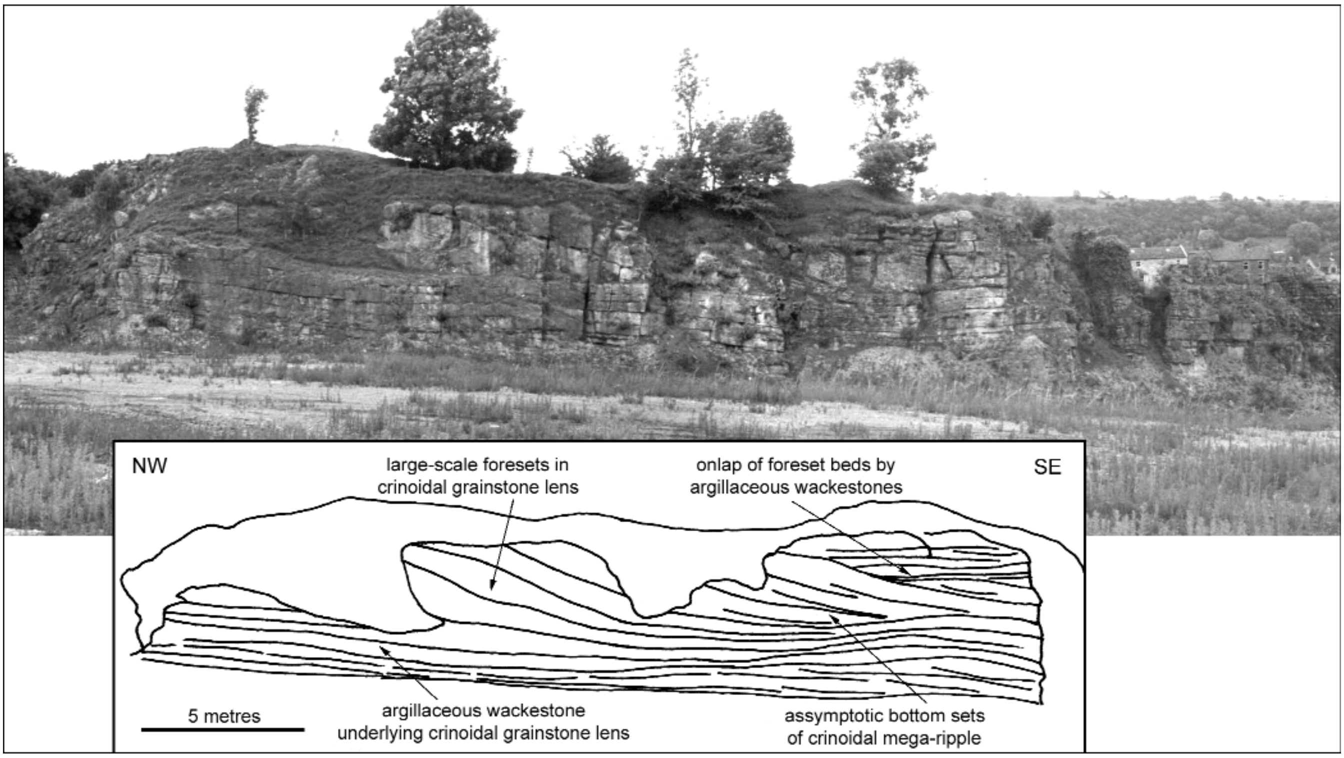
A sedimentological log of the southwest face of Dale Quarry shows the occurrence and relative abundance of the three depositional facies of the Monsal Dale Limestones described below (Fig. 2). The logged section is cut by one of the major slide planes described below. The three depositional facies are as follows.

Argillaceous wackestone: indicated as periplatform carbonate mud on Figure 2. This forms much of the Monsal Dale Limestones. It is a wackestone to carbonate mudstone with fragmented and comminuted bioclasts that include brachiopods, crinoids and foraminifera. The sediment is mottled and has a patchy distribution of bioclasts. Bedding planes are represented by argillaceous partings up to 10 mm thick made up of concentrations of numerous pressure dissolution seams. The beds are 0.05-0.25 m thick, show abrupt thickening and thinning, and are often thrown in to small-scale upright folds and monoclinal flexures. Tabular to rounded nodules of chert several 10s to 100s mm long are common in this facies, in layers parallel to bedding.

The occurrence of argillaceous sediment and carbonate mud suggests that the wackestone was deposited in a low energy, poorly winnowed environment below normal wave base. The mottling of the sediment is interpreted as the result of burrowing, indicating deposition in well-oxygenated, open marine conditions. The highly broken up and rounded bioclasts suggests that they have been repeatedly reworked and winnowed, and were probably derived from higher energy conditions in shallow water where they were subjected to continual wave or tidal reworking. This facies is interpreted as a mixture of periplatform carbonate mud and finely comminuted bioclasts that were winnowed from the shallow water environments on the top of the carbonate platform. The sediment was transported off the platform by storm and tidal currents and deposited below wave base on the platform margin slope. The abrupt thickness changes of beds and the common flexures are interpreted to result from down-slope creep of the semi-lithified sediment. This suggests that deposition took place on a slope.

Thinly bedded bioclast packstone/grainstone: indicated as bioclastic storm beds on Figure 2. This occurs as beds up to 0.2 m thick, interbedded with the argillaceous wackestone described above. It consists of coarse abraded bioclasts including brachiopod shells and spines, crinoid ossicles and spines and foraminifera. Bioclasts that have been bored and micritised are common. Beds have erosional, loaded bases and are sometimes graded with transitional tops. Some of the thinner beds have irregular, undulatory and transitional tops and bases and some of these beds occur as horizons of irregular bioclastic lenses enclosed by the argillaceous wackestone.

The abraded, bored and micritised bioclasts suggests that they have a prolonged history of reworking and transportation that may have included long periods resting undisturbed on the seabed between periods of transport. The beds with erosional bases, grading and transitional tops suggest that they represent rapidly deposited influxes of bioclastic sediment. These bioclastic beds were probably generated by storm action over higher energy environments on the shallower part of the carbonate platform. The bioclasts were reworked and redeposited below normal wave base on the platform margin slope. Some of the thinner beds were mixed with the surrounding sediment by intensive burrowing.



Figures 3 and 4. Composite panoramic photograph showing an isolated crinoidal grainstone carbonate sand body; length of section is about 50 m. This is the exposed top of the now buried limestone pillar containing Burton's Lead Vein in the central part of Dale Quarry. The sketch shows the sedimentological interpretation of the internal structure and lateral relationships of the crinoidal grainstone carbonate sand body seen in the photograph.

Crinoidal grainstone: indicated as isolated carbonate sand bodies on Figure 2. This occurs as isolated lenses up to 5 m in thickness and 30-50 m long, surrounded by and onlapped by the argillaceous wackestone. It comprises moderate to poorly sorted coarse bioclastic grainstone with abraded crinoids, brachiopod valves and spines and foraminifera. Many bioclasts have been micritised and bored. One of these lenses is exposed at the top of the Burton's Lead Vein pillar (Figs. 5 and 6). The lower part of the exposure is made up of the thinly bedded argillaceous wackestone with layers of tabular chert nodules. The lens of crinoidal grainstone can be seen in the upper part of the face. The left end (northwest) of the face consists of large-scale cross stratification dipping to the southeast. The set is some 4-5 m thick and individual sets are 0.5-1.0 m thick. Some small-scale cross bedding is superimposed on the large foresets. The foresets can be traced to the right (southeast) end of the face where they become asymptotic bottom sets and are onlapped by the thin beds of the argillaceous wackestone.

This structure is interpreted as an isolated mega-ripple up to 5 m in thickness and at least 45 m long of bioclastic sediment that indicates sand transportation to the southeast. The size of these crinoidal grainstone structures suggests that they migrated only during high-energy events such as storms and were built up by repeated storm activity. However, the presence of superimposed small scale cross stratification suggests that those deposited above normal wave base were reworked. The dip direction of the cross-bedded in this and other crinoidal mega-ripples formerly exposed in Dale Quarry indicate a consistent off-shelf transport direction down to the south or southeast.

This predominance of off-shelf sediment transport into the basin may suggest the southern platform margin was in a leeward setting. However, transport directions in shelf margin carbonate sands of equivalent age from the northern margin of the Derbyshire carbonate platform are also predominantly off-shelf and into the Edale Basin to the north (Gawthorpe & Gutteridge, 1990; Gutteridge, 1991). This suggests that the predominant wind direction may not be the only factor in determining transport direction at a platform margin.

Soft sediment deformation structures

Figures 5 and 6 show a measured section of the main south face of Dale Quarry before it was infilled; the level of infill is now some 1-2 m below the top of the face. Two slip planes are indicated. Slip 1 represents an initial slope failure that forms the basal slide plane of a large-scale slump sheet made up of recumbent folds. This is interpreted as the up-dip part of a slip plane with structural rollover of the slumped beds on to the slip plane. The slump sheet was at least 50 m long, though its original dimensions along depositional strike are not known. The convergence of folds in this slump sheet and the sense of structural rollover suggest that this slump moved down a slope dipping to the south or southeast. An upright fold at the western-most end of this section (Fig. 5) shows an apparent overturning to the northwest. Walkden (1970) regarded this as an anomalous structure because it apparently indicates a palaeoslope dipping to the northwest, as opposed to the general palaeoslope dip south of southeast interpreted from the regional facies analysis. However, this fold was associated with the initial slump that has had its upper limb cut off by a second slide plane (Slip 2).

Slip 2 could previously be followed for at least 100 m along the whole length of the quarry face to the southeast (Figs. 5 and 6). Apart from some structural rollover in the sediment overlying the slump plane, there are no slump folds associated with this second failure surface. However, its sense of movement and amount of displacement can be estimated because it intersects one of the crinoidal grainstone mega-ripples (Figs. 2 and 6). This shows it had a vertical displacement of at least 15-20 m and a lateral displacement of at least 40-50 m to the southeast. This syn-sedimentary deformation probably formed at a depth of several tens of metres in the sediment.

Another complex sequence of syn-depositional slumping is exposed (Fig. 7) at the lower entrance of Dale Quarry (Fig. 1). The lowermost slump plane on the right hand side of Figure 7 (southeast main face of Dale Quarry) is seen in strike view. The geometry of the structural rollover suggests that the sense of movement is into the quarry face. This slump plane can be traced round (to the left of Figure 7) into the lower entrance where it can be seen in dip section. This thrust plane has been folded and cut by a higher sub-horizontal slump plane that forms the 'sole' thrust of a set of imbricate structures, each bounded by smaller-scale oblique slump planes. This was later eroded, and a graded bed of very coarse brachiopod crinoidal grainstone buried and eroded the imbricate stack. A third thrust plane then over rode the eroded slump sheet. The sense of movement of these thrusts is towards the south and southeast. This slumping may have taken place at a shallow level (probably on the order of a few metres) in the sediment. Fractures and articulated brachiopods in this section contain traces of live oil.

Conclusion

Prior to infill, Dale Quarry provided an excellent section of the Brigantian Monsal Dale Limestones in the slope facies of the southern margin of the Derbyshire carbonate platform. Most of the platform margin slope comprises bioclast argillaceous wackestone that was deposited below wave base in low energy conditions. This represents fine-grained carbonate mud and finely divided

Figure 5. Section of the southwest face of Dale Quarry prior to infill showing two slump planes bracketing a slump sheet with recumbent folds. The position of the sedimentological log in Figure 2 is shown, and the location is marked on Figure 1.

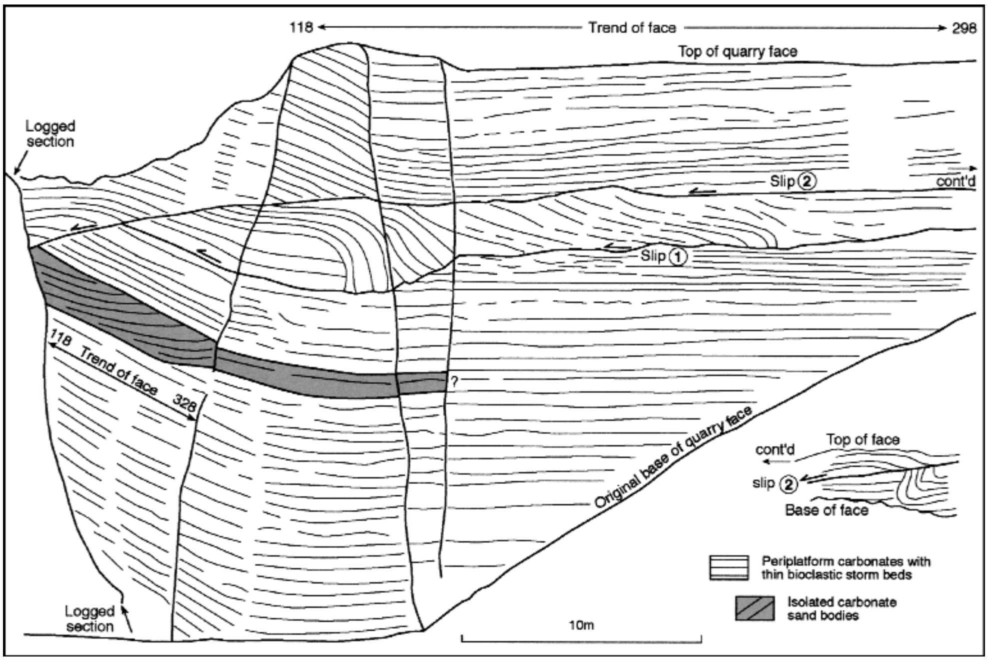


Figure 6. Section of the southwest face of Dale Quarry continued to the southeast of Figure 5. The inset shows the continuation of slip 2 that cuts an isolated crinoid grainstone carbonate sand body. The position of the sedimentological log in Figure 2 is shown, and the location is marked on Figure 1.

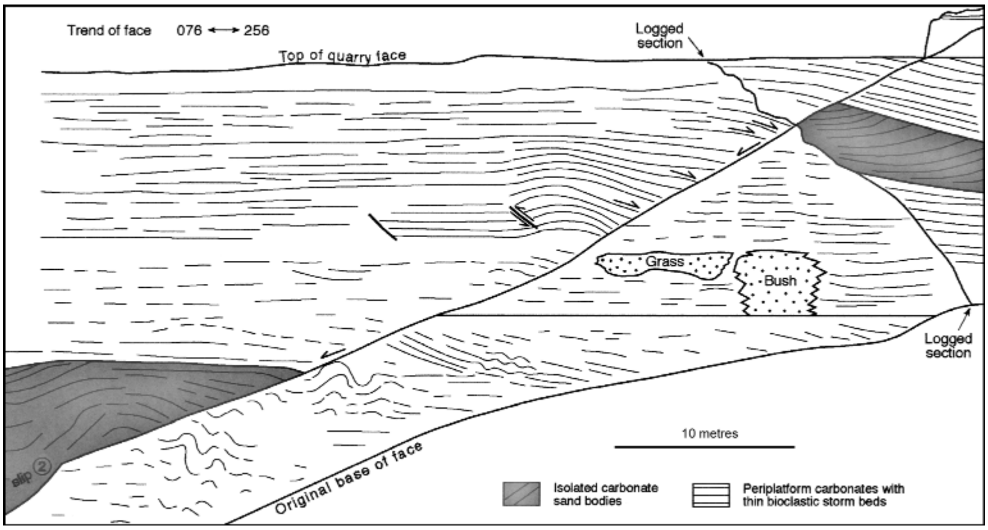
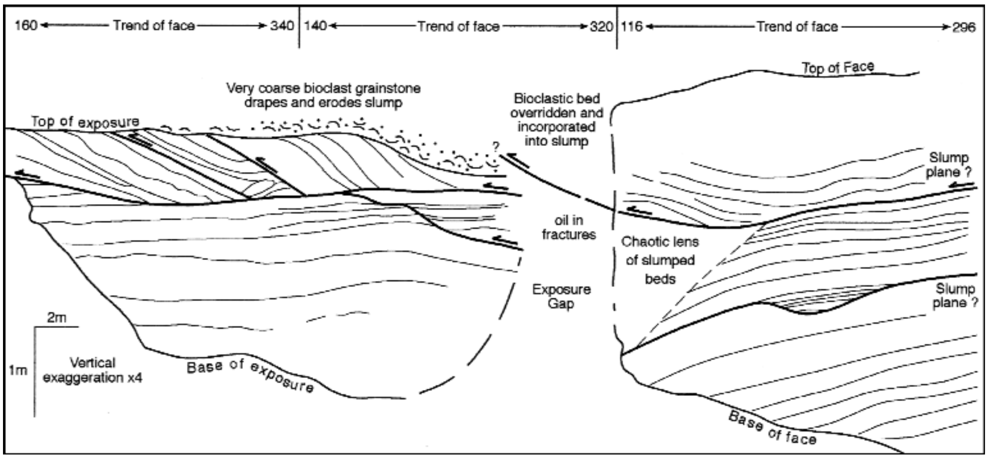


Figure 7. The complex sequence of syn-sedimentary slumping with the development of an imbricate thrust stack eroded by bioclastic bed. The section is exposed at the lower entrance of Dale Quarry; at the location shown on Figure 1.



bioclasts winnowed from shallow carbonate platform settings further up the depositional palaeoslope. The common small-scale, soft-sediment deformation features formed by a progressive down-slope creep of soft of semi-lithified sediment indicating rapid rates of deposition. Coarser bioclastic sediment was deposited on the slope during occasional storm events that caused reworking and deposition of bioclastic sediment derived from shallower water shelf environments. Isolated carbonate sand bodies formed during episodes of reworking and winnowing over the platform slope; this may have taken place during sea level low stands, when wave base over the slope would have been lowered. These bioclastic carbonate sand-bodies show a consistent off-shelf transport direction to the south or southeast. Large-scale syn-sedimentary deformation structures represent both compressional and extensional parts of slump sheets that formed at various levels within the sediment. All these structures indicate a palaeoslope dipping to the south or southeast.

Dale Quarry is in a critical location because the succession can be placed in its correct palaeogeographical and stratigraphical context and can be confidently correlated with platform-top carbonates exposed in Middle Peak Quarry and other disused quarries in the Wirksworth area. Dale Quarry previously provided an opportunity to examine sedimentary structures and large-scale slump structures in three dimensions developed in a carbonate platform margin setting unique in the British Dinantian. These disused quarries in the Wirksworth area represent an important teaching and research resource that need to be conserved. Dale Quarry is a geological SSSI and is described in a forthcoming Geological Conservation Review (Cossey et al, 2003). Any future re-development of the former Dale Quarry site should consider re-exposing these spectacular structures.

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William Martin, 1767-1810, pioneer palaeontologist

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Abstract. A biographical study of the early Derbyshire palaeontologist, William Martin, with a re-assessment of his published works.

One of the founders of British palaeontology, William Martin is best known for his illustrated book on the Carboniferous fossils of Derbyshire *Petrificata Derbiensia*, published in 1809. Brief biographies of William Martin have been written by Edwards (1931), Challinor (1947; 1948; 1970) and Stanley (1973) and there is an anonymous review of his life in the Monthly Magazine of 1811. A short note was included in the Dictionary of National Biography and a more substantial account has been compiled by H.S.Torrens for the forthcoming new edition. Otherwise Martin's contribution to geology has not received the prominence it should have attracted, and some of the general historians of geology, such as Geikie and Adams, totally ignored him.

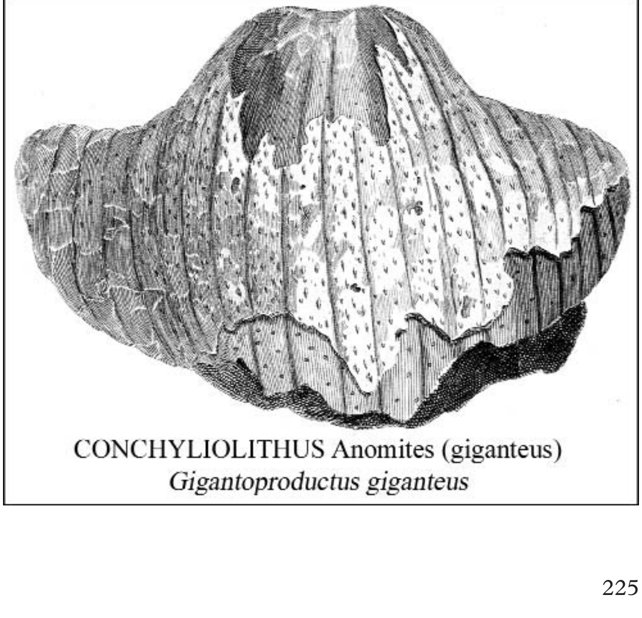
His personal history

William Martin was born in Mansfield, Nottinghamshire in 1767. He was the only son of Joseph Martin (died 1797) and Ann née Mallatratt (c.1746-1819). Joseph Martin was a hosier, but abandoned his wife and two-year old son and went to Ireland, where he adopted the name Booth and followed a career embracing actor, portrait painter and inventor. Later he moved to London and exhibited polygraphic paintings. He never saw his wife and son again and failed to support them in any way. He died in Vauxhall, London in 1797.

After being abandoned by her husband, William Martin's mother took up a career in acting and joined a group in Kibworth, Leicestershire, before going on tour. She supplemented her meagre income by putting young William on the stage from the age of five. He sang and even gave lectures in Buxton at the age of nine. While on tour he took up drawing and engraving as a pastime, and developed these talents to supplement their income further. Their tour encompassed Lancashire, Cheshire, Staffordshire, Derbyshire and Yorkshire. It was in the latter, at Halifax, that young Martin, then aged 12, was introduced to James Bolton who had a school at Stannary near Halifax. Bolton took Martin under his wing and taught him the arts of penmanship and drawing, particularly of birds. Bolton was an ardent naturalist and influenced young Martin's tastes in that direction. He lent Martin Da Costa's *Natural History of Fossils* (1757) (actually largely on mineralogy) so there must have been an element of geological education too. Bolton also taught him Latin.

At the age of 15, Martin joined Stanton's Company of actors in the Peak District of Derbyshire in 1782. He was an indifferent actor except in comedy roles (Anon, 1811). Much later his death notice in the *Gentleman's Magazine* described him as a comedian. Among his roles he played Trip in the School for Scandal. During his stage career, Martin visited local schools and taught drawing in his spare time. About 1785, Martin met the marble worker and naturalist White Watson (1760-1835) in Bakewell. Later Martin moved from full-time acting to teaching drawing and writing, firstly in Burton-upon-Trent from 1798, then in Chapel-en-le-Frith and Buxton from 1800, and from 1805 at the Kings School in Macclesfield. Martin bought a fourth share in the Buxton theatre and continued acting there in the summer season until 1809. During these moves he was accompanied by his wife, Mrs Mary Adams "an unfortunate but interesting young widow... and actress" whom he married in 1797 in Stoke-on-Trent. Mary Adams was widowed at the age of 19 and was taken into Mrs Martin senior's care as she could sing well, and presumably earned her keep on the stage. William and Mary Martin had six children, of whom the eldest, William Charles Linnaeus Martin (1798-1864), became a well-known writer on natural history and superintendent of the Zoological Society's museum 1830-8, with a long list of publications in the *Proceedings of the Zoological Society*.

William Martin died after a long illness with consumption in Macclesfield on 31st May 1810 at

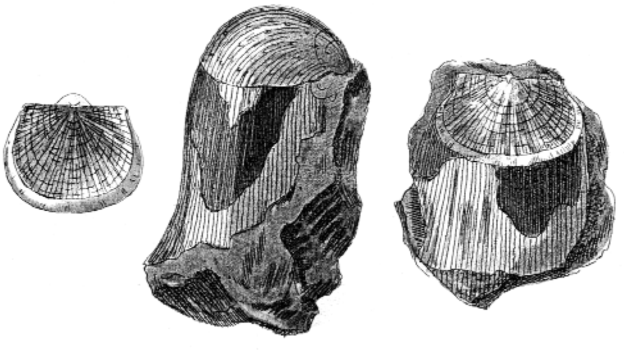


CONCHYLIOLITHUS Anomites (giganteus)
Gigantoproductus giganteus

the early age of 43. During his last year he lost his voice and could not sing or act. His illness may explain the large number of errata in the *Petrificata*. His wife helped in colouring some of the plates. He left his widow, six children and aged mother with very little financial means. Subscriptions were raised to help them but the outcome is not known. His widow tried to sell his uncompleted works and other papers, but neither the buyer nor the present whereabouts are known, if any survive. Martin's two posthumous papers were published two years later with editor's notes suggesting that they were among these unfinished works but what happened to the rest is unknown.

William Martin developed his liking for natural history and is said to have published his first scientific paper, on ants, in 1788 (Torrens, *pers comm*). Within a year or so, inspired by the geologist Abraham Mills (c.1750-1828), Martin started to study the fossils and minerals of the Peak District. He met A.B.Lambert (Vice President of the Linnean Society) while on tour, and the latter was so impressed with his drawings of birds and fossils that Martin was elected a member of that Society in 1796. On the title page of his book *Petrificata Derbiensia*, Martin described himself as being a Corresponding Member of the Manchester Literary & Philosophical Society and an Honorary Member of the Geological Society of London, to which he was elected in June 1809.

Martin's claim to fame lies chiefly in his *Petrificata Derbiensia*, subtitled "Figures and Descriptions of Petrifactions collected in Derbyshire". This project apparently arose out of a proposal by White Watson in 1790 whose Prospectus dated 6 May 1790 was for a three-volume Catalogue and Description of the Derbyshire Fossils then said to be "nearly prepared for the press". It is doubtful if Watson ever prepared anything, as no such matters are mentioned in the catalogue of his works compiled by E.R.Meeke (1996). Within a year an almost identical prospectus (undated but probably also 1790) was for an illustrated catalogue said to be under joint preparation by White Watson and William Martin. There is some doubt as to what fossils (the term then encompassed minerals as well) were actually supplied by Watson for Martin to draw and describe. There is no mention of this matter in Meeke's compilation, and his transcription of Watson's cash book (which only started in 1796) has only brief entries regarding a "List of Specimens sent by Watson to Martin on 17th Dec. 1800", and "rec'd from Martin two half notes May 14/23 1809". Apart from these Watson specimens, Martin evidently did some collecting on his own. Several of his *Petrificata* descriptions gave localities around Ashford-in-the-Water, which was very much home territory to White Watson. Whether the latter supplied the fossils or simply directed Martin to the localities is not known. From about 1800 Martin supplied fossils to James Sowerby (1757-1822) who noted them in his *Mineral Conchology* before they were passed to the British Museum (Natural History) collection (Muir-Wood, 1951; Stubblefield, 1951).



CONCHYLIOLITHUS Anomites (productus)
Productus productus

Figures with this paper are reduced versions of Martin's drawings from Petrificata Derbiensia, together with their later "official" names.

No portrait of Martin is known. He was described as "below the middle size, slender and of delicate appearance even in the best of health" (Anon, 1811).

Figures and Descriptions

In 1793 Martin alone issued another prospectus "Just Published in quarto – Number 1" of "*Figures and Descriptions of Petrifactions collected in Derbyshire .. to which are added a Systemtical List of the Minerals, which have been found constituting the Substance of Extraneous Fossils in that County and a brief Introduction to the Knowledge of Petrifactions in General*", printed for the author by Lyon & Atkinson in Wigan and sold by Benjamin and John White of Horace's Head, Fleet Street, London, W. Creech of Edinburgh, W. Lyon, bookseller of Wigan, and the author in Buxton. Although dated 1793, it did not appear until the following year.

Martin's 1793 prospectus noted that the "Figures and Descriptions ... would be completed in fourteen numbers ... with all convenient expedition". However only four subsequent numbers are known to have been issued from 1794 to 1796. No mention of Watson was made in these but the latter noted in the preface to his *Delineations of the Strata of Derbyshire* (1811) that many of the specimens were his (Watson's) but that the drawings were by "one who has departed and shall not be named", i.e. Martin, as stated in the 1790 prospectus. No written agreement between the two has been found. Challinor (1970) recorded that the five parts contained the first 29 of the 52 Plates in *Petrificata Derbiensia*, but with subtle differences.

As no correspondence between Watson and Martin survives, it is impossible to resolve what the working relationships were, but it seems likely that Martin "borrowed" at least some of Watson's specimens without giving him much credit.

Martin's Anomites

A paper on fossil Anomitae (a term roughly equivalent to brachiopods today) found in Derbyshire was read to the Linnean Society in 1796 and published in 1798. In it, Martin was largely concerned with the unusual Spiriferid now known as *Syringothyris cuspidata*. He had found a single specimen at Castleton – now lost (Muir-Wood, 1951). He gave a detailed description with comments on its mode of life. Comparisons were drawn with other Anomites though they were not named. From his sketches these can be identified as *Dielasma*, *Productus*, *Spirifer*, *Pugnax* and *Riphidomella*. Surprisingly, Martin included *Gryphea* in his comparative discussion and sketches: indeed he made little distinction between brachiopods and bivalve molluscs.

Outlines of an Attempt to Establish a Knowledge of Extraneous Fossils on Scientific Principles

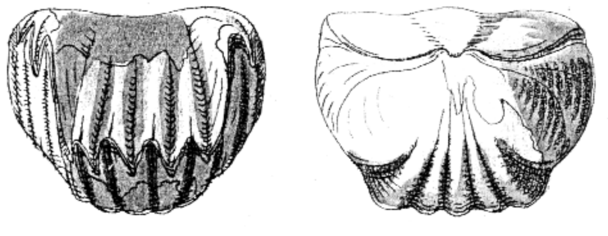
This book was published in April 1809 and was dedicated to A. B. Lambert, Vice President of the Linnean Society and Fellow of the Royal and Antiquarian Societies. It was printed by J. Wilson of Buxton and sold by the author in Buxton, and by J. White, Fleet Street, and Longman's & Co, London. The *Outlines* appeared three months before Martin's *Petrificata Derbiensia*. Though not well known it was reprinted by P.P.B.Minet and the Geological Society in 1972. According to Challinor (1970) and Stanley (1973) it was regarded as the first palaeontological textbook to appear in English.

Martin's preface (18 pages) opened with the statement that " The Study of Extraneous Fossils is …. useful to the Geologist – it enables him to distinguish the relative ages of the various strata". This is the basic William Smith principle which was being promulgated then, chiefly by Smith's disciple, John Farey (1811), though Smith's own work was not published until several years later (1816-7). Whether Martin arrived at the same conclusion independently is not known. Martin then stated the principles on which he distinguished Extraneous Fossils or Reliquia from minerals by their organic and organized form, the material (rock or soil) in which they are preserved being of lesser significance. He remarked on the lack of any previous treatise on extraneous fossils. He proposed to remove from nomenclature those names that gave no reference to their biological origin, though, of course, fossil names based on localities or persons became commonplace much later. Four pages of Addenda and Emendanda followed the preface.

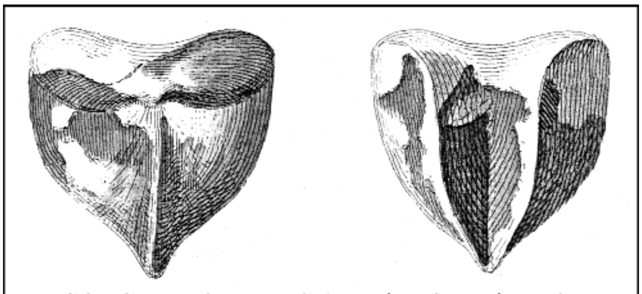
Martin was evidently well read, as footnotes refer briefly to the opinions of such writers as Werner, Hutton & Playfair, Gmelin, Hauy, Kirwan, Bergman, Cuvier and Jameson. His *Outlines* book was contemporary with James Parkinson's *Organic Remains* though it differed in approach. In Martin's view none of the above writers made a clear enough distinction between the substance (i.e. mineral composition) of a fossil and its organic form. Fossils were either "organized" (i.e. animal or vegetable - with organic structures) or "unorganized" (i.e. mineral). At that time "Native Fossils" meant minerals as they were "native" parts of the enclosing rock, and true fossils were "Extraneous". It is unknown how or where Martin had access to the continental works or whether he was proficient in foreign languages, though Bolton had taught him Latin, but he acknowledged assistance from Professor Hull in Manchester on matters of nomenclature. In his last years he also corresponded with Hull on health matters.

After Section I which is a brief definition of Animals, Vegetables and Fossils, Section II (35 pages) was concerned with general principles: Reliquia could be divided into Conservata wherein the original substance, wood, bone etc. was preserved, and Petrificata wherein the fossils took on some characteristics of the enclosing rock. He noted that Reliquia were not to be found in granites, schists, toadstones (basalts) etc and very rarely in mineral veins or in strata associated with salt or gypsum. Lengthy footnotes gave a summary of geological principles in general, former extent of the sea, deposition of sedimentary rocks, origin of mountains, etc. and including the Wernerian system of First, Second and Third periods. Various shrewd observations were included, such as "towards the middle of the (second) period mammalia and other land animals were created or greatly increased". This was a fore-runner of the sequence of life through time, with a hint of evolution thrown in.

Section III (142 pages) was by far the longest in the book. It covers matters of preservation (broadly covering what would be called taphonomy today), including impregnation, substitution and transmutation (replacement), and whether the fossils were intrinsic (with internal structures preserved) or extrinsic (with outward form only preserved). The Section then defined the various biological groups from mammals to insects and "worms" (this last term covered most invertebrates; molluscs, corals and other such groups were not separately defined) and the many groups of plants.



CONCHYLIOLITHUS Anomites (Pugnus)
Pugnax pugnus



CONCHYLIOLITHUS Anomites (acuminatus)
Pugnax acuminatus

He moved on to substances, relative ages, structure (of "soils"), materials (calcareous, argillaceous and arenaceous). There are long footnotes of miscellaneous observations relating to fossils, and glossaries of anatomical and other biological terms.

Section IV was very short with only one page that emphasized the importance of recording localities in detail, though Martin's own record of localities did not often follow this principle.

Sections V, VI and VII (40 pages) were on the closely related themes of Arrangement, Nomenclature and Delineation. Martin used a modified Linnean System of classification, Class, Order, Genus, Family, Species, adapted to treat fossils as separate from living species. Thus Class meant Reliquia, i.e. simply fossils; there were only two Orders - Animalia and Vegetalia. Genus was the main division, broadly equivalent to family today, whilst Family to Martin was a subdivision of Genus. Fossil names were distinguished by the addition of -lithus, thus Mammodolithus, Ornitholithus, Amphibiolithus, Ichthyolithus, Entomolithus (insects, trilobites), Helmintholithus (non-fabricated worms), Conchyliolithus (shells), Erismatolithus (fabricated worms, i.e. corals and bryozoans). Reptiles were included in Amphibolithus. Shells included brachiopods and molluscs, the latter embracing bivalves, univalves and cephalopods. Thus Martin's name in *Petrificata* "Conchyliolithus Anomites striatus", the well-known spiriferid brachiopod, signified genus, family and species. "Phytolithus" included all fossil plants. With reference to vertebrates, Martin debated the use of Permanent and Temporary names: whole skulls could be permanently named but separate teeth or bones were only temporary, until the whole fossil was found. Cumbersome and invalid as it may be to modern eyes, the *Outlines* appears to have been the first attempt at systematic nomenclature and classification of fossil organisms.

Part II of the Outlines was a list of "Genera" with very brief definitions in Latin. Many of the "genera" are recognizable today as families of molluscs and other organisms, e.g. Mytilitiae (mussels). Some of the terms used in the *Outlines* were criticized in the Antijacobin Review, presumably in the summer of 1809 (Anon, 1811).

Petrificata Derbiensia

William Martin's best known book, with its pseudo-latin title, was a collection of hand-coloured engravings of Carboniferous fossils from Derbyshire, dedicated to Sir Joseph Banks, and published in August 1809. It was printed by D. Lyon in Wigan and, while several sales outlets were noted, no publisher is cited; so effectively it was privately published by Martin in Macclesfield. However, bibliographies usually list Wigan as the place of publication.

Petrificata Derbiensia has 52 plates with no particular arrangement, either by stratigraphy or by biological group, though a key was included after the title pages. Two pages of errata were also bound in at the front, and Martin offered the excuse that these were due to difficulties in keeping in contact with the printers. Among the fossils illustrated are 18 plants, 13 brachiopods, 6 corals (including one bryozoan), a miscellany of molluscs, two trilobites, several crinoid stems and one of tufa encrusting a feline skull. Short diagnoses in Latin, usually only one or two lines, were followed by English descriptions amounting to one or two pages for each fossil. Somewhat more than half the fossils are from the Carboniferous Limestone and the rest from Millstone Grit or Coal Measures. The title page noted that it was Volume 1. An announcement for Volume 2 in 1809 declared "A considerable portion of the plates ... will be appropriated to the illustration of specimens of such species of Reliquia as have not hitherto been figured or described by English authors". Regrettably, volume 2 was never published.

Localities were only given to the nearest town or village, e.g. Castleton or Chesterfield, though anyone who knows Derbyshire fossils well could probably place many of them more accurately.

Martin added a separately paginated (28 pages) Systematical Arrangement list wherein his fossils were cross-indexed to Plate numbers and listed by biological groups. However, his list reveals some confusion: both plano-spiral gastropods and goniatitic cephalopods appear on one plate. Crinoid stems were assigned to a group Helmintholithus without discussion of their echinoderm affinities, in spite of Whitehurst (1786) having compared modern and fossil crinoids in detail nearly 30 years before. Trilobites were considered to be some kind of insect and referred to the genus Entomolithus. Brachiopods were placed in a "family" *Anomites*. All plants were referred to a group Phytolithus. Corals were listed uner the name Erismatolithus (misprinted several times as Erismolithus), and further subdivided into Madrepores and a Millepore (the latter being a bryozoan).

It is Martin's system of nomenclature which has caused difficulties to later palaeontologists. It was a trinomial system in contrast to the Linnean binomials. He was aware of Linnaeus' method, as

Martin's "species"	Modern genus and species	New author
Conchyliolithus		
Anomites giganteus	*Gigantoproductus giganteus*	J Sowerby
" crassus	*Gigantoproductus crassus*	J Fleming
" aculeatus	*Krotovia? aculeatus*	J Sowerby
" punctatus	*Echinoconchus punctatus*	J Sowerby
" scabriculus	*Buxtonia scabricula*	J Sowerby
" acuminatus	*Pugnax acuminatus*	J Sowerby
" lineatus	*Phricodothyris lineatus*	J Sowerby
" triangularis	*Fusella triangularis*	J de C Sowerby
" acutus	*"Spirifer" acutus*	T Davidson
" rotundus	*? Brachythyris routndus*	?
" glaber	*Martinia glabra*	J Sowerby
" cuspidatus	*Syringothyris cuspidatus*	J Sowerby
" sacculus	*?Girtyella sacculus*	J de C Sowerby
Nautilites sphaericus	*Goniatites sphaericus*	J Sowerby
" listeri	*Gastricoeras listeri*	J Sowerby
" woodwardii	*Leveillia woodwardii*	J de C Sowerby
gastropod		
Erismatolithus		
(Madreporites)	*Lonsdaleia duplicata*	M'Coy
duplicatus	*Lonsdaleia floriformis*	M'Coy
"		
floriformis		

his eldest son had the middle name Linnaeus, but he seemingly thought that the Linnean system had to be modified to deal with fossils. Of the three names, the first is usually Conchyliolithus, which simply means "shell-stone". In the *Outlines*, as noted above, this first name is the genus, but this categorization was not discussed in the *Petrificata*. Martin's second name is what we would regard as the genus today but he regarded it as a family name. His third name (usually given in parentheses and sometimes with a capital initial) was the species name. If one ignores the first name, the second and third could have been made to fit the Linnean system but Muir-Wood and Stubblefield thought otherwise.

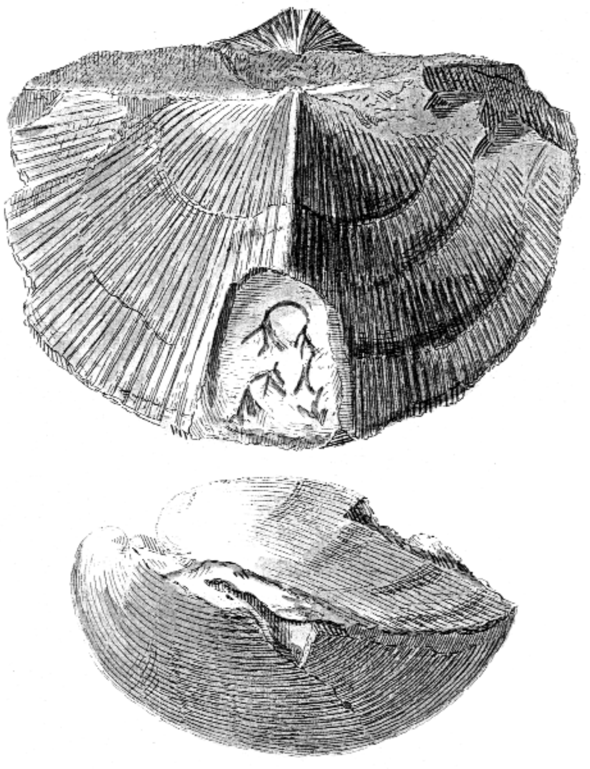
Validation of Martin's specific names

Martin's trinomial system of nomenclature soon came to be regarded as unnecessary and it was superceded by the Linnean binomial system from the Sowerbys onwards. However, both the Sowerbys and many subsequent writers used Martin's specific (=trivial) names which became common features of Carboniferous palaeontological literature, with Martin cited as the author of the species. In 1948, the International Commission on Zoological Nomenclature ruled that all Martin's names were invalid as they were trinomials. The Commission also ruled that the attachment of Martin as the species author was thereby invalid and the next subsequent author to describe the species should thenceforth be regarded as the true species author, in many cases Sowerby, but in a few Davidson and M'Coy (see also Anon, 1950). Muir-Wood (1951) and Stubblefield (1951) discussed the nomenclature, type specimens, synonymy and definition of the following common Carboniferous fossils, and made formal applications to the Commission for validation of the redesignated Martin specific names. Bivalves, gastropods, corals and plants received only passing comment by Muir-Wood and Stubblefield. Martin's trilobites were not mentioned. Martin's carbonicolid bivalves were noted by Wheelton Hind (1894-6) and his plants by Kidston (1923-5). The correlations tabulated above are mostly taken from Muir-Wood (1951) and Stubblefield (1951) to whom reference should be made for details of nomenclatorial changes. Among others, *Dictyoclostus* (*Productus*) *semireticulatus*, *Schizophoria resupinata* and *Pugnax pugnus* can be recognized from Martin's plates (see Davidson, 1857; Thomas, 1914; Muir-Wood, 1951).

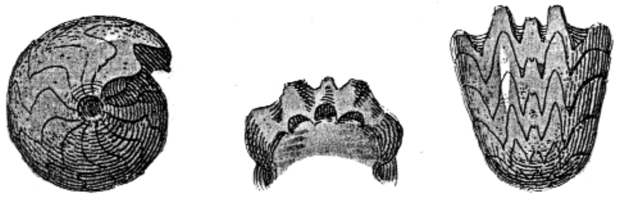
Later Martin was honoured by his name being used in other redefinitions – *Martinia* for a group of smooth-shelled spiriferid brachiopods (M'Coy, 1844) and *Lithostrotion martini* for a well-known Carboniferous coral (Milne-Edwards & Haime, 1851) (see Challinor, 1970).

Unpublished works

While no Martin manuscripts are known to survive, there are mentions of several items that could be of great interest if they could be found. The anonymous obituary of 1811 recorded that he had prepared a Zoological Table in 1789 in which he laid out a classification of the animal kingdom. Manuscript volumes were also drawn up about the same time and included Zoological Tables, and he



CONCHYLIOLITHUS Anomites (striatus)
Spirifer striatus



CONCHYLIOLITHUS Nautilites (sphaericus)
Goniatites sphaericus

intended to compile a Fauna Britannica on Linnean lines, in Latin with common English names added. Illustrated volumes on birds, fish and Derbyshire minerals were projected but never completed. His own introduction to the *Petrificata* claimed that volume 2 was in preparation but it never appeared. His obituary recorded that he kept up a regular correspondence with his teacher James Bolton, and that Bolton's daughter took the letters to America about 1809, but what happened to them thereafter is again unknown. A letter to Dr Hull in Manchester noted that he had prepared a paper "On the Origin of Pipe Veins in Derbyshire" about 1809 but no trace of this has been found.

Late in his life, Martin met John Farey and they conceived a joint project relating Martin's fossils to Farey's stratigraphic units, but this never came to fruition (Challinor, 1970). A letter to the Rev, James Cumming of Trinity College, Cambridge, (Anon, 1811) intimated Martin's intention of drawing the specimens in the Woodwardian Museum (now part of the Sedgwick Museum) but the authorities there decreed that the Woodwardian Professor was to write the text while Martin was to be paid £3 for each of the drawings. Another project was to draw and describe the fossils in the Leskean Museum in Dublin. His premature death prevented these projects being started.

Obituaries

The only full obituary traced is an account of Martin's life in the *Monthly Magazine* of 1811, anonymous but obviously by a close friend with information supplied by his widow. The *Gentleman's Magazine* (1810) contained only a brief death notice which described Martin as a botanist, painter and comedian! There was no mention of his work on fossils in the latter.

Conclusions

It is difficult to judge the influence of Martin's works on contemporaries, as none of his papers survive. Carboniferous palaeontology would have progressed whether or not Martin had compiled his *Outlines* and *Petrificata*, but his specific names have passed into palaeontological literature with suitable modifications. His drawing of attention to Derbyshire fossils doubtless spurred others on to more complete works later in the 19th century. Many of his specific names survive and other fossils have been named after him. His modification of Linnean systematic nomenclature did not survive and probably held things back. Martin is not known to have travelled widely, indeed he was so impecunious that he could not afford a horse, and his books make few references to fossils outside Derbyshire, so he is unlikely to have become a second William Smith (see Smith, 1816, 1817). Martin's early death at the age of 43 may have robbed us of more significant works to follow such as the catalogues of fossils in the Woodwardian and Leskean Museums and the joint project with Farey. Martin's collaborator in the 1790s, White Watson, lived for another 25 years after Martin's death and could possibly have continued his work but failed to do so.

Martin's Publications

1788. On ants. (whereabouts not traced).

1794 (dated 1793). *Figures and Descriptions of Petrifactions collected in Derbyshire*. Part 1. (four more parts followed – all five were revised and combined in *Petrificata Derbiensia*, 1809).

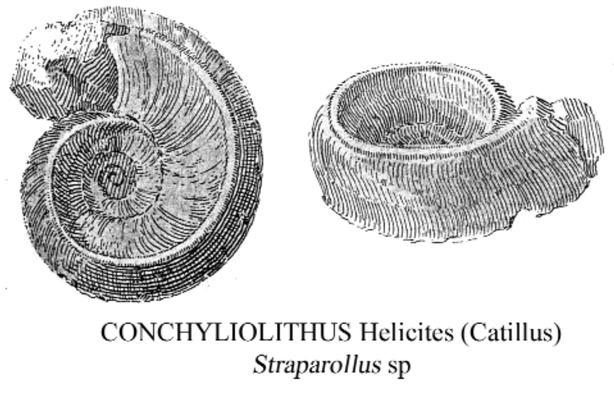
1798. An account of some species of Fossil Anomiae found in Derbyshire. *Transactions of the Linnean Society*, **4**, 44-50.

1809. *Outlines of an Attempt to Establish a Knowledge of Extraneous Fossils*. Macclesfield. 250 pp. (Reprint 1972 by the Geological Society of London & P.P.B.Minet, Chicheley, Bucks).

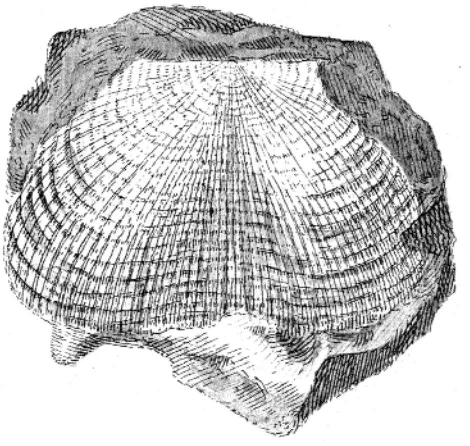
1809. *Petrificata Derbiensia*. 29pp & 52 Plates and explanations, to which is appended *A Systematical arrangement of the Petrifactions Described*. 28 pp separately numbered. Wigan.

1812. On the localities of certain Reliquia or extraneous fossils found in Derbyshire. *Philosophical Magazine* (*Tilloch's*), **39**, 81-85.

1813. Cursory remarks on the mineral substance called in Derbyshire – Rottenstone. *Memoirs of the Literary & Philosophical Society of Manchester*, Series 2, **2**, 313-327; and in *Journal of Natural Philosophy, Chemistry & the Arts*, Series 2, **36**, 46-56.



CONCHYLIOLITHUS Helicites (Catillus)
Straparollus sp



CONCHYLIOLITHUS Anomites (semireticularis)
Dictyoclostus (Productus) semireticularis

Acknowledgements

Thanks are due to Hugh Torrens for an advance copy of his revision of the Martin entry in the forthcoming new edition of the Dictionary of National Biography, and to Roy Paulson for his efforts in locating some of Martin's publications. The drawings that accompany this text are copies of Martin's originals.

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REPORT

New developments on the Quaternary of Norfolk

David Keen's excellent talk to the Society on the Quaternary of the Midlands will no doubt have reminded members of a Foundation Lecture which one of us (RJOH) gave three years ago on the Quaternary of Norfolk. Since then certain developments have occurred which affect the dating of the Norfolk deposits and their correlation with those described by Professor Keen.

At the time of the Foundation Lecture (Hamblin, 2000), Oxygen Isotope Stages for the Norfolk glacial sequence were suggested as in Table 1. Uncertainty as to the date of the Lowestoft Formation has now been largely resolved by further work on material from the Hoxnian type section at Hoxne (Grün and Schwarcz, 2000). This places the interglacial deposits at Hoxne in Stage 11, in which case the immediately underlying Lowestoft Till is almost certainly Stage 12. This was already a difficult conclusion to avoid since the Lowestoft glaciation extended the farthest south of any glaciation in south-east England, and has long been believed to have accounted for the diversion of the River Thames. Evidence from the terraces of the Thames placed that diversion in OIS 12 (Bridgland, 1994).

The Corton Formation has been re-named the Happisburgh Formation, partly because a more complete sequence is exposed at Happisburgh than at Corton, and partly to avoid confusion since Corton is also the type site of the Anglian Stage. Important evidence for the dating of the formation has been found at the Leet Hill pit near Bungay in the Waveney Valley (Rose et al, 2000; Hamblin et al, 2000). Boulders of basic volcanic rocks, high-grade metamorphic rocks and Carboniferous limestone, many of them with angular edges, were found in fluvial gravels of the Bytham Formation (Fig. 1). They do not resemble the erratic suite of the Lowestoft Formation, but do suggest a correlation with the Happisburgh Formation. This interpretation is supported by the presence of clasts of sandy till, similar to that of the Happisburgh Till (Lee et al, 2002). Since the Lowestoft glacial advance overran a terrace of the Bytham Formation that post-dates by at least one warm period the terrace gravels in which the Happisburgh marterial was found, the Happisburgh and Lowestoft are clearly separate glaciations. Since the Lowestoft glaciation dates from OIS 12, and there is no good evidence for a global glaciation in Europe in OIS 14, whereas global ice appears to be important in OIS 16 (Raymo,1997), we suggested (Hamblin et al, 2000) that the Corton (now Happisburgh) Formation dates from OIS 16.

Formation	*Member*	*OIS*
Overstrand	Briton's Lane Sand and Gravel	6
Overstrand	Hanworth Till	6
Lowestoft	Walcott Till	10 or 12
Corton	Happisburgh Till	12 or 14

Table 1. The earlier concept of the stratigraphy.

Figure 1. Bytham Formation terrace gravels at Leet Hill. These contain glacial erratics and till balls, indicating a glaciation earlier than OIS 12.

The above developments occurred in time to be demonstrated at the QRA field meeting at Norwich in April 2000, at which we proposed (Moorlock *et al*, 2000; Hamblin *et al*, 2000) that Norfolk had been subjected to three pre-Devensian glaciations, in OIS 16, 12 and 6. However, further work cast doubt on the relationships of the members of the Overstrand Formation. We had proposed that the Hanworth Member till and the Briton's Lane Sand and Gravel belonged to the same glaciation because both were believed to be of Scandinavian derivation, but whilst this is undoubtedly true of the Briton's Lane Sand and Gravel, Jonathan Lee's clast analyses of the tills failed to demonstrate a Scandinavian connection in the Hanworth Till. Indeed, a letter to Quaternary Newsletter (Moorlock *et al*, 2001) failed to elicit any evidence for Scandinavian erratics in any deposits older than the Briton's Lane Sand and Gravel.

This discovery suggests that the Hanworth and Briton's Lane members belong to different glaciations, and this is indeed in accord with their relationships, since the latter is found draped over an eroded surface cut in the former, with no interdigitation. Further, the Briton's Lane Member exhibits constructional geomorphology in the form of the Blakeney Esker and the kames of the Glaven

Formation	*Member*	*OIS*
Overstrand	Briton's Lane Sand and Gravel	6
Beeston Regis	Hanworth and Bacton Green	10?
Lowestoft	Walcott Till	12
Happisburgh		16

Table 2. Revised pre-Devensian stratigraphy in Norfolk.

Valley, whilst the Hanworth Till has no such appearance of constructional topography. We have thus raised a new formation, the Beeston Regis Formation, to include the Hanworth Member, whilst the Briton's Lane Member remains in the Overstrand Formation. Also, we have divided the tills of the Beeston Regis Formation into the Hanworth Member, which lies south of the Cromer Ridge and is not glacially deformed, and the Bacton Green Member, which occurs north of the Cromer Ridge and demonstrates impressive soft-sediment deformation - the "contorted drift" of the traditional sequence.

In view of its constructional appearance and Scandinavian origin we are satisfied that the Briton's Lane Member is OIS 6 as originally proposed, but the Beeston Regis Formation is likely to be older: OIS 8 is unlikely as this was not a very cold period, so OIS 10 and 12 are possible, although we do not believe that OIS 12 is likely since there is no obvious relationship between the Beeston Regis and Lowestoft formations, with the former resting on an eroded surface of the latter. The most likely age would appear to be OIS 10, particularly since Rowe *et al.* (1997) record a peat of OIS 9 age resting upon a till of believed OIS 10 age at Tottenhill, NW Norfolk. There would thus appear to have been no less than five glaciations in Norfolk, in OIS 16, 12, 10, 6 and 2 (Devensian), and we would suggest correlation of the Lowestoft (OIS 12) and Beeston Regis (OIS 10) formations with the Thrussington and Oadby tills of the East Midlands as described by David Keen (p242 in this journal). Our new pre-Devensian stratigraphy is thus as in Table 2.

Finally, the realisation that the OIS 6 glaciation is the only Scandinavian glaciation to reach Norfolk has interesting repercussions in the geology of the North Sea and English Channel. It has long been believed that the Strait of Dover was cut during the Anglian (assumed OIS 12) glaciation, by the overflow of a pro-glacial lake that formed when British and Scandinavian ice joined to block the northern outlet of the North Sea (Gibbard, 1988, 1995, Hamblin *et al*, 1992). However, palaeontological evidence on the isolation of Britain during interglacial stages, such as would occur after cutting the Strait, imply that isolation did not occur before the Ipswichian (OIS 5e) (Meier and Preece, 1995; Stuart, 1995; Sutcliffe, 1995). Most recently, Ashton and Lewis (2002) cite the likely cutting of the Strait in OIS 6 as an important factor in explaining the absence of human populations from England in OIS 5. The inevitable prognosis of the cutting of the Strait in OIS 6 is that at no time before then was the North Sea blocked by the convergence of British and Scandinavian ice, which is in accord with our findings in Norfolk.

Acknowledgements

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HOLIDAY GEOLOGY

Mitchell Caverns, California

From Barstow towards Phoenix, interstate I-40 takes a roller coaster ride eastward through Basin and Range country of the Mohave Desert. It is thought that this journey has doubled in length over the past 17 million years due to the stretching of the region westward. This created north-south faults that are nearly vertical at the surface but are thought to curve to near horizontal at depth. These accommodate both the westerly movement and the fall and rise of the basins and ranges respectively. Near to Barstow, in the western part of the province, most of the vertical movement is on the western sides of the ranges. As a result many of them tilt. The Providence Mountains, 70 miles from Barstow in the Eastern Mojave Desert, are one such range. Although the western side is the higher, the eastern face is still quite dramatic, and in the 2000 feet high cliffs, lie the Mitchell Caverns, just 12 miles north of I-40.

The small Natural Preserve has a surface nature trail around the desert flora, and there are extensive views east over the basin floor of Precambrian crystalline rocks partially covered with eroded Tertiary lavas. West above the visitor centre, the cliffs are formed of a craggy Upper Carboniferous limestone that contains caves in its lowest 200 feet. However, a little to the north the cliffs change abruptly to a reddish Tertiary rhyolite capped with dark lava flows. Further north still, several mesas each have a dark lava cap. To the south, the cliffs are a smooth white syenite, contrasting the craggy limestone.

The caves can be visited only in groups accompanied by a ranger. Once inside, visitors must not touch or even brush against anything, and coughing and sneezing are definitely not allowed. There is a well-made cement path with low-level guide lighting and railings where needed. Stops are made, and at each a choreographed lighting display reveals a spectacular scene that draws the usual sounds of approval from the American members of the group. The chambers are not particularly large but there is a profusion of stalactites, stalagmites, pillars, and calcite shields. Much of the walls are coated with flowstone. A coral is exposed at one point, but most fossils are covered by the flowstone. We were impressed.

Various questions were addressed by our guide, but geology was not mentioned, and the age of the calcite formations is said to be unknown. The profusion and complexity of the calcite deposits suggests a long and interrupted history, probably related to climatic variations in the Pleistocene. The caves were totally dry during our visit, but are said to drip after rain.

Interpretative panels in the visitor centre suggest that the caves initially formed beneath the water table, and were subsequently drained to allow the dripstones to form in free air. The drainage was ascribed to erosion of the Tertiary lavas in the adjacent basin, but this was not related to the scope for rejuvenation instigated by relative uplift of the fault block.

The Mohave Desert is a classic drive-through for an itinerant geologist. Well worth drop-in visits are both the Mitchell Caverns and the nearby Hole in the Wall, with its spectacular rhyolite cliffs full of holes.

Alan Filmer

A ceiling packed with calcite stalactites in Mitchell Caverns.

LANDMARK OF GEOLOGY IN THE EAST MIDLANDS

The reef at High Tor

Impossible to miss where it looms over the A6 highway into the Peak District, High Tor is well known as a fine example of a Carboniferous reef - known more precisely as a carbonate mud mound. This splendid structure is cleanly exposed in the vertical limestone cliff above the east bank of the Derwent Gorge between Matlock and Cromford. High Tor forms the highest part of the cliff at SK306589, about 1 km downstream of Matlock.

The structure of High Tor is best seen from the footpath between Matlock and the Heights of Abraham, at SK292589 above the west side of the Derwent Gorge looking down the easterly dip slope of the limestone (Fig. 1). The main cliff is made up of bedded limestones of the Monsal Dale and overlying Eyam Limestone Formations of Brigantian age that enclose a lens-shaped mass of pale unbedded limestone (Fig. 2). The Great Rake, a mineralised fault previously worked for fluorspar, cuts the southern edge of High Tor is marked by a line of old mine workings and High Tor Rake emerges on to cliff face immediately to the north of the carbonate mud mound (Ford, 2001). The ground behind High Tor is formed by late Brigantian and early Namurian shale, with Riber Castle built on the escarpment of Ashover Grit forming the skyline (Smith *et al*, 1967).

The lens-shaped mass of pale unbedded limestone at High Tor is an excellent example of a carbonate mud mound; the main type of reef found in limestones of Carboniferous age around the world. Reefs were constructed by communities of organisms that formed a rigid structure on the sea floor supported by their calcareous skeletons. Modern reefs are constructed by corals, sponges and calcareous algae that grow in tropical conditions found around Florida, the Red Sea and the Great Barrier Reef of Autralia. Reefs were built by different communities as organisms evolved through geological time; corals, sponges, bivalved molluscs and calcareous algae were responsible for many Mesozoic and Tertiary reefs, while corals and stromatoporoids were important reef-builders during the Palaeozoic and blue-green algal reefs occur in late Pre-Cambrian carbonate successions. However, the Carboniferous was an unusual period in geological history because no dominant reef-building community was present and it is not known how carbonate mud mounds, including the one at High Tor, grew.

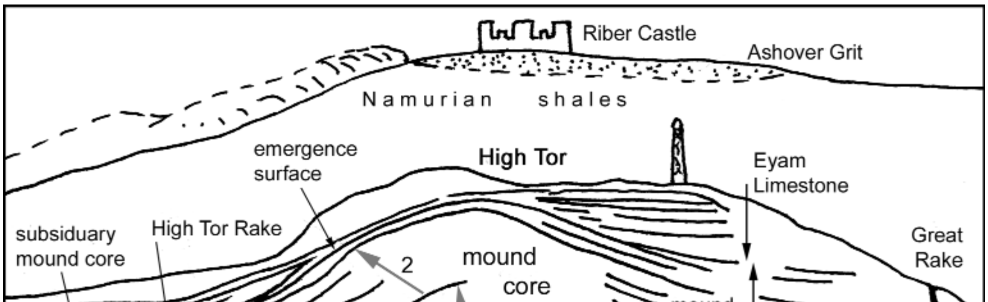

Figure 1. Panorama of High Tor looking due east across the Derwent Gorge from the footpath up to the Heights of Abraham. The length of the cliff section is about 650 m, seen in this down-dip view. Mineral workings of the Great Rake lie in the trees to the right of the main cliff.

Figure 2. Internal structure of the carbonate mud mound, sketched from the same viewpoint as in Figure 1. The mound core initially grew vertically (1) followed by a phase of lateral growth (2).

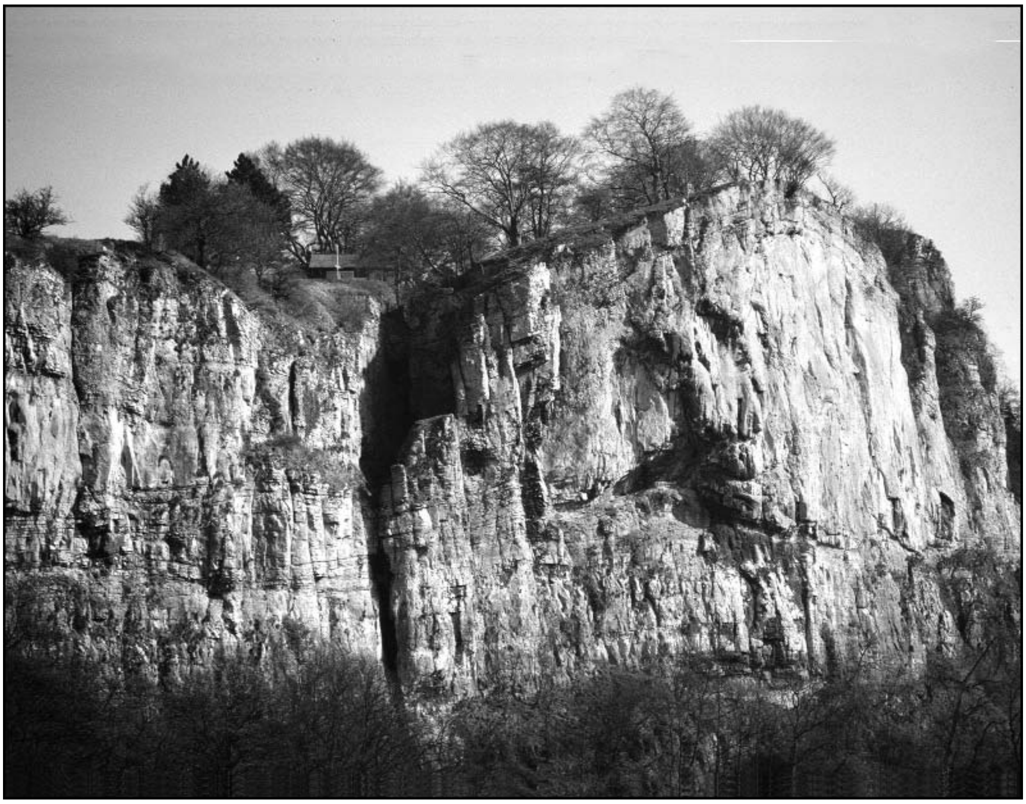

Figure 3. High Tor seen across the Derwent from Shining Cliff. The unbedded lens of the carbonate mud mound on the right passes left into bedded limestones of the mound flank and intermound areas. Part of a second, smaller tabular mound core is present at the left edge of the photograph. The shadowed cleft in the centre is High Tor Rake, a mineralised fault that emerges from behind the cliff.

The lens of unbedded limestone represents the core of a dome-like mound that probably stood some 10-20 m above the surrounding sea floor at its maximum development. It is composed almost entirely of carbonate mud; fossils are scarce but include brachiopods, fenestrate (fan-like) bryozoans, bivalves and crinoids. The brachiopods and bivalves often occur as clusters (Gutteridge, 1990) while the fenestrate bryozoans and crinoids are scattered through the mound core. Unlike modern reefs, no organisms with large calcareous skeletons capable of constructing a supporting framework are present.

The main mound grew by the amalgamation of smaller mounds that can be seen around the base of the mound core (Fig. 2). Bedding planes that dip away from the mound core become more prominent towards the margins of the mound core. These are the mound flank beds that represent the original surface of the carbonate mud mound, with depositional slopes that may have been as steep as 30-40°. Like the mound core, the mound flank beds are composed mainly of carbonate mud, but with fewer brachiopods and more abundant crinoids (Gutteridge, 1995). The disposition of the mound flank beds shows that the carbonate mud mound had a two-stage development. An initial phase of vertical growth was followed by the development of much thicker mound flank beds as the carbonate mud mound spread out across the surrounding sea floor. It was during this second phase of growth that a separate, smaller tabular mound core was initiated a few hundred metres north of the main mound core. The internal structure and the final form of the carbonate mud mound seen on Figure 2 represent different stages of mound growth. There is no evidence that the High Tor mud mound was modified by erosion.

Further away from the mound core, the mound flank beds merge with the flat-bedded limestones that were deposited in the shallow water of the surrounding flat-topped Derbyshire carbonate platform (Biggins, 1969). The contact between the top of the carbonate mud mound and the overlying bedded limestones represents an episode of subaerial exposure killing the community that built the carbonate mud mound (Biggins, 1969; Gutteridge, 1991). The carbonate mud mound failed to re-establish after sea level rose, and the now-dead carbonate mud mound was buried by limestone and then shale.

The mud mound debate

A number of questions about how carbonate mud mounds grew are unanswered:

- Where did the carbonate mud come from?
- How was the carbonate mud able to support such steep depositional slopes?
- Many carbonate mud mounds grew in shallow water high energy conditions, so why are erosional features within carbonate mud mounds rare, even though the carbonate mud should be easily eroded?
- There is no evidence of a frame-building community of calcareous organisms, so what type of organisms built these carbonate mud mounds?

It is possible that carbonate mud carried in suspension was trapped by fenestrate bryozoans or crinoids to form a carbonate mud mound. However, fenestrate bryozoans are too sparsely distributed to have any baffling effect. The case for trapping of carbonate mud by crinoids is more compelling because many carbonate mud mounds are surrounded by what must have been a submarine forest of crinoids. But field relationships show the crinoids colonised the flanks of the carbonate mud mound only after the mound core was fully established. This shows the crinoids therefore played no rôle in the initiation of carbonate mud mounds. In thin section, the evidence against a detrital origin of the carbonate mud is clearer. The texture of the carbonate mud in the mounds is quite distinct from that in the surrounding limestones. The source of the carbonate mud appears to have been on the mound core itself.

The lack of erosional features in carbonate mud mounds and the steep mound flanks suggest there was some means of stabilising the surface of the carbonate mud mound. Organisms adapted to, or forming hard substrates are very rare and the brachiopods and bivalves found in mound cores were suited to soft or firm sediment (Gutteridge, 1990, 1995). Production of carbonate mud by communities of algae and bacteria offer the best explanation for the origin of carbonate mud mounds. Under the microscope, the carbonate mud resembles the biological precipitates of bacteria and blue green algae (Pickard, 1996). Microbial communities occur as rubbery mats that bind modern carbonate sediments. It is likely that similar mats, probably about 50 to 100 mm thick, bound the surface of carbonate mud mounds protecting them against erosion and supporting the steep depositional slopes. The mat was breached by small erosional hollows that were colonised by brachiopods and bivalves which were preserved in clusters (Gutteridge, 1990). If you could stand on the surface of a carbonate mud mound, it would probably have supported your weight up to a point. The rubbery mat may have broken and you would have sunk into the soft carbonate mud. Your legs would probably penetrate to knee depth with your feet feeling firmer sediment a few tens of centimetres beneath the surface.

Carbonate mud mounds are only common in the geological record immediately after mass extinctions when the main reef building organisms were wiped out. This allowed algal-bacterial communities to diversify and expand into ecological niches that were otherwise occupied by framework reefs. A mass extinction during the late Devonian cleared the marine ecosystem of reef-building communities and allowed carbonate mud mounds to become the main reef type during the Carboniferous (Bridges *et al.* 1995). There are many more carbonate mud mounds exposed in Derbyshire, including those near the National Stone Centre and in the western end of Lathkill Dale (described on page 254 in this Mercian Geologist), but the one at High Tor is one of the best exposed examples.

Half an exhumed reef knoll

The present day topography over the back of High Tor may be partly controlled by the Dinantian sea floor topography, as the High Tor hill mimics the shape of the carbonate mud mound. It may be considered as a partially exhumed reef knoll that was then fortuitously cut through by the Derwent.

The origin of the Derwent Gorge may itself be related to the carbonate mud mound at High Tor. Ford and Buerk (1976) suggested the River Derwent previously flowed at the level of the limestone plateau to the west of the Derwent Gorge. The river migrated eastwards by uniclinal shift, down the dip slope of the limestone, by eroding the shale cover faster than the limestine. The carbonate mud mound at High Tor interrupted this erosion because it projected upwards into the shale and diverted the course of the River Derwent vertically downwards to form the Derwent Gorge. However, it may be questioned that an isolated feature of the limestone outcrop could cause a major diversion in drainage. An alternative view suggested by Smith *et al.* (1967) is that the Derwent Gorge represents a glacial diversion from an older course along the limestone/shale boundary.

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LECTURE

Upright individuals and death by decapitation: unusual preservation of some Lower Palaeozoic crinoids

Summary of lecture presented to a joint meeting of the Society with the Yorkshire Geological Society on Saturday, 9th November 2002 by Dr. Stephen Donovan, of Nationaal Natuurhistorisch Museum, Leiden, The Netherlands

One of the simplest deductions that can be made concerning fossil crinoids is that the stem was upright and the crown was elevated above the seafloor. The image of the upright crinoids feeding with their outstretched arms is familiar from textbooks. However, the first observations of extant stalked crinoids, which live at a water depth of 100+ m, were only made using research submersibles in the 1970s (Macurda and Meyer, 1974) and earlier reconstructions got the orientation wrong. Originally thought to be rheophobes, living in low-energy environments with the crown spread to catch a gentle rain of detritus, they are now known to be rheophiles and orientate the crown perpendicular to the current to act as a fine 'fishing net.' If such a basic interpretation was incorrect, perhaps other deductions about fossil crinoids are in need of review.

Almost invariably, complete fossil crinoids are preserved parallel to bedding, that is, in a presumed death orientation, but were they necessarily upright in life? Some stalked crinoids may indeed have had recumbent columns, but the majority are interpreted as being elevators. How do we confidently recognise that this elevation occurred? Only rarely we find fossil crinoid columns preserved in an elevated position. Unusually, crinoid columns are preserved perpendicular to sub-perpendicular to bedding (=life orientation) in the Upper Silurian Moydart Formation, Arisaig Group, of Nova Scotia (Donovan and Pickerill, 1995). Such preservation has only rarely been reported previously. These columns invariably lack the crown and any obvious mode of attachment. Loss of the crown presumably occurred after the distal column was buried; the stalk may even have continued to live after loss of the crown (see below). Absence of any obvious root structure may be due to cut effect or could be indicative that at least some Palaeozoic crinoids lacked an identifiable attachment. Burial was rapid, but not enough to topple the crinoids, and occurred as a series of sediment influxes.

A further recent observation on extant crinoids is that loss of the crown does not necessarily lead to death of the column. Studies of extant stalked crinoids have shown that their stems are capable of surviving after detachment of the crown following self-mutilation, called autotomy (Oji and Amemiya, 1998), or predation (Donovan and Pawson, 1998), presumably feeding subsequently by the absorption of nutrients through the ectoderm (West, 1978). Isolated fragments of isocrinid column may survive for over a year under laboratory conditions and bourgueticrinid columns apparently endure following predatory decapitation, sealing over the wound with stereom and in some examples growing apical, root-like structures (Fig. 1a).

Such abilities may now be invoked to explain the common preservation of certain Palaeozoic crinoids without the crown, due to either predation or autotomy. Locally common crinoid pluricolumnals (that is, fragments of column) from the Upper Ordovician (Cincinnatian) of Kentucky, Ohio and Indiana that have rounded ends reminiscent of the overgrowths seen in modern bourgueticrinids following predation (Fig. 1b, c) (Donovan and Schmidt, 2001). These pluricolumnals are derived from the gracile disparid crinoid *Cincinnaticrinus* Warn & Strimple. Such specimens have hitherto been interpreted as globular distal attachments or distal terminations of mature individuals that have become detached from their holdfasts. However, it is more probable, by analogy with similar overgrowths in extant, decapitated bourgueticrinids (Fig. 1a), that some or all of these specimens represent overgrowths of the column following predation. If this new interpretation is correct, then implications include post-decapitation survival of crinoid stalks is now recognised for most of the history of this group and lethal predation on crinoid crowns occurred at least as far back as the late Ordovician.

The crinoids originated in the early Ordovician. The specimens illustrated herein (Fig. 1b, c) suggest that predation was an early phenomenon in the group's history. It seems probable that such predation was relatively uncommon, otherwise it should have been widely documented already. This is supported by studies of modern *Democrinus* spp., in which, from a sample of about 250 individuals, only 1.6% showed this pattern of predation (Donovan and Pawson, 1998), although many more specimens were regenerating one or more arms. The most probable predators in the Cincinnatian were vagile cephalopods, which are common fossils in the Upper Ordovician of the American Midwest, rather than the rarer fishes.

The ability for the column to survive following decapitation may have been a contributory factor in the development of large scale deposits formed primarily of crinoid debris called regional encrinites, which were accumulated in the Ordovician to Jurassic, that is, during the interval when stalked crinoids were a common component of the shallower water benthos. Regional encrinites are generally recognized to represent unusual deposits which show patterns of sedimentation different from other bioclastic accumulations (Ausich, 1997). It is not known how long such 'headless' crinoids may have survived, although modern isocrinid column fragments can live for over a year, at least, following autotomy (Oji and Amemiya, 1998). If predation on crinoid-rich sea floors was higher than has hitherto been recognized, then disarticulated skeletal elements may have been added to the sediment budget during defaecation by predators, while the 'headless' crinoids persisted amongst unaffected individuals, acting as baffles to current flow and aiding accumulation.

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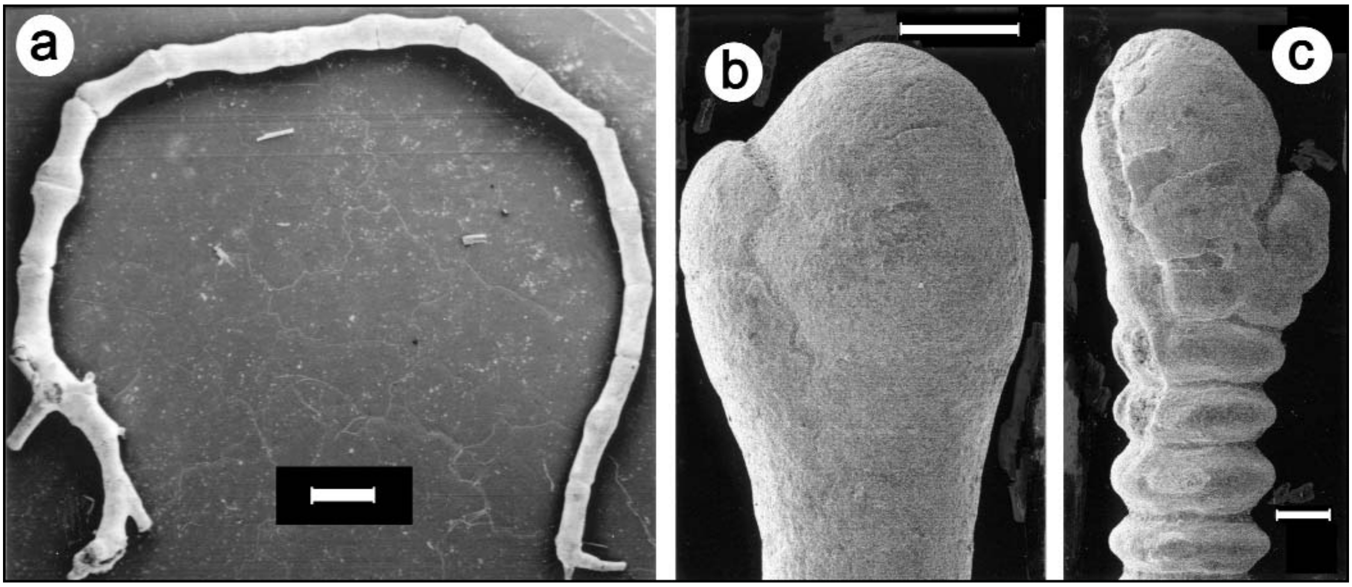

Figure 1. 'Headless' crinoids, ancient and modern.
a. Decapitated Recent bourgueticrinid, *Democrinus chuni* (Döderlein), south Atlantic Ocean (after Donovan and Pawson, 1998, fig. 1A). Complete specimen with attachment (left) and apical overgrowth (right); the curvature is due to storage in a glass jar. (USNM E11616).
b and **c**. Upper Ordovician crinoids interpreted as decapitated, *Cincinnaticrinus* spp. from Kentucky and Ohio, U.S.A. (after Donovan and Schmidt, 2001, fig. 3D, B, respectively). (b: BMNH EE 6641. c: BMNH EE 6642).
Specimens: National Museum of Natural History, Smithsonian Institution, Washington (USNM) and Natural History Museum, London (BMNH). Scanning electron micrographs of specimens coated with 60% gold-palladium. Scale bars are 1 mm long.

LECTURE

Memorable moments in the history of crinoids: highlights of their evolution and adaptation

Summary of lecture presented to a joint meeting of the Society with the Yorkshire Geological Society on Saturday, 9th November 2002 by Dr Mike Simms of the Ulster Museum, Belfast

Compared with other, more mobile, echinoderms, such as sea urchins and star-fish, the plant-like crinoids, or sea lilies, would seem to have rather limited potential for conquering the world's oceans. But in late Palaeozoic times they were by far the most diverse and abundant echinoderm group and even today >600 living species are known. Typical crinoids comprise a highly jointed stem or column, used for attachment and elevation above the sea floor; a somewhat rigid cup, housing the vital organs, usually of 2 or 3 interlocking circlets of plates; and highly jointed, and usually branched, arms which form the feeding structures of the animal. This multi-element skeleton and its morphological division into stem, cup and arms, and the filter-feeding lifestyle which it supports, are features largely inherited from the earliest crinoids and their ancestors >500 Ma ago. Each of the ossicles of which the crinoid skeleton is made are a single crystal of calcite, an inherently brittle and highly inflexible material which imposes 'architectural' constraints on crinoid morphology. However, each calcite ossicle has a stereom structure, a ramifying network of cavities filled with soft tissue, which imparts much greater resistance to fracture than does solid calcite. In turn, each ossicle is connected to adjacent ossicles by soft tissues which impart flexibility to the skeleton. It is only within the limits imposed by these inherited and architectural constraints that crinoids can adapt to their environment and, through evolution, improve the way they feed and reproduce.

During the evolution of crinoids each of these three divisions, stem, cup and arms, has shown such evolutionary changes, often through ingenious adaptations and economic use of the basic building materials.

The main function of the cup is to house and protect the vital organs of digestion, nervous control, and the water vascular system characteristic of all echinoderms. In the earliest crinoids it comprised 4 circlets of plates, each offset and interlocking with adjacent circlets. However, reducing the cup to three, or even just two, offset and interlocking circlets does not significantly compromise its rigidity and this has happened independently in several crinoid groups. Its shape varies from saucer, to bowl, cone or globe-shaped, but its upper surface is covered with a plated flexible membrane or more rigid structure onto which both the mouth and the anus open. The obvious problem here of potential contamination of food is overcome in many crinoids by the development of an anal cone or tube, an analogy perhaps being drawn here with the tall chimneys found at many chemical and industrial works.

The arms support the tiny tube feet, which capture food particles and pass them down to the mouth. Increasing the effective arm length, usually by branching of various types, therefore increases the food-gathering capacity of the arms. Often the arms divide equally but one type of branching, called endotomy, in which smaller side branches arise at regular intervals from one side of a main arm branch, has been likened to the pattern of roads on a banana plantation. The analogy here is that this represents the most efficient configuration for a large filtration fan using a minimum of materials (Cowen, 1981), yet it is a pattern seen in very few crinoids. The arms may have additional uses in respiration and locomotion. Most post-Palaeozoic crinoids have some muscular articulations in the arms, in contrast to the entirely ligamentary arm articulations of

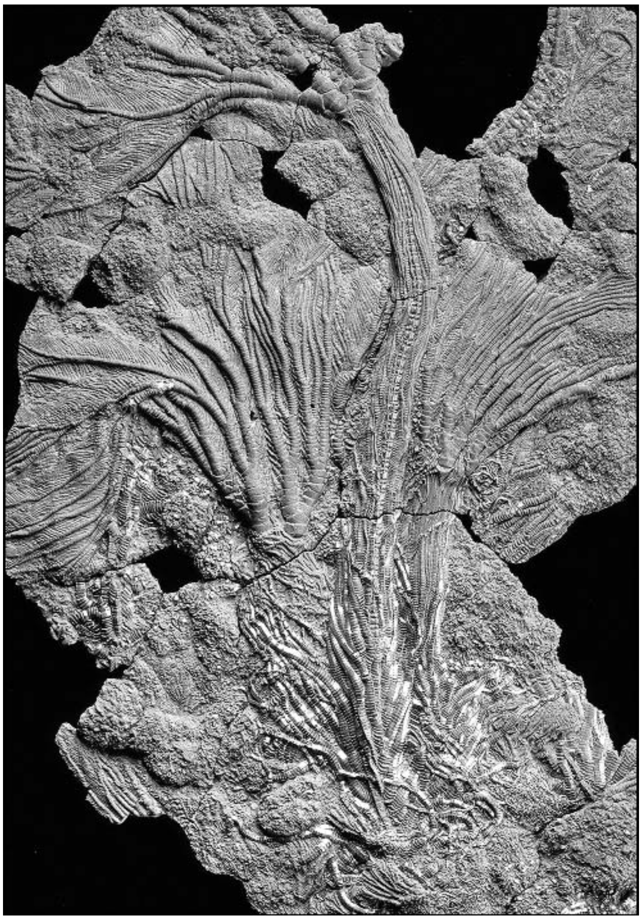

Figure 1. The early Jurassic pseudoplanktic crinoid *Pentacrinites fossilis*, from the Lias of the Dorset coast. This shows the typical morphology of many stalked crinoids - a flexible stem with numerous cirri, a small cup (just visible in the top specimen), and long and highly branched arms. Height of specimen c.250 mm.

Palaeozoic taxa. These muscles provide rapid and active movement to the arms, to the extent that some extant species are know to use the arms for swimming. The smallest of crinoids, termed microcrinoids, have a cup typically no more than 2 mm high and lack arms since energy demands do not require a large food-gathering apparatus.

The crinoid stem serves as an attachment structure and, more importantly, to elevate the feeding structure (the arms) above the sea floor and the benthic boundary layer. Attachment may be by a permanently cemented holdfast or by cirri, flexible appendages arising from the stem and which appear able to grasp sea floor objects or root the animal in softer sediment. In most crinoids the ossicles, or columnals, of the stem are connected by ligaments while crenulations on adjacent ossicles interlock to resist twisting and shearing stresses. During periods of high crinoid diversity, particularly in the Carboniferous, competition between different species of crinoid must have been intense at times. In response to this a distinct tiering appears to have developed, with different species having different stem lengths so that they did not all feed at the same level in the water column (Bottjer and Ausich, 1986). In the dominant extant crinoid group, the comatulids, the stem is absent and cirri arise directly from a centrodorsal plate to which the plates of the cup are attached. They use the cirri to grip on to rocks, corals, or even other crinoids, using these objects as surrogate stems to raise them above the sea floor.

A few crinoids have been interpreted as planktic in habit, floating in the water column. Most of these are tiny microcrinoids from the Mesozoic but one Devonian group, the scyphocrinitids, were quite large and appear to have dangled beneath a large bulbous float formed from highly modified cirri. Three other crinoid groups, the late Devonian melocrinitids, the late Triassic traumatocrinids, and the early Jurassic pentacrinitids, independently adopted a pseudoplanktic lifestyle, attached usually to driftwood or other floating detritus. They include the largest crinoids known, with arm spreads for *Traumatocrinus* and *Seirocrinus* (a pentacrinitid) of >0.5 m and stems of >20 m long in *Seirocrinus*. They also all have endotomously branched arms despite this pattern being generally very rare. It seems that the precarious existence of these crinoids (the driftwood might sink under the increasing weight of its passengers at any moment) exerted intense selection pressure to grow fast, requiring the most efficient filtration fan, and produce huge numbers of offspring so that at least a few might find a suitable floating attachment in the vastness of the open ocean, hence their large size (Simms 1986).

These pseudoplanktic species exemplify crinoid engineering at its best. The same selection pressures produced the same elegant solutions, in the process creating some of the most spectacular and beautiful fossil crinoids ever discovered.

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LECTURE

Glaciations in the Midlands: some revisions of traditional views

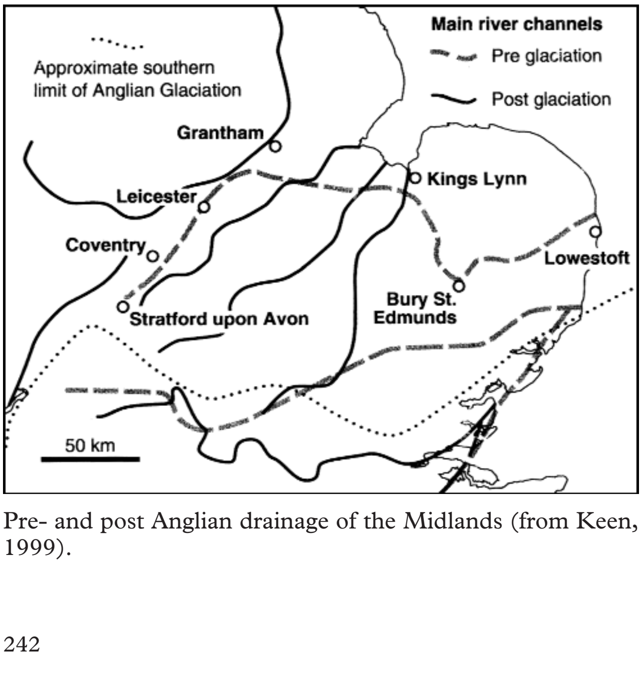
Summary of the lecture presented to the Society on Saturday 16th November 2002 by Professor David Keen of Coventry University.

The English Midlands have been an important area in research into the Quaternary from the earliest days of the Earth Sciences in the 19th century, with some of the first recognition of interglacial faunas being made by Strickland in the 1840’s and the extent of local glaciation by Lloyd in the 1870’s.

The first detailed model of the sequence in the region was produced by Shotton (1953), although this synthesis of the glacial and interglacial succession of the Middle and Late Pleistocene drew heavily on the mapping of the Avon terraces by Tomlinson (1925) for its timescale. The Shotton sequence recognised the units in Table 1 in the glacial sediments around Coventry.

The “pre-glacial” fluvial sequence of the Baginton Sands and Gravels was held to have been deposited in a NE flowing river that Shotton traced north of Leicester and named the “proto-Soar”. The proglacial lake sediments of the Wolston/Bosworth Clay were held to have been deposited in a pro-glacial lake, Lake Harrison, which occupied the area between Leicester, Birmingham and the Jurassic escarpment. This lake was filled with proglacial sands ahead of the advancing Oadby Till ice which eventually over rode the lake sediments and reached a final terminus at Moreton-in-Marsh, Gloucestershire.

Overlying the Dunsmore Gravel was the terrace sequence of the Avon recognised by Tomlinson as being a staircase of terraces with the highest (Terrace 5) being the oldest and the lower terraces (4, 3, 2, 1) being recognised in decending order to the modern river. Avon Terraces 3 and 4 both yielded temperate mammalian and molluscan faunas and Tomlinson and Shotton both assumed that they were from the same temperate stage although deposited after a complicated pattern of incision, aggradation, and then sculpting of the fill into the two terraces. As this cut and fill sequence was the product of one temperate episode and all the terraces post-dated the glaciation, the time available for the whole glacial and terrace succession was short and could be fitted into the late Middle and Late Pleistocene.



Pre- and post Anglian drainage of the Midlands (from Keen, 1999).

The revision of the sequence of terrestrial Quaternary deposits was prompted by the recognition from the 1970’s of the complexity of climate change indicated by the record in the deep ocean basins compared to the simple sequences identified on land. In the Midlands the sequence was challenged first by the identification of only one chalky till glaciation from Norfolk to Warwickshire instead of the two separate glaciations previously recognised (see Rose, 1987). At first the Chalky till was thought to be relative recent perhaps in keeping with Shotton’s model, but the relation of the succession to the Cromerian and Hoxnian interglacial deposits in East Anglia made it clear that the glaciation was dated to an early stage in the Middle Pleistocene.

The discovery of the Waverley Wood interglacial deposits (Shotton *et al.* 1993) interbedded with the base of the Baginton Sands and containing a mammalian and molluscan fauna of Late Cromer Complex age also strongly indicated an early date for the glaciation. Identification of the Baginton Sand and Gravel, directly underlying the glacial sequence in the Midlands, with the Ingham Sands and Gravel of East Anglia, that occupy a similar position below the type Anglian glacial deposits to the east, also unified the sequences in both areas (Rose, 1987).

The glaciation can also be dated from the overlying deposits. The terraces of the Avon were known by Tomlinson to post-date the glaciation, but the sequence in the crucial area between Evesham and Pershore as investigated by Maddy et al. (1991) did not show the complicated cut-and-fill sequence of Tomlinson, but a simple terrace staircase in which Avon terraces 4 and 3 occupied different rock-cut steps and were separable on the basis of molluscan biostratigraphy (Keen, 2001). As Avon Terrace 3 yielded *Hippopotamus* at a number of localities in the

Dunsmore Gravel	Outwash
Oadby Till	Chalky till from NE
Wolston/Wigston Sand	Proglacial sand
Wolston/Bosworth Clay	Proglacial lake clays
Thrussington Till	Triassic-rich from N & NW
Baginton Sand & Gravels	Proto-Soar sands & gravels

Table 1. The Shotton sequence.

stage	OIS	local deposits and events
Devensian	2	(*glaciation in Northern England*)
Ipswichian	5	Avon Terrace 3
	6	(*possible glaciation in Eastern England*)
	7	Avon Terrace 4
	8	
Hoxnian	9	Avon Terrace 5
	10	latest glaciation in area; Oadby Till
	11	
Anglian	12	Thrussington Till
Cromerian	≥13	Baginton Sands and Gravels

Table 2. Possible correlations between the oxygen isotope stratigraphy of the oceans and key Middle and Late Pleistocene events in the Midlands.

lower Avon it is clear that it must have been deposited in the Ipswichian interglacial, the only phase in the Middle and Late Pleistocene when this animal was present in Britain. The older Avon Terrace 4 has yielded a mammoth/*Corbicula fluminalis* fauna typical of numerous sites across southern Britain which have been dated to Oxygen Isotope Stage 7. Deposits other than river terraces are rarely found resting on the glacial deposits, but at Frog Hall east of Coventry sediments have yielded pollen and amino-acid ratios indicating an age in the Hoxnian Interglacial, either OIS 9 or 11 (Keen *et al.* 1997).

Although the succession, age relationships and distribution of the major units of the Quaternary in the Midlands have remained unchanged since the early years of the 20th century, modern views of the timescale involved in their deposition suggest their formation over perhaps twice the time thought necessary by Shotton and Tomlinson (Keen, 1999). The continuity of the Baginton Sands and gravels with the Ingham Sands and Gravels suggests deposition in a major west-east flowing river which dominated the drainage of the Midlands in "pre-glacial" times. The occurrence in these deposits at Waverley Wood of stone tools indicates the importance of this succession for the early human settlement of Britain. The glaciation, with two ice advances, separated by a non-glacial episode of lacustrine and deltaic deposition is still not well known in terms of its age or the timing of the ice advances. The conventional view (see Keen, 1999 for discussion) is that both the Thrussington and Oadby tills belong to the same cold stage (OIS 12) on the basis of the intensity of cold of that episode in the oceanic record and on the dating of the later deposits resting on the tills. However, no fully acceptable means of dating has been applied to the sequence and Sumbler (2001) has proposed that the two ice advances may be the product of separate glacial stages in OIS 12 and 10. Certainly, so far no fluvial deposits of the "new" rivers draining to the Wash and the reversed Avon, which replaced the "proto-Soar/Ingham River" older than OIS 9 have been found resting on the glacial succession, perhaps suggesting an OIS 10 age for the latest glaciation of the area. This date is also suggested by the ages of the river terraces of the "new" rivers which developed on the Anglian glacial deposits after the ice retreated and replaced the Ingham River with a SW flowing river (now the Warwick/Worcestershire Avon) and three major rivers (the Welland, Nene and Great Ouse) flowing to the Wash replacing the eastern extent of the Ingham River. None of these rivers has a terrace that can be dated as being older than OIS 9, thus suggesting that these "new" rivers began their evolution after an OIS 10 ice retreat. The development of terraces in each temperate stage after OIS 9 provides the necessity of a long time span between the end of the glaciation and the present. This is unlike the model of the workers in the mid-20th century, but is more in keeping with modern views on the pattern of Pleistocene climatic change.

Sediments of Avon Terrace 3 at Eckington.

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LECTURE

Catastrophic loss of the Aral Sea

Summary of one part of the lecture to the Society on Saturday 14th December 2002, by Dr Tony Waltham of Nottingham Trent University.

The Aral Sea lies in a sparsely populated desert split between the new republics of central Asia. The desert has less than 90 mm, but the Aral is fed by two great rivers - the Syrdarya draining the Tien Shan into the northern end, and the Amudarya draining the Pamirs into the southern end (Fig. 1). As a closed body, the level and extent of the Aral Sea has always fluctuated in response to the flows of these input rivers, both of which are dominated by huge spring flows of meltwater from the snowfields and glaciers of their headwater mountains. But the Aral naturally stabilised with a mean level at about 53 m (a.s.l.) and an area of about 67,000 km^2 (Glantz, 1999).

On the open sea, fleets of 500-tonne trawlers harvested over 40,000 tonnes of fish every year. Huge ferries took all day to cross the 400 km between Moynaq and Aralsk, the two main fishing ports, which were also beach holiday resorts. The Amudarya delta was a splendid wetland with reed beds and beautiful lakes rich in wildlife. But all this is in the past, because mankind has virtually destroyed the Aral Sea.

The shrinking sea

Life in the desert depends on water that has always been taken come from the two big rivers - and this included water for farmland irrigation. In 1900 there was 20,000 km^2 of irrigated land in the Aral Sea basin, and by 1960 this had crept up to a sustainable 40,000 km^2. But then soviet central planning in Moscow decided to create a massive cotton industry in the region - which was then a part of Russia. By 1980 irrigated land had exploded to over 70,000 km^2. All the flatlands became wall-to-wall cotton fields. The largest single soviet creation was the Karakum Canal, which extends for 1370 km and takes 12.9 km^3 of water per year to irrigate 9000 km^2 of cotton fields in the Turkmenistan desert (Fig. 1).

Around 90 km^3/year are now extracted from the Amudarya and the Syrdarya - about 75% of their total flows. With natural evaporation losses in the desert, both rivers can now run dry, and there is often no water left to flow into the Aral Sea. The result is the steady shrinkage of the Aral Sea - entirely due to man's interference with a naturally balanced ecosystem. Moscow's politicians and planners carried on expanding the cotton fields until they lost control around 1985. They ignored the Aral Sea's demise, because they were relying on eventual remedy to be provided by diverting water from Siberia's rivers into the Aral basin instead of the Arctic Ocean. Plans for this even greater environmental bombshell were only abandoned in

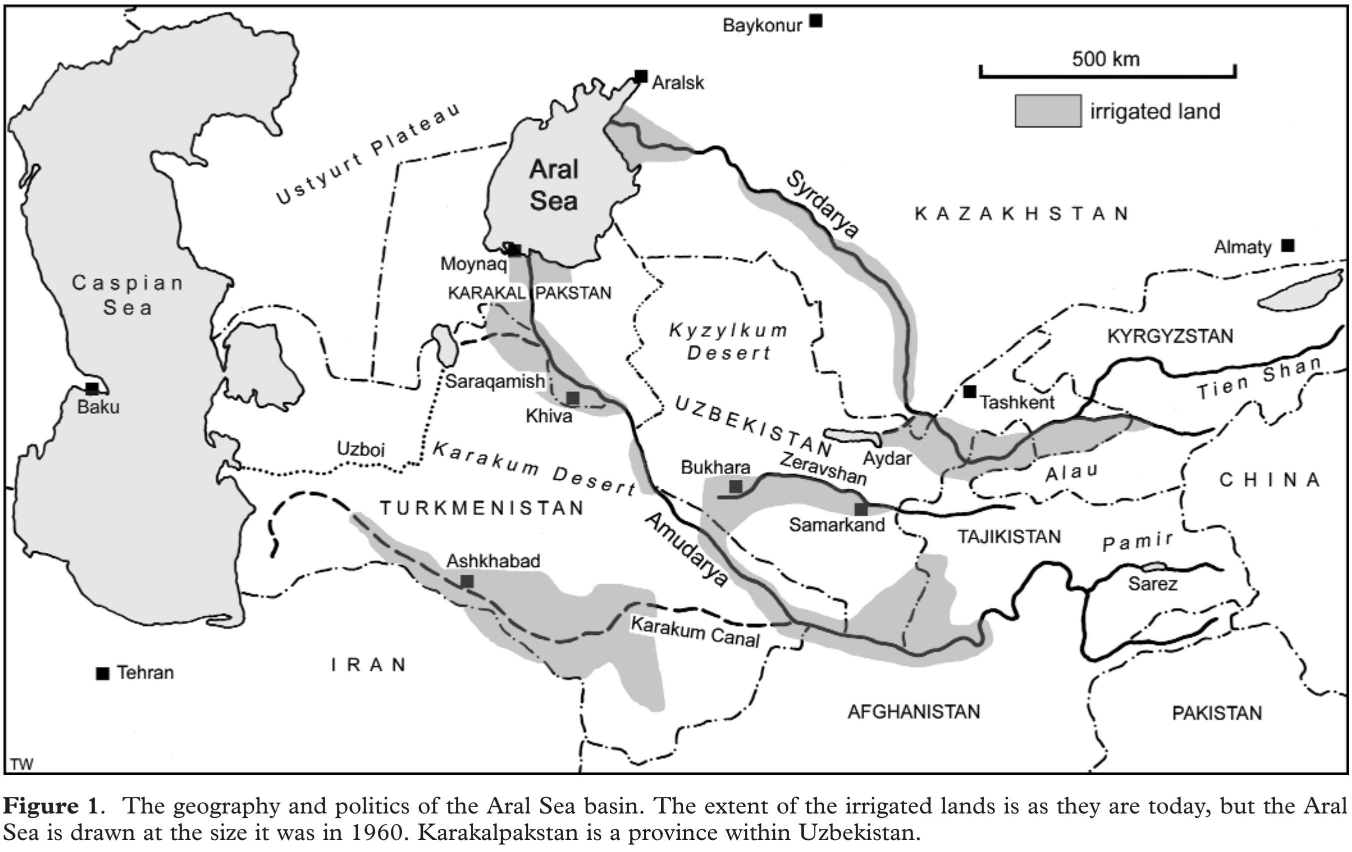

Figure 1. The geography and politics of the Aral Sea basin. The extent of the irrigated lands is as they are today, but the Aral Sea is drawn at the size it was in 1960. Karakalpakstan is a province within Uzbekistan.

the 1980s. But by then the Aral Sea was doomed, and it was already half-dead.

As the irrigation canals were opened up in the 1960s, the flows of the two rivers into the Aral Sea went into major decline. The direct effect was that the Aral Sea went into a matching decline, slowly from 1960, and then more rapidly after 1970 (Fig. 2). In 1960, the two rivers poured 55 km^3 of water into the Aral Sea. In 1982 they contributed none; and modest inputs were achieved in only the wetter of subsequent years.

With its inflow curtailed, the level of the Aral Sea fell by more than 20 m over a period of 40 years, while its volume shrank to just one fifth of its natural state. The most visible impact was the shrinkage of the area of the sea (Fig. 3). Most of the sea was only ever shallow, so the falling level created some massive retreats. Parts of the east coast have receded by 75 km. In 1987 the Aral Sea split into two, as its falling level exposed new dry land. In the north, the Small Aral took most of the remaining flow from the Syrdarya and has continued to decline at lower rates. But the Large Aral in the south loses more to evaporation, and its level continues to fall unabated.

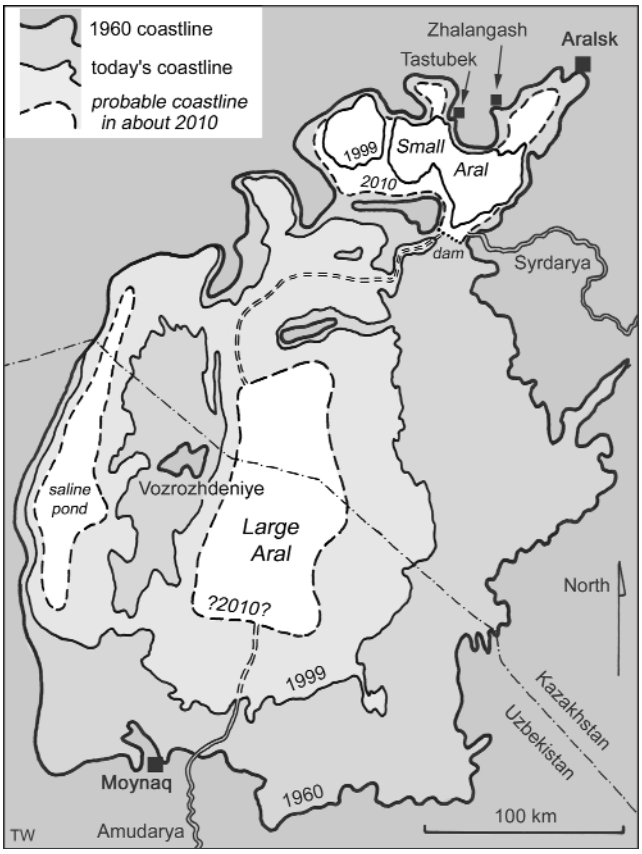

Figure 3. Map of the Aral Sea, with its original (pre-1960) coastline, its present extent (mapped in 1999) and the likely future extent of its three separate seas.

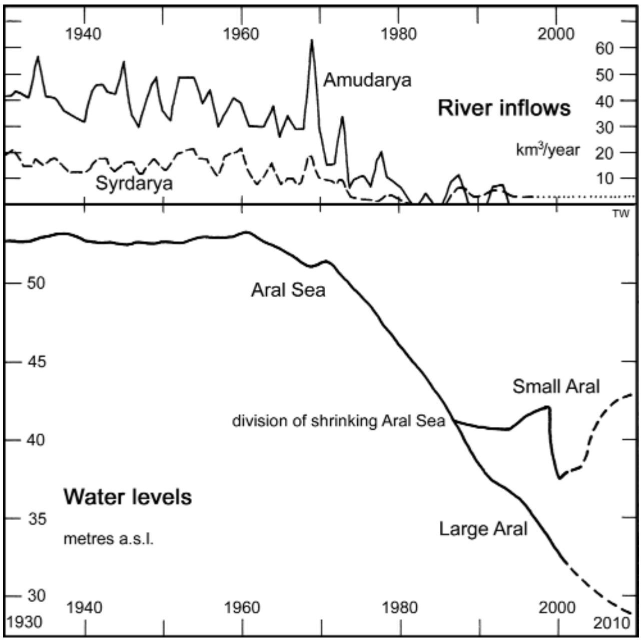

Figure 2. The fall in water level of the Aral Sea correlated with the falling inflows of its two feeder rivers from 1930 until today, with estimates until 2010. The Aral split into two in 1987. Inflows are approximate after 1990.

Not only is the Aral Sea shrinking; it has been dying. The Amudarya delta wetlands have dried up, with the loss of the famous reedbeds and the local industry of muskrat hunting. The ferries stopped running in the 1970s with the loss of navigable channels. Fishery catches withered to zero by 1980, and the last indigenous fish species died out around 1985. Perhaps most important, the Aral Sea ceased to be a climatic stabiliser. Its open water had underpinned a stable block of moist air. When this was lost, winds from the north swept across unabated, and the southern deserts became hotter in summer and colder in winter.

Where the salinity of the Aral Sea was once a healthy 1%, it is now an almost uninhabitable 6% in the Large Aral. Over 40,000 km^2 of the original sea floor are now exposed. Most is dry mud flats that any geologist would recognise as a playa floor (Fig. 4). This dry mud is heavy with salt, and is also enriched with a cocktail of chemicals - including DDT and other toxic pesticides that have been washed out of the irrigated soils. Contaminated soil and water have now produced a massive health problem among the people condemned to remain in the dying towns and villages. Two thirds of the people now suffer ill health. Khiva has rampant hepatitis, Moynak is afflicted with birth deformities and Aralsk has an epidemic of tuberculosis. This environmental disaster knows no bounds (Waltham and Sholji, 2001).

The Large Aral today

Though it sits astride the border, the Large Aral is largely the problem of Uzbekistan, who have the

Amudarya that should feed it and also have the populated old delta lands around the southern end. Their problem lies partly in the gross inefficiency of the ageing irrigation schemes, with huge leakages and uncontrolled evaporation losses and no local incentives to repair the disintegrating canals (Hannan, 2000). But it also lies in the cotton, which is among the world's most thirsty crops; it uses twice the amount of water for an equal cash value of wheat or rice, and ten times the amount for potatoes or sugar. Uzbekistan cannot afford to change its main cash crop when there is no practicable means for mass export of perishable food crops - cotton is easier, and the current plans are to expand the cotton fields.

Meanwhile, the largest water user is the Karakum Canal - owned by Turkmenistan, who have no interest in the Aral Sea. Sadly, the political problems run deeper. The Aral Sea wetlands, which are suffering the most, are in Karakalpakstan - a subdivision of Uzbekistan with a different indigenous population. And the controlling Uzbeks have far more concern for their own cotton industry than they have for the entire existence of the Karakalpaks. Signs of positive change are minimal. There is a scheme to clean up the Amudarya delta wetlands (but the wildlife has already disappeared), and another project aims to increase farming and irrigation efficiency in the Khiva basin (but this covers only a tiny part of the basin).

The future is bleak for the Large Aral Sea. A sustainable sea needs an annual inflow of 28 km^3 from the Amudarya, but any hope for this is unreal. An inflow of 11 km^3/year could maintain some form of shrunken sea, but even this is doubtful. Massive reductions of the irrigated areas and major improvements of irrigation technology are just not foreseeable. Turkmenistan's cotton could be maintained with just half the water in the Karakum Canal, and that would put 6 km^3/year back into the Aral Sea. Far more likely is the total failure of the canal, when even more water will then be lost into the Caspian catchment.

Both Tajikistan and Afghanistan are likely to take more water from the Amudarya when their present wars are over and they start to industrialise. The most likely future for the Large Aral is further shrinkage. It will then divide into two again. The eastern sea should become sustainable with modest inflows from the Amudarya and also overflow water from the Small Aral (see below). Meanwhile the western half will continue to shrink, and will ultimately become a saline pond or a salt flat.

The Small Aral today

Lying entirely in Kazakhstan, along with most of its Syrdarya feeder, the Small Aral Sea does avoid some of the political problems of its larger neighbour. But it too has suffered. Aralsk is the old fishing port and coast resort. Once a thriving town served by the Moscow-Almaty railway, it is now a ghostly relic. Where the Aral Sea once stood there is now only desert that produces dust storms on 65 days a year. The holiday beach has no water, commercial fishing stopped in 1980, and fading "seafront" houses look out to the decaying hulks of fishing boats stranded in the new desert. Aralsk is a very sad place, and its inhabitants struggle merely to survive.

The enduring symbols of the Aral Sea disaster are the ships' graveyards, and there is one near Zhalangash - with a scatter of eight ships rusting in a desert that was once a sheltered bay (Fig. 5). The village is awfully depressing. A dusty main street reaches from empty desert to where the Aral Sea is now replaced by more empty desert. Dust has replaced spray. Eagles have replaced seagulls. The men who once worked the trawlers now tend camels, goats and sheep, which struggle for feed on the thin dust-smothered grass. Even more desperate is Tastubek, with less than 30 families eking out an existence on the edge of nowhere. On a section of coast where the seabed was steeper, the Aral Sea has only retreated a kilometre with its falling level, so they survive on subsistence fishing for poor-quality flatfish, but they catch nothing that is worth hauling to distant markets.

When the Aral split into two seas in 1987, much of the remnant Syrdarya flowed into the smaller northern sea. In 1994 an embankment dam of sand was built to divert all the Syrdarya into the Small Aral and also prevent any overflow into the Large

Figure 4. Once a ferry route, now a car track across the old floor of the Aral Sea.

Figure 5. The ships' graveyard near Zhalangash.

Aral. The level of the Small Aral actually rose, until the frail dam succumbed to wave erosion and was broken through in April 1999. The idea of splitting the Aral Sea into sustainable fragments had first been mooted in Moscow in the 1970s. Now it was seen to be feasible. A new dam will be stronger and will be nearly 13 km long. It has a budget of £57M with 75% coming from the World Bank (Williams, 2003). Construction started in spring 2003. After three years to build, and another three to ten years to fill (depending on mountain snowfalls), it will allow the Small Aral to reach a level controlled between 39 m and 42 m, with excess water discharging into the Large Aral.

The new sustainable Small Aral will rely on a maintained inflow of about 3 km^3/year from the Syrdarya. But that is considered achievable, after a modest review of irrigation in the cotton fields up-valley and improved management of flows and storage in some upstream reservoirs. The sea will never again reach Aralsk, but it will reach a stable level, and it should be a lake of almost fresh water with its permanent outflow. Then new coastal settlements and renewed fishing should be possible.

This does offer a glimmer of hope to the people in Aralsk, in Zhalangash, in Tastubek and in the other towns and villages - but only around the new Small Aral. The loss of the larger Aral Sea has been an environmental disaster on a massive scale; sadly, it has occurred entirely due to man's interference.

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LECTURE

Soft-bodied sensations from the Silurian

Summary of the lecture presented to the Society on Saturday 18th January 2003 by Professor David Siveter, University of Leicester

Our detailed understanding of the history of life relies on the fossil record, and most especially on rare fossil deposits that preserve not simply the hard parts of animals but their entire bodies, soft parts and all. These conservation deposits (or Konservat-Lagerstätten) allow palaeontologists to reconstruct whole animals and communities with much more confidence. Three of the best known lagerstätten are those from Chengjiang, China, the Burgess Shale of British Columbia, and the Orsten deposits of Sweden. These have provided a wealth of information about the life forms that flourished during the Cambrian (490-540 million years ago). One such lagerstätte has recently been discovered in Herefordshire (Briggs, Siveter & Siveter 1996). It contains spectacular fossils of small marine invertebrates that lived about 425 million years ago (during the Silurian Period), and now preserved as crystals of calcite within rock nodules. Not only do the fossils preserve entire animals in fine detail, but almost uniquely they are fully three-dimensional rather than squashed flat.

The Herefordshire fossils represent an ancient community of small invertebrates that lived on the sea floor. They died and were preserved when they were engulfed in ash from a volcanic eruption. The animals themselves soon rotted away, but their shapes were faithfully recorded, initially by the ash itself, and then by crystals of calcite that grew within the resulting hollows. These crystalline shapes are now found within hard nodules in the ash layer. This is the first time that soft-bodied fossils have been found in a marine deposit of volcanic origin. Other volcanic rocks have yielded soft-bodied fossils, but not from marine settings and not from nodules.

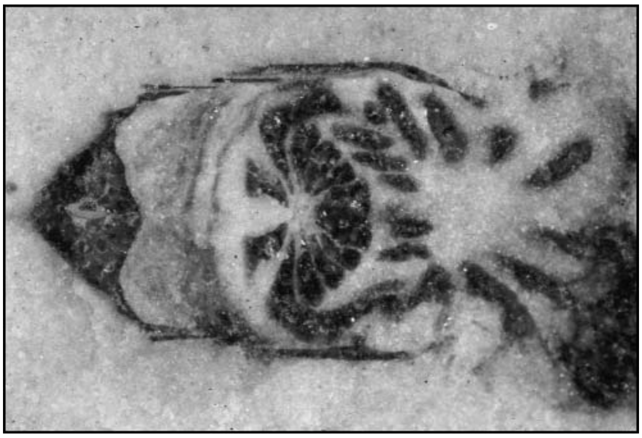

Figure 1. Photograph of a longitudinal section of the chelicerate 'king crab' *Offacolus kingi*. Note the battery of appendages surrounding the mouth area.

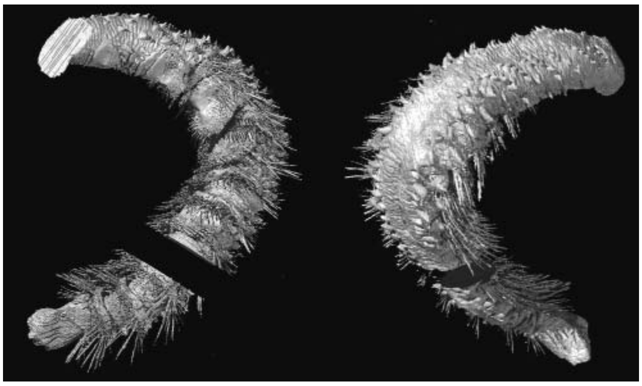

Figure 2. Virtual fossil: dorsal and ventral views of the worm-like mollusc *Acaenoplax hayae* (total length is about 30 mm).

It is a sobering thought that the rocks that yield the Herefordshire Lagerstätten were the stamping ground of no less a luminary than Sir Roderick Murchison, during his pioneer work that eventually saw the establishment of the Silurian System in the 1830's. Since then the area has been visited by generations of geologists.

The Herefordshire fossils cannot be studied effectively by normal means. They cannot be etched from the matrix because their chemical composition is the same as that of the nodules. Moreover, because of their small size and finely preserved structures, they do not easily lend themselves to any kind of mechanical preparation. So, they are reconstructed using a novel approach. This involves computer technology and, paradoxically, the destruction of the fossils themselves. First, in the laboratory the nodules are split to expose the tell-tail specs of calcite, indicating the possible presence of a fossil (about one in three nodules yield such palaeontological gold!). Fossil specimens are then ground away intervals of 20-30 microns at a time, and a digital photograph is taken of each freshly exposed surface (e.g. Fig. 1). Tens to hundreds of

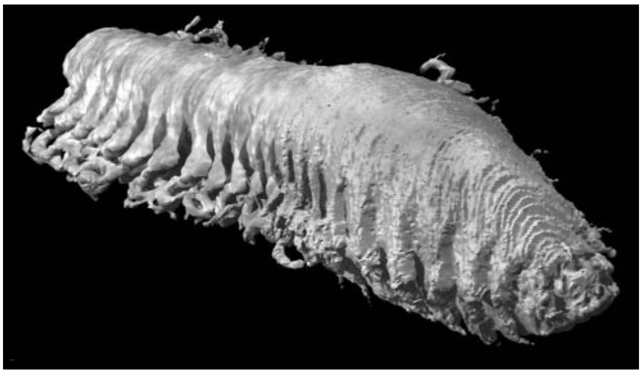

Figure 3. Virtual fossil: the polychaete ('bristle') worm Kenostrychus clements (total length is 15-20 mm).

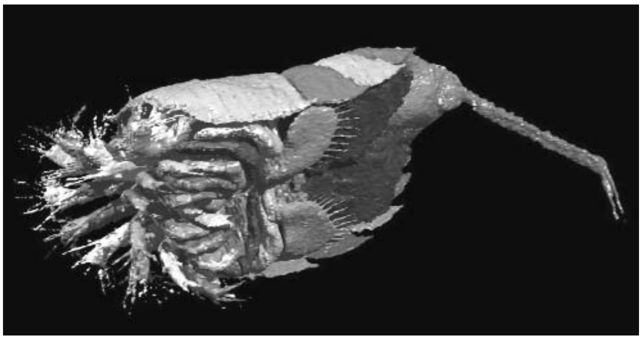

Figure 4. Virtual fossil: the chelicerate 'king crab' *Offacolus kingi* (total length is about 7 mm).

these photographs are then used to create a high-fidelity 'virtual fossil', which can be rotated or even dissected on a computer screen. The computer reconstruction can even be turned into a physical model through rapid -prototyping technologies.

The reconstruction of any one 'virtual fossil' is a time consuming process, but it has rich scientific rewards. The Herefordshire animals date from a period of time for which we have little knowledge of soft-bodied faunas, so they are helping us fill in a gap in the history of life. Those studied in detail so far (Sutton *et al.* 2002 and references therein) include the worm-like mollusc *Acaenoplax hayae* (Fig. 2), the bristle worm *Kenostrychus clementsi* (Fig. 3) and the tiny arthropod king crab *Offacolus kingi* (Fig. 4). These fossils are representatives of previously unknown evolutionary lineages, and are helping to resolve controversies about the relationships both of extinct animals and of those alive today. One of the aims of the research is to eventually reconstruct a snap-shot sea-scape of Silurian life as faithfully as possible. What is certain is that we have many more exciting finds now being studied; who knows what other amazing animals we may recover from the hundreds of 'unopened' nodules that we have collected.

Acknowledgement

Research on the Herefordshire fossils has been supported by NERC and The Leverhulme Trust, and is a collaboration between Professor Derek Briggs (Yale University), Professor David Siveter (University of Leicester) and Drs Derek Siveter and Mark Sutton (University of Oxford).

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LECTURE

A new look at the geological map of southern Britain

Summary of lecture presented to the Society on Saturday 12th April 2003 by Dr John CW Cope of Cardiff University.

Post-Cretaceous movements that affected the British Isles are generally summarised as the Alpine folding that produced E-W trending folds in southern England. However, perusal of the '10 mile' Geological Survey map of southern Britain shows that there is a preponderance of older rocks in the north and west and younger ones in the south and east. A line drawn from Anglesey to London crosses formations of every geological system from the late Precambrian through to the Palaeogene, in close order of succession and only lacking the Permian. This means that effectively there is a south-easterly regional dip for southern Britain.

Studies of the rocks of northern and western parts of southern Britain, using techniques such as apatite fission track analysis, have indicated various thicknesses of lost cover, but the more recent figures suggest that the most deeply eroded areas have lost in excess of 2000 m of cover since the Late Cretaceous. By taking an area that has purportedly lost such a cover thickness (such as the Cheshire Basin) it is possible to reconstruct a stratigraphy that can explain this lost thickness. As the Cheshire Basin was a major Triassic depositional centre, it is likely that, in the context of British regional geology, it also once had a thick Jurassic cover. The Prees outlier, in the southern part of the basin, preserves a thick basinal facies of the lower and middle parts of the Lias Group, so it is not too difficult to imagine an original succession there comprising perhaps 1600 m of Jurassic rocks and 400 m of Cretaceous rocks.

If areas in the north-west have lost up to 2000 m of cover, what about areas farther south and east? The Rugby area lies on the Triassic-Jurassic boundary and must have lost the thickness of Jurassic and Cretaceous rocks that lie to its south-east. Simple extrapolation reveals that this amounts to some 800-900 m, whereas the Chiltern Hills that have outliers of Palaeocene rocks on them, can hardly have lost any cover (Cope 1994). It is thus possible to build up a 'contour' picture of southern Britain by comparing amounts of cover lost; these contours parallel in a remarkable way the outcrop patterns of the Mesozoic formations in southern and eastern England (Figure 1). The area with the greatest loss is in the Irish Sea and may be locally over 2500 m. The uplift was caused by igneous activity that can be dated to the earliest part of the Palaeogene and may well be related to an early phase of dyke activity, dated in the East Irish Sea Basin to 65·5-63.0 Ma. It is likely that such activity caused underplating of the crust and initiated a series of episodes of uplift and erosion that lasted perhaps

30 Ma. If the uplift totalled some 2000 m in the Cheshire Basin fading to zero on the Chiltern Hills, a simple trigonometrical calculation shows that the regional south-easterly dip imparted by such an event is of the order of 50 minutes of a degree. This is too small a figure to feature on a geological map, but enough to produce the result we see.

Other evidence for this uplift and erosion in the north-west is provided by a study of the gravity map of the area, which shows a positive Bouguer anomaly over northern and western Britain, with its contours curved in a similar manner to those of the Mesozoic formations of south-eastern Britain. Over the eroded area Caledonian granites are well exposed and virtually all the outcrops of the Precambrian and Lower Palaeozoic rocks of England and Wales lie within this area too (Fig. 1). This significant period of uplift and erosion explains many of the geological anomalies of western Britain such as the almost total absence of the Chalk. Despite some of the highest sea-levels in the Phanerozoic there is no preserved Chalk in the whole of the Irish Sea, although there are considerable thicknesses of Jurassic rocks in the Cardigan Bay and Kish Bank basins. It now appears clear that the Chalk was once deposited over the whole of this area and has since been removed by erosion. It also explains why mature hydrocarbons occur at relatively shallow depth in the Eastern Irish Sea Basin; the area has lost some 2000 m of Jurassic and Cretaceous rocks (Cope 1998).

The material eroded from the uplifted area, amounting to some 200,000 km^3, would have been rapidly removed under the tropical regime of Palaeogene Britain. Erosional products were transported to the North Sea in the east, and across Ireland to the Porcupine Basin and other areas on the Atlantic margin of Ireland. Sediment would have been transported along major river systems that would have flowed radially outwards from a centre now in the Irish Sea, to the north of Anglesey. These would be the forerunners of today's drainage and it is remarkable that all the long rivers of southern Britain rise in the west and flow eastwards, while those of Ireland rise in the east and flow westwards; this is a direct result of their post-Cretaceous origins. The margins of the Irish Sea, including Cardigan Bay, and northwards to the Solway Firth have undergone later down-faulting that has produced short rivers that flow into the Irish Sea on both the Anglo-Welsh and Irish sides; these have captured some of the flow from the principal drainage. Although the drainage has been modified by glaciation, its origins remain remarkably clear.

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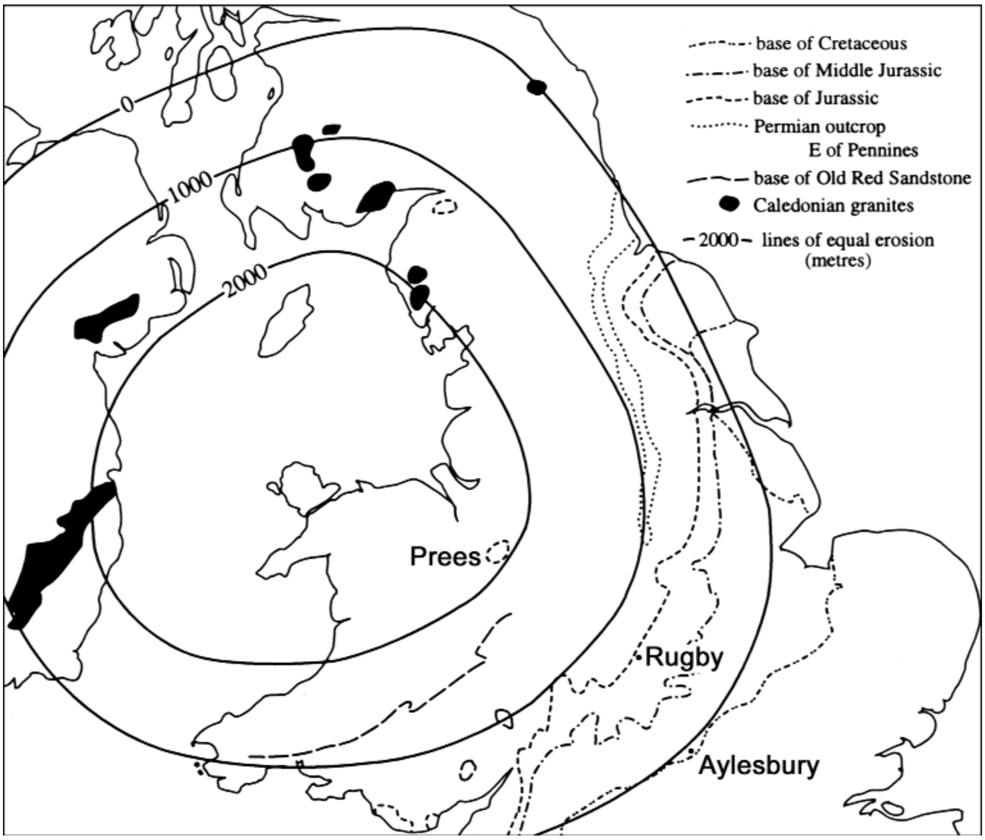

Figure 1. Possible extent and amount of the net erosion of the Irish Sea and surrounding areas. Note the marked parallelism with the formation boundaries, except in north Yorkshire where they curve around the pre-existing Cleveland Basin. All outcrops of Precambrian and Lower Palaeozoic rocks of England, Wales and eastern Ireland lie within the eroded area. Position of the contours over southern Scotland more conjectural since they have been affected by the later uplift of western Scotland. Reproduced by permission of the Geological Society of London.

LECTURE

The end-Permian mass extinction

Summary of a lecture presented to the Society on Saturday 8th February 2003 by Dr Paul Wignall of Leeds University.

Our knowledge and understanding of the end-Permian mass extinction has increased dramatically in the past 10 years as the pace of research on this, the largest mass extinction event of all time, has intensified. Much of the long-standing dogma has been swept away, particularly the notion that it was a protracted crisis, spread over millions of years, associated with a spectacular sea-level fall. It is now generally appreciated that the extinction was geologically fast (spread over tens of thousands of years). The event also appears to have occurred during a phase of rapid sea-level rise not fall! This change in perception has come from the study of widely scattered Permian-Triassic boundary sections and an improvement in the diversity of dating techniques for Late Permian strata. Thus, many sections previously thought to be lacking Uppermost Permian rocks have been shown to have a complete record of this interval.

With the new data have come new ideas as to the cause of the extinction. The marine extinctions are associated with the widespread development of oxygen-poor bottom waters; lethal conditions that seem to have spread into remarkably shallow water settings and thus to have severely restricted the available habitat area for marine life. On land there is abundant evidence for dramatic global warming across the Permian-Triassic transition and this climatic change is almost certainly responsible for the dramatic extinction of terrestrial plant life particularly in higher latitudes.

Undoubtedly the most significant development in the past decade has been the realisation, thanks to vastly improved radiometric dating techniques, that the eruption of the Siberian Traps flood basalt province coincided with the end-Permian mass extinction. These Traps are just one manifestation of the most voluminous form of volcanism known on Earth. Many other provinces have also been found to coincide with other mass extinctions in the past few years. The Siberian Traps were a particularly large province, with an original volume of extrusive volcanic material perhaps approaching 4 - 5 million cubic kilometres. The question has therefore arisen of how the observed phenomenon of extinction/ocean anoxia/warming can be related to the eruption of huge amounts of basalt. This question is also pertinent to other mass extinction horizons (for example the end-Triassic and early Jurassic extinctions) for which there is a similar coincidence of events.

The most obvious climatic impact of large, modern volcanic eruptions is the short-term cooling effect caused by the fine haze of volcanic dust and sulphate aerosols that can be injected into the stratosphere. However, these effects only last a year or so because the dust and aerosols are rained out of the atmosphere and they are only capable of affecting the hemisphere in which the volcanism occurs. It is a moot point whether such affects would have any long term damage. The quiet nature of flood basalt eruptions also makes it unlikely that the volcanic dust and gases would ever reach the stratosphere. Thus, many workers have tended to focus on the likely climatic impact of volcanic carbon dioxide emissions during flood basalt eruptions. After all, the geological record suggests that warming, not cooling, occurred during many mass extinctions including the end-Permian event. However, despite the size of the Siberian Traps, calculations, based on the known volume of gas emitted during modern basaltic eruptions, suggest that the rate of carbon dioxide emissions during Siberian volcanism are not likely to have greatly exceeded modern anthropogenic emissions.

This leaves the link between volcanism, climate change and extinction something of a puzzle and many workers now view the volcanism as a trigger in a chain of events. A favourite source of further greenhouse gases in many models is gas hydrates. This substance is essentially ice but it traps alkane gases, mostly methane, in its interstices and is found in huge volumes below the seafloor on many continental slopes. Just a few degrees warming of ocean water would be required to melt these hydrates and release their methane load into the atmosphere, whereupon it would greatly exacerbate any warming trend. Thus, the eruption of a giant volcanic province is envisaged to trigger a lethal positive feedback mechanism of rapid global warming, the effects of which seem to have been to slow down ocean circulation and cause an oxygen crisis for marine life. The parallels of such scenarios with modern environmental concerns are of course very apparent. The end-Permian mass extinction should perhaps be viewed as a warning from history.

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EXCURSION

The East Devon and Dorset coast

Leaders: Chris Pamplin, Richard Hamblin (BGS)

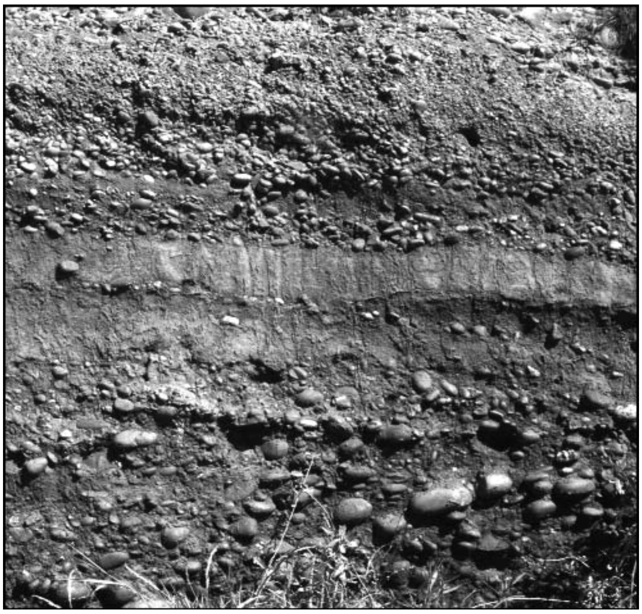
Weekend 7th-8th September 2002

This weekend trip was organised to celebrate the granting of World Heritage status to the coast of East Devon and Dorset, in recognition of the outstanding sections of Triassic, Jurassic and Cretaceous rocks exposed in a series of sea cliffs. For the Saturday we were lucky to have the services of local professional tour leader Chris Pamplin, and for the Sunday we were led by Richard Hamblin, who had recently been working in this area for the BGS Sidmouth mapping project (Edwards *et al*, in press). Unfortunately only eight further members of the Society were able to attend, staying in accommodation around Sidmouth.

Both the Saturday and Sunday were blessed with warm sunny weather. The plan was to start low in the Trias and work our way up the succession, so the EMGS members met up with the leader on the sea-front road at Budleigh Salterton, left our cars and walked westward along the beach to the cliffs of Budleigh Salterton Pebble Beds Formation. Here we discovered that Chris is the type of leader who asks awkward questions rather than dishing out dull facts, and although we probably all knew already that the formation was of fluvial origin, we were obliged to search diligently for actual evidence! Fortunately the thick beds of conglomerate yielded ample evidence of imbrication, with trough cross bedding in the intercalated sand beds, while dreikanter, desert-varnished and wind-faceted pebbles at the top of a conglomerate bed, demonstrated a desert climate. The conglomerates contain very well rounded pebbles and cobbles largely of metaquartzite, with a little porphyry, vein quartz and tourmalinite. No fossils were found in the quartzites on this occasion, but brachiopods eg *Orthis budleighensis* and *Lingula leseuri*, bivalves and trilobites indicate derivation from Ordovician and Devonian rocks in Brittany, Normandy and Cornwall. Detailed sedimentary analysis indicates a large, fast, south to north flowing braided river.

From Budleigh Salterton we drove to Ladram Bay and parked in the car park of the caravan site, then walked westward along the cliff top. From here there are splendid views of the impressive sea stacks in the bay. These are formed from the Otter Sandstone Formation, a softer unit than the Budleigh Salterton Pebble Beds, comprising reddish orange-brown cross-bedded fine- to medium-grained sandstones, with subordinate conglomerates and mudstones. Like the Pebble Beds, the Otter Sandstone was deposited in braided and meandering stream channels in arid to semi-arid environments, in a south to north flowing river system. From Ladram Bay we drove to Beer, although on the way most people stopped, illegally, on the road descending from Peak Hill towards Sidmouth, from which the view eastward is spectacular, with the full succession of the Mercia Mudstone Group cropping out in the sea cliffs beyond Sidmouth and overlain by Upper Greensand on the hilltops. The Mercia Mudstone Group constitutes the bulk of the Triassic succession in the district, whilst the Upper Greensand Formation, of Albian (late Early Cretaceous) age, overlies it unconformably. The Albian sea transgressed from the east, with the unconformity resting on Jurassic rocks in the east, cutting down almost to the base of the Mercia Mudstone at Peak Hill, then re-appearing west of the River Exe where it rests upon Permian and Devonian strata.

In Beer, the leaders ate their sandwiches on the beach while the Society members investigated the delights of the town, then we walked westward along the beach to the first cliff exposure, where the Chalk Group is seen resting on the Upper Greensand. The Upper Greensand Formation comprises a series of calcareous sandstones, calcarenites and chert beds, and the topmost member hereabouts, now termed the Bindon Sandstone Member, is a coarse, calcareous sandstone with calcarenite, slumped beds, contortions and festoon-bedding structures in its upper part. The lowest formation in the Chalk Group in East Devon is the Beer Head Limestone, a near-shore shallow-water condensed sequence equivalent to the Zig Zag Chalk Formation farther east in the Wessex Basin. At Beer this comprises 0.6 m of highly bioturbated porcellanous limestone including three prominent mineralised hardgrounds associated with glauconitic (green-coated) pebbles. It sits on a hardened surface of Upper Greensand calcarenite, indicating a marked sedimentary break, but with no detectable unconformity.



Budleigh Salterton Pebble Beds at their type locality.

Cliffs of the Mercia Mudstone Group east of Sidmouth overlain by the Upper Greensand at Golden Cap.

Finally for the Saturday we drove to Lyme Regis and parked at Monmouth Beach, and for the fourth time that day walked westwards, this time to look at the lower part of the Early Jurassic Lias Group. The foreshore here is a wave-cut platform in the Blue Lias Formation, with the lowest member of the overlying Charmouth Mudstone Formation, the Shales-with-Beef, cropping out in the cliffs. The Blue Lias comprises interbedded grey shales and hard, fine-grained, blue-hearted limestones. The thickest mudstone is 1.8 m thick, and the thickest limestone about 0.6 m (Edwards *et al*, in press). The Shales-with-Beef Member comprises thinly bedded grey mudstones with numerous beds up to 0.2 m thick of fibrous calcite colloquially referred to as 'beef', and a few discontinuous beds of limestone as in the Blue Lias. Because of the high risk of cliff-falls we restricted our activities to examining the rich fauna exposed in the foreshore limestone pavements in the Blue Lias, finding a surprising number of specimens of *Nautilus*, and a variety of ammonites, some of prodigious size.

Sunday again dawned fine and sunny and we met at Charmouth, but as the tide was high, a decision was made to leave the beach walk until after lunch, so we headed inland. After a hiatus when the leader realised he had left his camera in the car park at Charmouth and discovered just how fast a BGS Ford Escort will go, we met up again at Pilsdon Pen, an iron-age fort surmounting the highest point in Dorset. The view was clear as far as the Mendip Hills to the north, and to the west appeared to be an unbroken flat plateau of Upper Greensand, but the leader explained that we were looking at a series of fault-blocks, each of which had rotated to dip eastwards (towards us) as they were down-faulted to the west by listric faults flattening out westwards at depth.

A stop was made at Broadwindsor at a rock and fossil shop which turned out to possess the largest amethyst geode in captivity in Europe, imported from Brazil and not for sale. We then stopped at a development site nearby in Inferior Oolite Formation limestone, known to Ian Sutton, who had obtained permission for our visit from the Nature Conservancy. The fresh exposure revealed a very rich fauna of bivalves, ammonites and gastropods but no collecting was allowed. We then drove down to the coast at Burton Bradstock, where the valley descending to the sea follows a fault which at the beach throws the Middle Jurassic Fuller's Earth Clay against the Lower Jurassic Bridport Sands (Wilson *et al*, 1958). We walked westward along the beach to examine the impressive sea-cliffs of Bridport Sands, orange-yellow micaceous sands with prominent bands of blue-hearted calcareous sandstone. The shingle beach piled against these cliffs forms a part of Chesil Beach, which extends for 15 km to the Isle of Portland, clearly visible to the east. During the rest for lunch, at least one member of the party walked to the headland east of the fault, from which the more characteristic topography of Chesil Beach could be seen, with hollows and meres, some of them water-filled, between the great shingle bank and the low slope of the clay cliffs.

Having thus proved it was possible to walk eastwards along a beach, we returned to Charmouth, parked in the car park by the River Char, and walked eastwards beneath cliffs of the Charmouth Mudstone Formation of the Lias Group. The dip is about 2° to the east, dropping successive members to beach level. Immediately east of the river, the Shales-with-Beef Member is overlain by the Black Ven Marl Member, fissile dark grey mudstone with individually named beds of tabular and concretionary limestone including the 'Birchi Tabular' at the base and the 'Hummocky' at the top. This is succeeded by the Belemnite Marl Member, pale to medium grey massive calcareous mudstone with abundant belemnites in the upper part and the 'Belemnite Stone' limestone at the top. This is overlain by the Green Ammonite Member, black fissile mudstone with a few limestone beds, so-called because of the greenish calcite infilling the septa of some of the ammonites. Large numbers of small exquisitely pyritised ammonites were found on the wave-cut platform in the Green Ammonite Beds. The leader explained that inland in the Sidmouth district it had proved possible to distinguish the Belemnite Marl Member from the over- and underlying dark shale members, by its paler colour and its relative hardness, but that there was insufficient exposure to separate the Shales-with-Beef from the Black Ven Marl: in the Bridport district, where the Lower Lias is less affected by a soliflucted cover derived from the Upper Greensand, all four members have been mapped.

By this time it was late afternoon and most of the party set off for the East Midlands, although some not going straight home stopped to visit the excellent free museum on the quay in Charmouth.

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EXCURSION

Carbonate mud mounds in Ricklow and Lathkill Dales

Leader: Peter Gutteridge

Wednesday 24th July 2002

The aim of this excursion was to demonstrate the structure of a group of carbonate mud mounds at the top of the Monsal Dale Limestones in Ricklow Quarry and adjacent parts of Ricklow and Lathkill Dales, and to examine the succession around the Monsal Dale and Eyam Limestones boundary at the western end of Lathkill Dale. The party met at the lay-by where the B5055 crosses Lathkill Dale, east of Monyash (SK157664). The contact between the Monsal Dale and Eyam Limestones is exposed at about the level of the lay-bay and can be seen on either side of the dale (Fig. 1). The lower part of the Eyam Limestones is exposed on the north side of Lathkill Dale in a section about 200 m long along the B5055. Here, the Eyam Limestones consist of bioclast wackestone passing upwards into bioclast packstone with scattered gigantoproductid brachiopods; no carbonate mud mounds are present in the succession at this point. The party walked about 1 km down Lathkill Dale to a view point opposite Ricklow Quarry on the south side of the dale (SK163660). From here the complex of carbonate mud mounds can be seen in all their three dimensional glory.

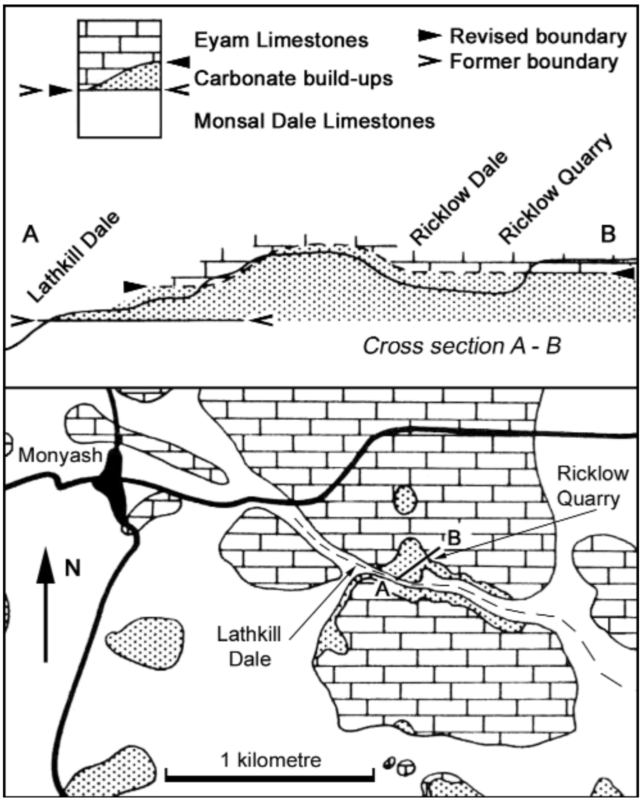

Figure 1. Geological sketch map and section of the upper part of Lathkill Dale and Ricklow Quarry (modified from Gutteridge, 1991).

Crossing back to the north side of Lathkill Dale the party climbed up a carbonate mud mound. This was a mounded feature on the Dinantian sea floor composed mainly of carbonate mud with scattered fenestrate, fan-shaped, bryozoans and pockets of brachiopods and bivalves preserved in their growth position. Proceeding over the crest of the carbonate mud mound into Ricklow Dale, the flanking beds that represent the margins of the carbonate mud mound can be seen along the sides of the dale. The flank beds dip by some 20° away from the cores and pass laterally into flat-bedded densely crinoidal limestone in the main part of Ricklow Quarry. This shows that the carbonate mud mounds were surrounded by dense forests of large crinoids. The top of the carbonate mud mounds and equivalent limestones are covered by a calcrete showing that they were subaerially-exposed soon after deposition (Adams, 1980). The limestones overlying the carbonate mud mounds seen in the road section are also exposed in Ricklow Quarry. These are bioclast wackestone and gigantoproductid packstone that were deposited during re-flooding of the carbonate mud mounds after exposure that were seen in the road section at the head of Lathkill Dale. Examining the initial stages of the carbonate mud mound's growth on the way back to Lathkill Dale involved some painfully rough walking over steep slopes covered in tussock grass and boulders hidden beneath vegetation. This shows that the carbonate mud mound started as a number of low relief tabular mud mounds a few tens of metres across. These amalgamated and expanded to form the fewer, larger cores at the head of Lathkill Dale and Ricklow Quarry.

Thanks to Ben Labarr, warden of the Lathkill Dale National Nature Reserve for granting permission to go off the public footpaths.

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