Home Counties North Regional Group Newsletter

Issue No. 21 - December 2024

Remembering the late Dr J.P. Bryan Lovell OBE FGS (10.2.1942 - 20.9.2024)
Past President of the Geological Society of London (2010-2012)
Past Chair of the Home Counties North Regional Group in the 1990s.
Home Counties North Regional Group Member
Contributor of many geoscience articles to HCNRG Newsletters

On 21st June 2014, members of the newly relaunched Home Counties North Regional Group met in Hertford for their first field meeting, led by John Wong. Dr Bryan Lovell OBE who was a member of the HCNRG joined the second half of the field meeting at the Hertford Castle ground, he gave an informative talk on Puddingstone and climate change.

John Wong FGS, Chair Home Counties North Regional Group

Photograph taken by Dr David Brook OBE FGS ©

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Home Counties North Regional Group Chair’s report 2024

John Wong FGS, Chair HCNRG

Dear Home Counties North Regional Group members,

I hope everyone and your families are well.

It has been a challenging year in terms of organising the AGM, delivering lectures (in-person/Zoom/hybrid) and field meetings (see Home Counties North Regional Group 2024 programme of events on the HCNRG website) because we did not have a full programme for which we were aiming.

The 2024 AGM was the highlight in the HCNRG calendar, the AGM has been well attended by members from every north home county (Bedfordshire, Buckinghamshire, Hertfordshire, Northamptonshire) and from the north and east London areas. My big thank you to Dr Ilias Karapanos FGS (member of HCNRG) who kindly hosted the AGM at Affinity Water’s Hatfield offices, arranged excellent complimentary buffet and refreshments; we all enjoyed it, I am grateful to Dr Ilias Karapanos FGS for looking after the members so well at the AGM.

Chartership Officer for the Geological Society, Dr Eleanor Williams FGS, presented a talk on Chartership, then followed by Dr Ilias Karapanos FGS gave an informative talk entitled ‘Managing water resources during the extremes – Droughts and Floods.’ HCNRG members said to me that it was an excellent talk.

In January, Kathryn Price presented her lecture ‘Ancient Rivers, Early Humans: The River Thames 500,000 - 1 million years ago’ at RSK Hemel Hempstead.

In February, we had our first advertised hybrid lecture at EWR Alliance in Milton Keynes, ‘East West Rail Stage 2 (Bicester-Bletchley) engineering geology & geotechnics’ presented by Katherine Kendall FGS and Simon Miles FGS.

In April, Dr Eimear Deady of British Geological Survey presented her talk on Zoom ‘Critical Raw Materials (CRMs) – A national-scale assessment of the geological potential for CRMs in the UK’.

In May, Nick Cameron FGS presented an in-person lecture ‘Ferruginous sandstones, the Grim’s Ditch Line and the Calabrian Surface’ at The White Hill Centre in Chesham.

Dr Ilias Karapanos FGS kindly arranged a special visit/in-person lecture at Affinity Water Hatfield offices, his talk was entitled ‘Map Talk: The Affinity Water supply system now & in the future’. HCNRG members said it was a great lecture.

For our London members, in June, we held a HCNRG lecture event at Burlington House again after a dry spell of five years. It was a double-lecture event – ‘William Joscelyn Arkell (1904-1958): The UK’s greatest Jurassic Stratigrapher’ presented by Owen Green FGS, and ‘Deformation in the northern part of the Moine Thrust’ presented by Roy Dunn, FGS. Both speakers put up information posters of their talks on panel boards in the Lower Library before the double-lecture event, Roy Dunn also display rock specimens of his talk. HCNRG members took the opportunity to speak to both speakers before their talks.

In September, we had our second hybrid lecture at the new venue at Soiltechnics Limited in Walgrave in Northamptonshire. ‘Ironstone: Geology, mining and legacy land’ presented by Dr Matt Hooper FGS and Ian Dunkley of Soiltechnics Limited.

In November, Professor Hilary Downes FGS presented her lecture on Zoom, entitled ‘Volcano Collapse’, this lecture was well attended, participants including FGS members from other Geological Society regional groups.

Mick McCullough FGS and Adrian Marsh FGS organised the Christmas Quiz in December at The Iron Room in Tring.

In May, Adrian Marsh FGS led a second-round field trip for the HCNRG members on the waiting list, to HS2 Chiltern tunnels South Portal and Colne valley viaduct sites, and Northmoor Hill Nature Reserve/Rock Route at West Hyde and Denham Green, Buckinghamshire.

In October, I led a field trip to Bardon Hill Quarry in Coalville, Leicestershire. The geology is Neoproterozoic ocean-arc andesitic volcanic complex, and Triassic Mercia fluvial deposits.

Home Counties North Regional Group Newsletter issue number 21 will be issued in December 2024.

Merry Christmas and a good happy New Year 2025 to all the HCNRG members and your families.

John Wong FGS, Chair HCNRG

Bardon Hill Quarry. Triassic Mercia mudstone and sandstone lie unconformably on Neoproterozoic ocean-arc andesitic volcanic complex.

Photograph taken by Rudy Domzalski FGS October 2024 ©

From the Newsletter Editor

John Wong FGS, Newsletter Editor HCNRG

Dear Home Counties North Regional Group members,

I would like to thank every contributor of newsletter articles to this newsletter for their time and generosity in writing excellent geoscience articles, with informative diagrams and postcard quality pictures and sharing your best knowledge with the members.

Thank you very much to Adrian Marsh FGS for writing up six Home Counties North Regional Group lecture reports.

Thank you very much also to Rudy Domzalski FGS and Richard Trounson FGS for their times in writing up a eight and half page report on the field meeting ‘The geological and geoarchaeological aspects of Londinium (Roman London) on two hills walk’.

In October, I heard the sad news Dr Bryan Lovell OBE CGeol FGS has passed away, Dr Bryan Lovell OBE has been a dedicated Home Counties North Regional Group member behind the scenes, he has contributed many articles for the Home Counties North Regional Group newsletters, and he often sent encouragement and compliment to me for what the committee members of the relaunched Home Counties North Regional Group have achieved.

Dr Bryan Lovell OBE asked me to include his published article ‘*The Proof in the Puddingstone: messages from a warm planet*’ and the abstract of his most recent published paper (2023) ‘*New exposure of the Cretaceous-Paleogene unconformity and Paleocene-Eocene pebble bed in Paleogene outlier at Collier’s End, Hertfordshire, UK*.’ in this newsletter and I am pleased to do so in his memory.

An oil painting portrait of Dr Bryan Lovell OBE is on the righthand side wall in the lecture theatre of Geological Society in Burlington House.

John Wong FGS, Newsletter Editor

The Proof in the Puddingstone: messages from a warm planet

Dr Bryan Lovell OBE FGS

Bryan Lovell OBE, sitting in a Hertfordshire copse, looks back on a life in sandstones and oil, and at the significance for Homo sapiens of events that took place 55 million years ago.

Part One – the Pudding

This cautionary tale is, like all stories, based on imagination. That imagination is in turn guided and constrained by some implacable messages to be read in rocks 55 million years old: messages of great significance to our grandchildren and to the state of the planet we shall pass on to them. I write for the widest possible field of readers of *Geoscientist,* in the hope that those experts hungry for specialist technical meat will find nourishment in the References.

Not far from the road that the Romans called Ermine Street and we more prosaically call the A10, one can walk north across a ploughed field with a left foot on 85 Ma chalk and a right foot on 55 Ma pebble beds. Evidence from elsewhere suggests persistence of the chalk sea in this area until around 65 Ma, then land with sea breezes – and eventually the A10. A perfect location for lines from Tennyson previously favoured by geologists: “There, where the long street roars, hath been the stillness of the central sea”.

Above the field stands a copse. The farmer has not sought to bring it under the plough, and there’s a good reason. The line separating chalk and pebble beds is now obscured by thicker soil and well-established trees growing between pits and mounds with relief of a few metres. Scattered on the surface between the roots lies evidence of the pebble bed below - rounded flint pebbles. These are mixed with a few angular fragments in which the rounded pebbles are firmly cemented together. Any fracture-surfaces in these angular fragments cut indiscriminately across both the flint pebbles and the cement that binds them. This is the Hertfordshire Puddingstone.

Over the years the farmer has been pleased to pass to an interested local geologist the larger fragments of puddingstone turned up by the plough on the path down the slope from the copse: Jane Tubb now has quite a collection (Figure 1). When the farmer's plough meets a big lump of puddingstone, his plough breaks - but puddingstone does not. Our remote ancestors, shaping it for use as querns for milling grain, dug large concretions of puddingstone (Figure 2) out of the largely uncemented Paleogene pebble bed in which they occur, broke them up and shaped them in the copse - carrying or rolling the products down the hill to Ermine Street (Lovell & Tubb, 2006).

Fig. 1.Hertfordshire Puddingstone artefacts discovered by Jane Tubb near Puckeridge, Herts. The main fragment is interpreted as a failed attempt by a disappointed Roman to make a beehive quern. Superimposed is a quarter-fragment of a previously successful attempt found nearby. Scale bars are 10cm long. From Lovell & Tubb, 2006, Mercian Geologist.

Fig. 2. Concretion of Hertfordshire Puddingstone, one of an outstanding collection made by the Parkins family of High Cross, Hertfordshire, during construction of the A10 bypass that cut through their farmland. Men working on the new road, some of whom were billeted at the farm, were charged by Bessie Parkins with bringing all puddingstone recovered in operations to her for safe keeping. Scale is 50cm. The white patch of sand seen in the centre is shown in detail in Figure 10.

Looking down that slope from the copse to the ancient route below provokes some comparisons on technology. Grinding corn with puddingstone querns was more important to the survival in that area of our Stone Age and Roman ancestors than oil is to us today. You *have* to eat: you don't really *have* to consume hydrocarbons by driving up the A10 and then flying from Stansted to Malaga – although that could be fun in the company of at least some Fellows of the Geological Society.

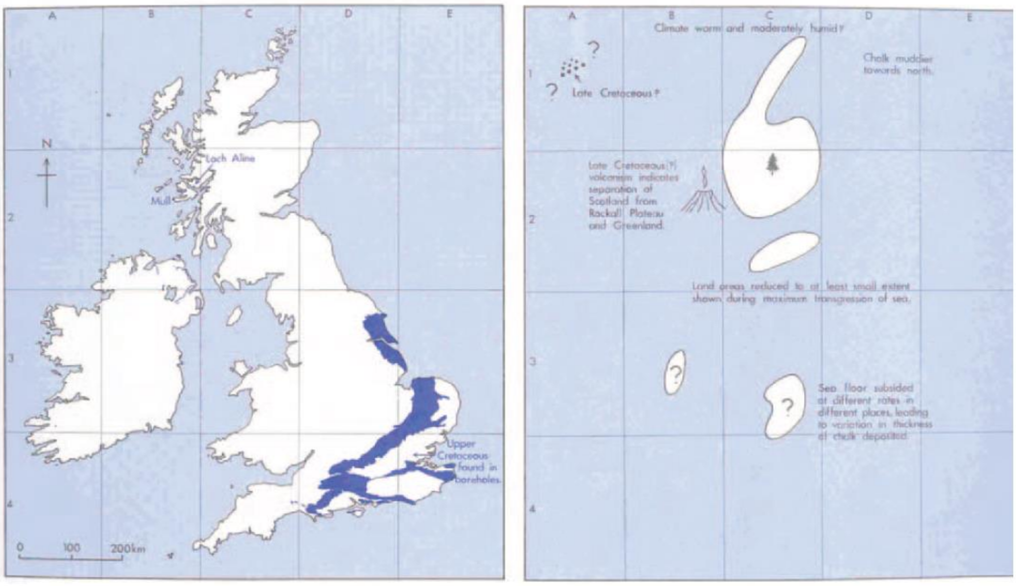


Fig. 3. Palaeogeography of Britain and Ireland around 80 million years ago (right), with areas of exposure of Late Cretaceous rocks shown (left) for reference. This sketch was made in the mid-1970s, by which time early results of drilling in the North Sea were becoming generally available. From Lovell, 1977, Allen & Unwin.

Figure 3, a sketch I made in 1977, shows how land and sea in the area of Britain and Ireland were distributed some 80 million years ago. Hertfordshire is indeed under Tennyson's central sea. Only bits of Scotland, Wales and Ireland form land; it is impossible to recognise anything resembling present-day coastlines. That map could only be sketched with confidence once we had information from beyond those familiar present-day shores, once exploration for oil and gas beyond the coasts of Britain and Ireland really got under way in the Sixties. That exploration led to some now legendary early successes and provoked geological liaison across tribal boundaries that persists to this day.

Dr David Jenkins, Chief Geologist with BP in Aberdeen, was flushed with the company's recent successful discovery of the giant Forties oilfield when, in November 1972, he came to Edinburgh to give a talk on North Sea exploration. I was his young host, then striving to be recognised as a specialist in sandstones formed in deep water, carrying out research at Edinburgh University. I had recently returned from my doctoral research with Raymond Siever at Harvard University, in an atmosphere where no one seemed snooty about either money or knowledge. Collaboration between geologists in universities and industry appeared to be a natural part of everyday life, in a fashion then emulated in Britain only by a few pioneers such as (ex-Shell) Harold Reading at Oxford University.

A tyro is characteristically proud of his specialist abilities – in my case, to distinguish between different types of sandstone. Fresh from camping in a small green tent amidst the turbidites of the Eocene Tyee Formation of the Oregon Coast Range, I was certainly not snooty about applying knowledge to practical matters. After all, the oil industry had paid for the tent. I was also more than happy to supplement a junior lecturer's salary. I listened keenly to the Chief Geologist and offered what I considered to be some quite nifty ideas over dinner with David and Evanthia Jenkins at Denzler's Swiss Restaurant.

Jenkins told me that there was an unresolved debate within BP concerning the deposition of the Forties reservoir sandstones: deep water or shallow water? "The depositional environment… is still under study…" (Thomas & others, 1974, p.400). Although he did not discuss it in the restaurant that evening, Jenkins already had a line of evidence indicating a relatively deepwater setting. I first became aware of this at a remarkable conference convened in Bloomsbury in November 1974. At this now famous meeting, immaculately suited oil company men mingled with dishevelled British academics. For the first time the companies were sharing previously secret information and ideas about the North Sea.

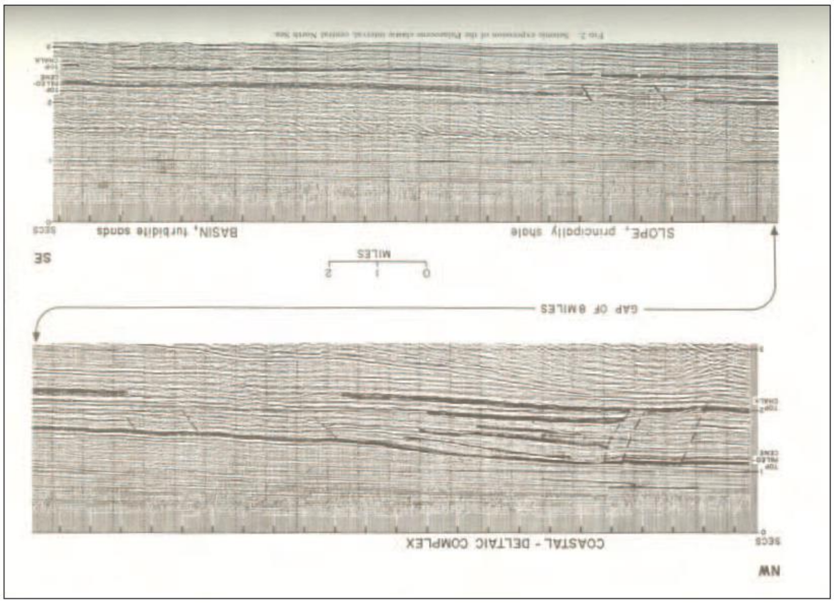


Fig. 4. Regional seismic cross section of rocks below the bed of the North Sea, extending from the east coast of Scotland into the Central North Sea where Forties oilfield is located. This section was first shown by John Parker of Shell at the North Sea Bloomsbury Conference in November 1974. It was published in the conference proceedings by Applied Science (for Institute of Petroleum) in 1975.

Shell had suffered a near miss with Forties, hitting only the eastern edge of the field in their own exploration acreage; but it was their man John Parker who spoke about the regional setting of this huge discovery. The rapt audience much appreciated being shown a seismic cross- section (Figure 4) (Parker, 1975): these were early days for what soon became the massive subject of seismic stratigraphy. From my brief view of the evidence flickering over the Bloomsbury screen, I could not be sure of the exact tracing of the key lines as they appeared to slope downwards from the Paleogene shoreline towards Forties, but the indications were that the reservoir had been deposited in relatively deep water.

A couple of months later, in January 1975, David Jenkins was back in Edinburgh. He was keen to recruit our better students from the Grant Institute of Geology into his team at Aberdeen, and into BP at large. We met in my room at the university and talked about graduate recruitment and about BP's continuing internal debate on Forties sandstones. Two days later I found myself in a storehouse of cores of rock near Dyce Airport, ripping the lids off wooden boxes containing sandstone cores recently cut from Forties Formation, my excitement heightening on being told that I was the first "outsider" to look at these specimens of one of the most perfect oil reservoirs ever discovered.

Indeed the sandstones are almost too perfect to reveal their origin. They are mostly quite homogeneous, and so porous that they crumble readily (Figure 5). For me then - and now – a key part of identifying deepwater sandstones is the study of their relationship with interbedded mudstones. Not until late in the day did I open a box containing cores from the uppermost part of the main reservoir: at last - alternating layers of sandstone and mudstone. I delivered my verdict: Forties Formation was deposited in relatively deep water - proximal turbidites, so there was more sand away to the southeast (I said). I detected a thin smile on the face of the Chief Geologist. It was almost as if David Jenkins already knew the answer.

Fig.5. Core of Forties Formation reservoir taken from c.2755-2765m depth in well Forties Delta 52 on 17 May 1982, as part of a programme to assess the feasibility of enhanced oil recovery using surfactants.

Photograph taken by the author with a Rollei B 35 camera, so old that nothing might spark.

Later that year, when the proceedings of the Bloomsbury conference appeared in print, I could see why Jenkins had smiled. “You must have known what the seismic showed in detail when you asked me to look at those cores” I complained, when next we met. That thin smile again: “I wanted to see if it was possible to reach the correct conclusion simply from the evidence within the cores.” It was. Two separate approaches had given the same answer, which in turn reduced BP’s risks in planning production from Forties, and guided new exploration.

That crucial final box of cores of Forties sandstone in Aberdeen changed the life of my young family. Encouraged by this happy experience of the usefulness of both knowledge and money, my wife Carol and I formed a consultancy group with my Edinburgh University colleagues Brian Price and Terry Scoffin. Then in 1981 I accepted an invitation from BP to join the oil industry full-time and moved south, into Hertfordshire Puddingstone territory. So it was that, fourteen fascinating years later, in May 1995, I was visiting BP’s Aberdeen office, enjoying talks on their research being given by Dr Nicky White and his young team from Cambridge University.

They explained that Scotland had first been lifted up some hundreds of metres out of the chalk sea around 65 million years ago, as a result of the intrusion of an underplate of magma a few kilometres thick at the base of the crust (Brodie & White, 1995). According to the Cambridge team, the classical geological history recorded in the glorious scenery of the Paleogene volcanoes of the Hebrides (Figure 6) was only part of the story. Most of the magma had been trapped deep beneath the surface, like a permanent jack beneath a car, holding Scotland above the waves.

“How fast did that magma come in beneath Scotland?” I asked Nicky.

“About the speed of a Cambridge cyclist - to quote Dan McKenzie” came the reply.

“Did those cyclists arrive in batches?” I asked. “That is an odd question” replied White. “Why?”

“Because if they didn’t arrive in batches, your explanation cannot be entirely correct” I ventured. “We know that the sand-rich submarine fans formed episodically, with muds deposited between them. So there must have been a series of upward movements of
Scotland, not just one big heave.”

Fig.6. Paleogene igneous rocks of Isle of Skye, Scotland: the threatening majesty of the Cuillins viewed from the southeast across Loch Scavaig. Photo: H. & F. Ascui.

Part Two – Hot blobs rising

We already knew from BP's detailed study of the North Sea that the Forties sandstones formed one of a series of sand bodies shed from ancient Scotland (Figure 7) (Stewart, 1987). These separate sheets of sandstone were laid down on the floor of the ancient North Sea in a number of episodes, at intervals of a million years or more. In between, muds were deposited - in time forming the seals that now prevent oil leaking to the surface. What we in the oil gang did not know in 1995 is just *how* Scotland had been pushed up out of the chalk sea. This was what Nicky White had presented to us. Nicky and I published our ideas (White & Lovell, 1997) and then began to seek a fuller understanding of how these pulses of sand originated and their fundamental cause. We came to realise that control of regional uplift by pulsed magmatic underplating, which we had favoured as an hypothesis in the years following our 1995 encounter, was only one particular example of a more general phenomenon. A decade later, during doctoral research funded at Cambridge by BP, our colleague Max Shaw Champion recognised evidence in his work and that of John Underhill (ex-Shell) and Friobjorg Biskopsto at Edinburgh University, for successive uplift of the sea floor in two different areas: first to the west of Scotland and then, 0.3-1.6 million years later, to the east of Scotland (Figure 8) (Shaw Champion & others, 2008; Rudge & others, 2008). This transient uplift took place around 55 million years ago. Peak uplift was at least 490 metres in the west, and some 300 metres in the east.

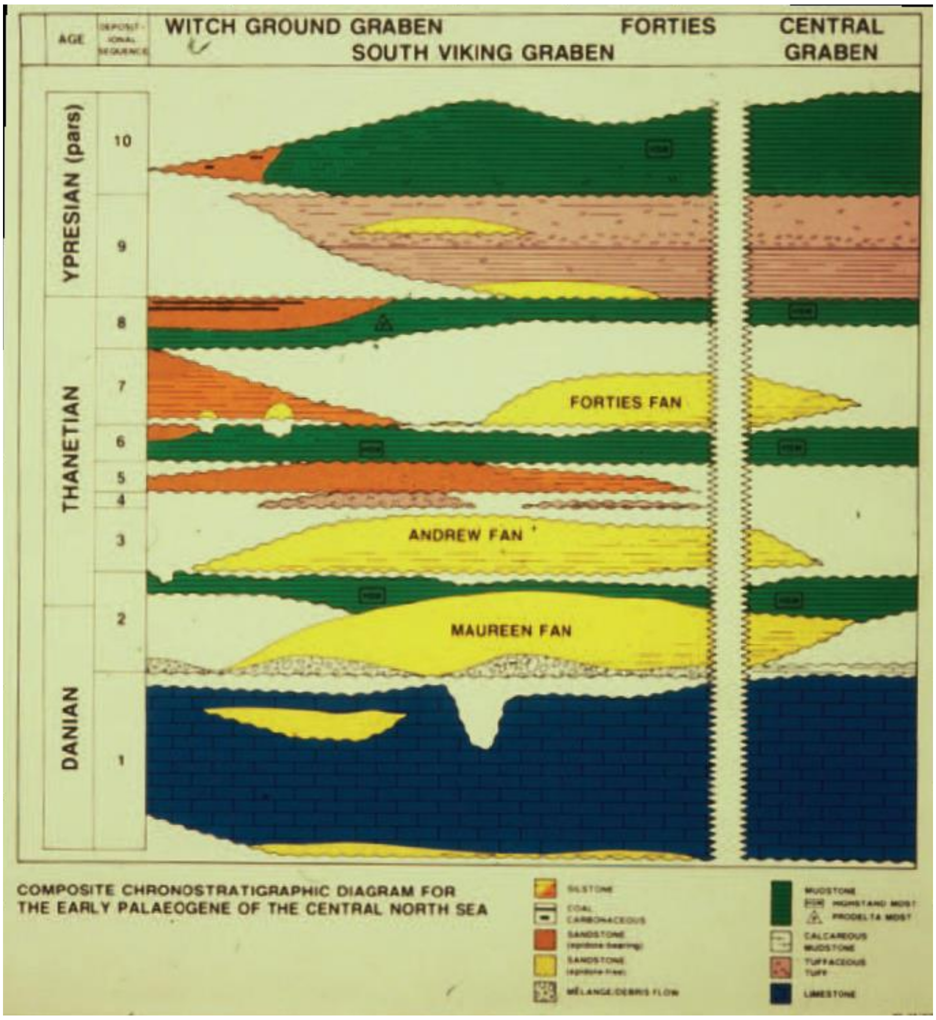


Fig. 7. The Paleogene sand bodies of the Central North Sea: diagram first shown at the North Sea Barbican Conference in October 1986 by Ian Stewart of BP, and published in the conference proceedings by Graham & Trotman in 1987.

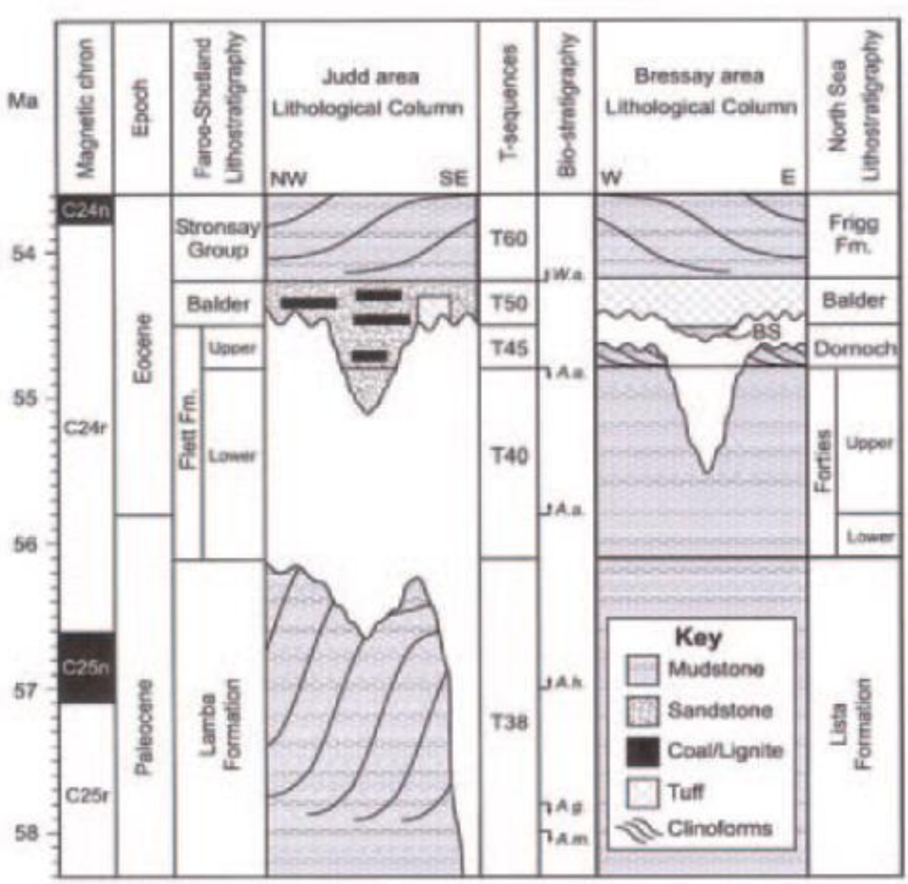


Fig. 8. Stratigraphical columns showing uplift of area of Scotland at 55 million years, first (and more) to west and then a little later (and less) to the east. From Rudge & others, 2008, Earth and Planetary Science Letters.

Dan McKenzie listened to Max's explanation of this diachronous uplift at one of the Bullard Laboratories' regular Friday afternoon research seminars. Max showed how he could generate a set of numbers for the timing and extent of the uplift, and that he could identify a probable cause - a hot blob, travelling from west to east deep below Scotland as a result of convection in Earth's interior. At Dan's suggestion, John Rudge took Max's numbers and generated a quantitative model of the asthenospheric flow involved. Geology had guided geophysics, and in return geophysics repaid geology handsomely, with an understanding of a fundamental control of high-frequency changes in the elevation of Earth's surface. Could we now explain those numerous marine transgressions and regressions for which a cause (in non-glacial times) had so long been elusive?

The "Hot Blob" caused transient uplift of Paleogene Scotland, leading to first regression and then transgression on an impressive scale. As uplift took place and more land emerged from the Paleogene ocean, rivers carried quantities of sand east to the shores of the early North Sea. Those sands were then carried further offshore to form the Forties sandstones. That volume is also impressive, estimated at over 3000 cubic kilometres for the Balmoral-Forties submarine fan of sediment alone (Reynolds, 1994). Once again, this took place during that special time in Earth history - 55 million years ago, the probable age of the Hertfordshire Puddingstone.

Coincidence? The Scottish uplift was also felt in England. With our new information we can sketch with more understanding the geography of the London and Hampshire basins of 55 million years ago (Figure 9). We see a recognisable outline of present-day Britain and Ireland emerging from the chalk sea as a result of both transient thermal uplift and permanent magmatic underplating. And

Hertfordshire lay right on that Paleogene coastline – just where you might expect to find white sand and rounded pebbles on warm beaches (Figure 10).

Fig. 9. Paleogeography of Britain and Ireland around 55 million years ago (right), showing a coastline hinting strongly at the present-day configuration of land and sea. Outcrop of Paleogene rocks shown (left) for reference. Sketch made in the mid-1970s using then recently available data from the North Sea, including Forties oilfield, the position of which is shown. From Lovell, 1977, Allen & Unwin.

Fig.10. Hertfordshire Puddingstone - a handy 55 million year pebbly beach for North Londoners: close-up of the patch of uncemented fine white sand lying on the surface of the concretion shown in Figure 2. Coin is 25 mm across. From Lovell & Tubb, 2006, Mercian Geologist.

Meanwhile, on the ocean floor away to the west, in the developing North Atlantic Ocean, an episode of dramatic global climate change was being recorded in deep-sea sediments. Thanks to the international programme of deep-sea drilling, we can now read that record 55 million years later. We can do this using the thousand-year definition of the astronomical timescale, created by Nick Shackleton and his colleagues. This brings the story onto a human timescale: we are thereby led to some uncomfortable conclusions about the effects of burning all that North Sea oil.

It is commonly said that our present-day release of carbon into the atmosphere of Earth is an uncontrolled experiment with an unknown outcome. That is not really true. There has already been a release of fossil carbon comparable in rate and volume to that which we are now causing (Figure 11) – and it happened 55 million years ago (Norris & Rohl, 1999). This was long before we were around to light so much as a campfire - so we didn't do it, but now we know about it. Although we cannot predict the outcome of our own experiment, the main effects of the 55 million year release of fossil carbon provide hefty clues about what is likely to happen. Admittedly starting conditions were different. The Late Paleocene was already warmer before the large release of fossil carbon than Earth is now. A world map of Paleocene land and sea does not look wholly familiar to us, but the story we can read from rocks formed at the time is clear enough.

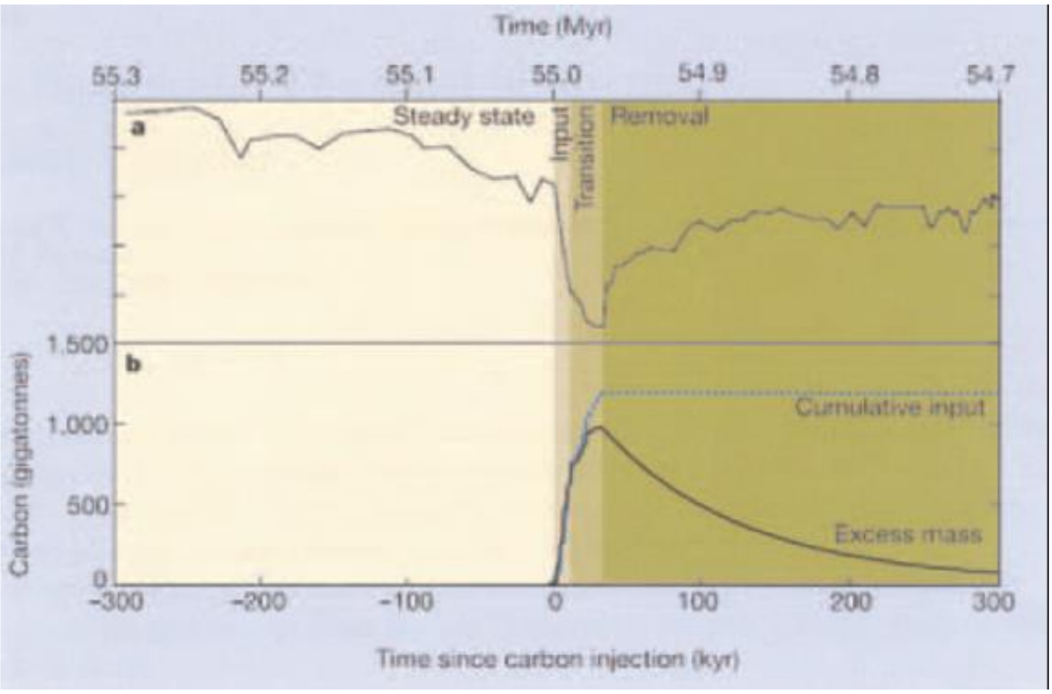


Fig. 11. Illustration from Gerald Dickens, 1999, Nature, showing rapid release of fossil carbon at 55 million years. Its subsequent removal from the atmosphere and oceans took over 100,000 years.

Earth became a lot warmer (Cohen & others, 2007). Even on the deep ocean floor, temperatures increased by several degrees centigrade. The boundary between the Paleocene and Eocene epochs is defined by the resulting extinctions in the fossil record. Oceans became notably more acid, and then received large volumes of carbon as recycling of the released gases took place. It was over 100,000 years before the planet returned to something approaching its previous state. The whole episode may plausibly be regarded as an earlier, and complete, version of the experiment on which we have ourselves embarked.

The "Paleocene-Eocene Thermal Maximum" (PETM), to give this event its proper title, has now been studied in many places across the world, providing abundant confirmation of the massive and rapid release of fossil carbon, over a few thousand years – followed by a period of recovery extending over at least 100,000 years. What triggered the carbon release? This we do not yet know for certain.

An early (and still favoured) explanation is that the PETM was triggered by destabilisation of subsea methane hydrate deposits at quite shallow depths within the sediments draping the continental slopes (Dickens, 1999). But what could cause such destabilisation? One possible process is uplift of the sea floor – reducing the weight of water bearing down on the unstable hydrates (Maclennan and Jones, 2006). The key to their idea lies in modern-day Iceland, with its volcanoes, and the hot springs in which field geologists can relax happily in the worst of the weather (Figure 12). The Iceland hotspot already existed 55 million years ago (Figure 13).

Could that hotspot have been responsible? The geological record indicates that from time to time the Iceland hotspot gets even hotter. More molten rock reaches the surface when the temperature of the hotspot is relatively high, and study of past volumes of magma suggests that activity pulses at irregular intervals, a few million years apart. Maclennan and Jones appeal to one of these episodic heating events as the trigger for the PETM. Their notion is that this pulse caused uplift of the sea floor of the Paleocene North Atlantic Ocean 55 million years ago. This uplift destabilised methane hydrates and thereby rapidly added large volumes of fossil carbon to the atmosphere. The resulting increase in greenhouse gases caused more trapping at Earth's surface of heat from another, much larger external source – the Sun.

We are taken back to Aberdeen in May 1995 and the discussion I had with Nicky White, which led within months to our identifying pulses of uplift and sand deposition. As a result of pulses of heat in the early Iceland hotspot, pulses of sand were shed from the uplifted early Scottish landmass. One major pulse occurred 55 million years ago. To the east of Scotland, it created the body of sand that later became the reservoir for the four billion barrels of oil trapped in the Forties oilfield. To the west of Scotland, that same pulse may have destabilised methane hydrates on the flanks of the developing North Atlantic Ocean, triggering the warming event.

Fig. 12. Hotspot with quite a nice spa attached – the geothermal plant at the Blue Lagoon, Iceland.

Photo: © Ted Nield FGS

On the one hand we have a large volume of oil, a significant and famous part of one of the world's notable oil provinces. On the other we find a possible trigger of dramatic climate change, a cautionary tale from geological history. It seems to be telling us: "here is what happens when you release large volumes of fossil carbon". At this stage my hero, Socrates, might ask: "Is this not a natural process? What is so special about this element carbon that you make such a fuss?"

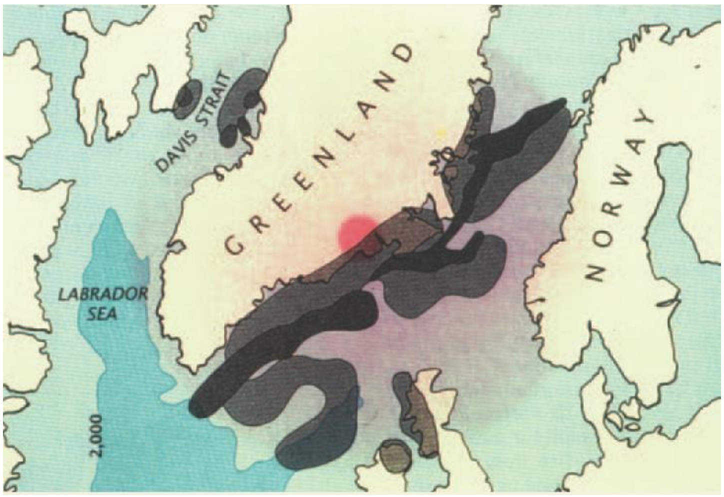


Fig. 13. Sketch of a likely position of the early Iceland hotspot beneath Greenland around 55 million years ago and of the associated volcanic rocks. After White & Mckenzie, 1989, Journal of Geophysical Research.

Part Three – Reservoirs to the rescue?

Half-a-century ago, those with sufficient imagination projected away to the north and east the position of the carbon-rich mudstones exposed on the shores of Dorset and Yorkshire. To the north and east lies – of course - the North Sea. We now count Kimmeridge Clay Formation as one of the most valuable rocks on the planet, in dollars as well as in stratigraphy. Oil from the Kimmeridge Clay Formation made its way up from below, migrating into the Forties Formation, where it was trapped under a gentle arch of rock and sealed by overlying mudstones (Figure 14). Source, reservoir, trap and seal - and four billion barrels of oil in place. But the rapture of at least some of those who discovered, and recovered, that spectacular wealth must now be tempered by the realisation that they are responsible for starting a piece of unfinished business with Earth's carbon cycle.

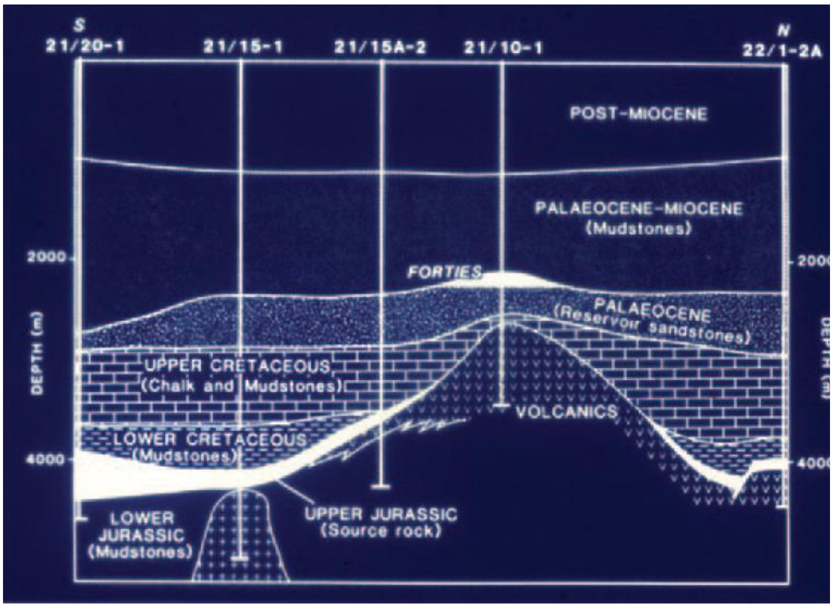


Fig. 14. Schematic cross-section of the regional setting of Forties oilfield, indicating migration of oil from the underlying Kimmeridge Clay Formation. From BP report, May 1985.

Although getting carbon out of the ground is expensive, the customer is happy to pay because the product is so useful. But the customer has not paid for another cost in that process, the sum of which has only recently been fully recognised. The combination of hard-won fossil carbon with atmospheric oxygen bears a heavy penalty in Earth Court, which cannot simply be discharged with payment of a single fine or a limited period of community service. We have greatly accelerated the rate of release of fossil carbon. The unfinished business is to control that rate of release to safe levels.

As we all cope with that demand, oil geologists themselves may not feel particularly in need of redemption, despite the obloquy dished out to them by many environmentalists. But if the oil gang does feel abashed, help may lie close at hand, in their very own reservoirs.

At a time of record oil prices in the early 1980s, BP ran an experiment in enhanced oil recovery using surfactants in Forties oilfield (Figures 15 and 16). Chris Sladen led the work on the fine details of reservoir geology, especially the post-depositional changes in porosity. (For the record, these include quartz overgrowths in places and books of kaolinite across the throats of some pores.) Other oil companies and universities were engaged in comparable studies and wanted to exchange information and ideas. So, in August 1982, Sladen and I flew first-class to Hawaii to present the Forties data at a Geological Society of America Penrose Conference on diagenesis. (Yes, the oil price was *really* high!) Among those we met there with common interests was one Yousif Kharaka of the United States Geological Survey.

Fig 15. Hardworking and quite muddy team of BP sedimentologists recovering core of Forties Formation reservoir on the deck of Forties Delta on 17 May 1982. Photograph by Chief Sedimentologist.

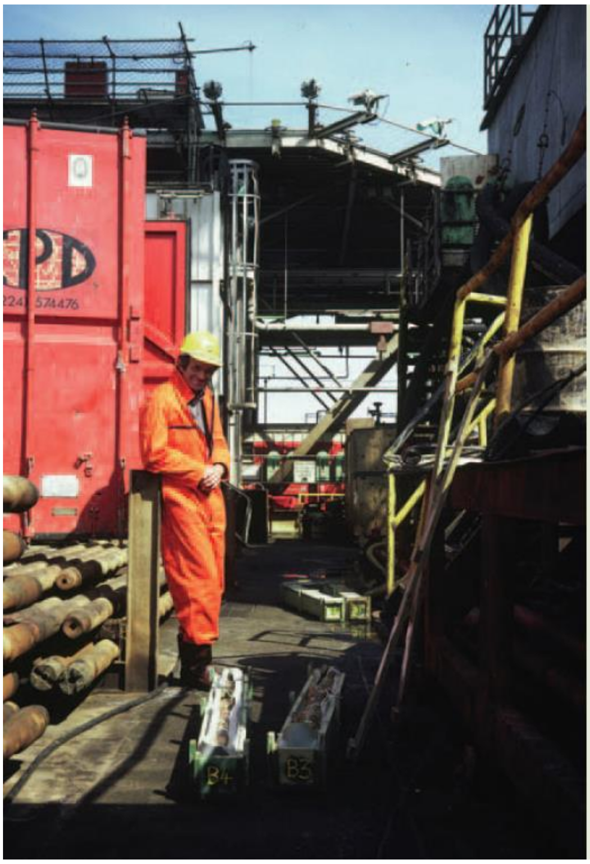


Fig. 16. BP's Chief Sedimentologist relaxing during core-recovery on the deck of Forties Delta on 17 May 1982. Note the immaculate and mud-free protective clothing.

Now, over a quarter of a century later, Yousif comes back into my story. A recent (2006) paper, of which he is senior author, concerns the effects on the rocks themselves of storing greenhouse gases in sedimentary basins and lies on my desk as I write this. Yousif is still looking at reservoirs, but now with a view to putting fossil carbon *back*. The oil business will consider this idea favourably if it can make a profit commensurate with the risks. As well as considering the future price of a barrel of oil, the prospective value of a tonne of carbon put safely back underground becomes crucial. At least some of the technical and commercial skills required to *produce* oil and gas are comparable to those needed to inject and store CO2.

Princeton University researchers Robert Socolow and Stephen Pacala, in a study sponsored by the oil industry, do their patrons no special favours (2004). They conclude that the concentration of atmospheric CO2 must be kept at a level not far above that already reached, requiring the application of technology on a heroic scale. The good news is that the technology is familiar: the issue is not one of innovation, but of scale and motivation.

The numbers suggest that we do not have the luxury of choice between consuming less fossil fuel on the one hand, or carbon capture and storage on the other. Socolow and Pacala tell us that we need to do a lot of both, to have any hope of holding levels of carbon dioxide in the atmosphere at 550ppm by the middle of this century (Figure 17). (Then their targets get still tougher to meet.) Current oil production stands at c. 80 million barrels a day. Depending on how much you compress CO2 before injecting it, you could achieve, say, 20% of the Princeton target by pumping 80 million barrels of it underground each day, into reservoirs like Forties.

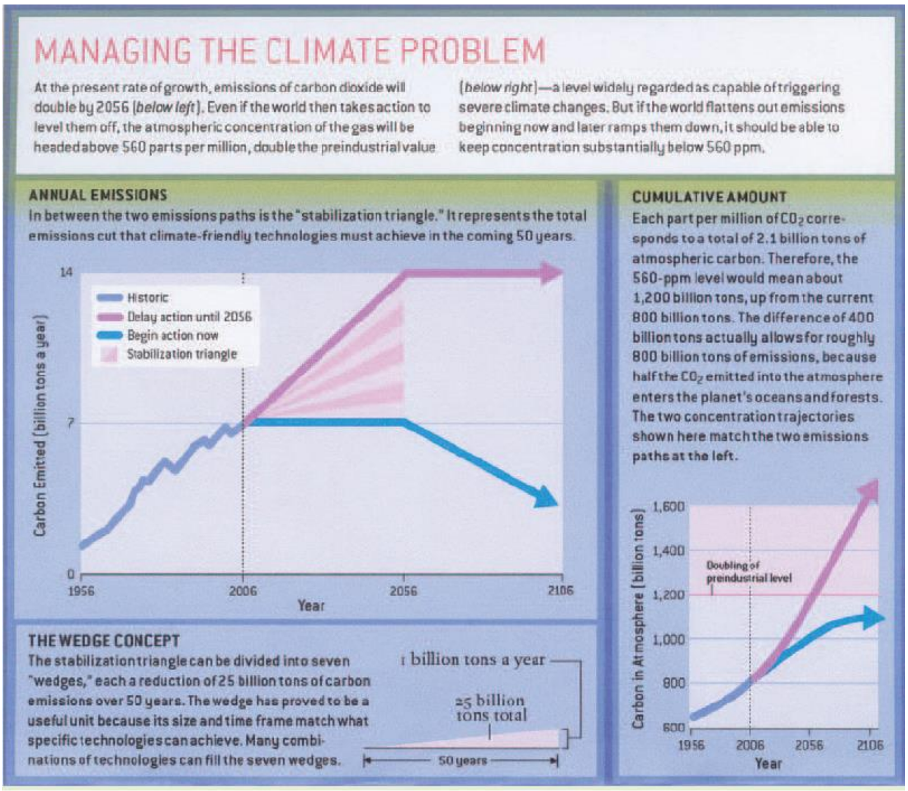
But is a new, giant industry - equivalent in size to that currently devoted to oil *extraction* - really going to be created, to pump carbon back underground? The prospect becomes slightly less preposterous when we consider that the oil industry is really a water industry. About three-quarters of all production from the world's oil wells is not oil at all, but brine. Include this and the total flow is over 300 million barrels per day.

Pumping 300 million barrels of compressed CO2 into underground storage each day would achieve most of the Princeton target. But though the potential for a significant contribution clearly exists, 300 million barrels a day looks like an oil pipe-dream. We who buy the oil industry's most useful product do so to feed the engines of planes, ships and cars – which don't lend themselves to easy CO2 capture. However, capturing fossil carbon at coal-fired power stations is a simpler matter. The storage of their CO2 probably provides the best prospect for using the oil industry's skills to help meet those stringent targets.

And why should the oil industry not seize this opportunity? True, pumping waste into long-term storage is not what we veteran frontier explorers are used to, with our techno-gambler culture of high risk and high reward (Figure 18). This would be a future service industry, with a price per tonne for all carbon safely stored. The dull psalm of duty would appear to replace the trill of pleasure – but that is to set the technical challenges too low. The reservoir geology and engineering involved are interesting enough to quicken the blood of skilled young people. The task could be tackled properly between now and 2050.

Closing circles

Geological evidence is implacable. Geological processes act over periods of time far removed from human experience. Messages from rocks, read correctly, should be heeded. The Paleocene-Eocene Thermal Maximum (PETM) at 55Ma affected evolution to the point of defining the boundary of an Epoch. Though its significance appears reduced in comparison with the drama of the closely preceding Era-ending extinctions of dinosaurs and ammonites at 65 Ma, it was a time of major change in the evolution of mammals. There was another effect on mammals at the PETM, apart from the vicious change in climate. Thanks to uplift caused by the 55 Ma hot blob in the early Iceland hotspot, distant ancestors of the present-day thoroughbred racehorse were able to browse their way from one side of the nascent North Atlantic Ocean to the other over a land bridge (Hooker, 1996). So it seems appropriate that the headquarters of British racing is at Newmarket, where the gallops stretch out over the well-drained chalk downs, formed from ooze on the Cretaceous sea floor, and first lifted up to form Cambridgeshire and Suffolk as part of the development of the early Iceland hotspot.



MANAGING THE CLIMATE PROBLEM

At the present rate of growth, emissions of carbon dioxide will double by 2056 (*below left*). Even if the world then takes action to level them off, the atmospheric concentration of the gas will be headed above 560 parts per million, double the preindustrial value (*below right*)—a level widely regarded as capable of triggering severe climate changes. But if the world flattens out emissions beginning now and later ramps them down, it should be able to keep concentration substantially below 560 ppm.

ANNUAL EMISSIONS

In between the two emissions paths is the "stabilization triangle." It represents the total emissions cut that climate-friendly technologies must achieve in the coming 50 years.

CUMULATIVE AMOUNT

Each part per million of CO_2 corresponds to a total of 2.1 billion tons of atmospheric carbon. Therefore, the 560-ppm level would mean about 1,200 billion tons, up from the current 800 billion tons. The difference of 400 billion tons actually allows for roughly 800 billion tons of emissions, because half the CO_2 emitted into the atmosphere enters the planet's oceans and forests. The two concentration trajectories shown here match the two emissions paths at the left.

THE WEDGE CONCEPT

The stabilization triangle can be divided into seven "wedges," each a reduction of 25 billion tons of carbon emissions over 50 years. The wedge has proved to be a useful unit because its size and time frame match what specific technologies can achieve. Many combinations of technologies can fill the seven wedges.

Fig. 17. Figure from Robert Socolow and Stephen Pacala, 2006, Scientific American, indicating the scale of the task involved in holding levels of carbon dioxide in the atmosphere to 550 parts per million by the middle of this century.

Newmarket is less than an hour by internal combustion engine (rather than horse) from the Hertfordshire Puddingstone quarry where this tale began. The sediments that were eventually laid down on top of the puddingstone were muds – the London Clay, through which many of the capital's tunnels are cut. From the hippo bones it contains we know that the climate of Bloomsbury was even steamier then than when the Wolfs lived there or geologists met to exchange North Sea secrets in 1974; yet it was already considerably cooler than during the warming of the PETM, 55 million years ago.

Is there a direct link between that intense heat, and that unusual rock, the Hertfordshire Puddingstone? We cannot be sure; we do not have in these rocks the stratigraphical precision achieved by Shackleton and others elsewhere. But silica is more soluble at higher temperatures (Pettijohn & others, 1987): one may speculate that the cement that bound pebble and sand together into the plough-smashing menace of Hertfordshire farmers was formed as a result of the PETM.

The circle closes. Heat from the Earth's interior temporarily increased at the hotspot that marked the location of Iceland in the early North Atlantic. A pulse in mantle convection at 55Ma lifted Paleogene Scotland above the waves. Erosion poured sand onto its flanks. That sand, carried further offshore into the precursor of today's North Sea, was finally covered and sealed by layers of mud. Later still it filled with oil from below. And there it waited until October 1970, when BP came along, and drilled exploration well 21/10-1.

On proto-Scotland's west flank the same hot blob may have triggered the PETM. Thus the same event that gave us a famous oil reservoir may also be sending us a warning about what will happen if that oil is not used wisely.

How will the age of oil end? All around the puddingstone copse where we began, flints lie scattered with fragments of puddingstone, unworked. The old joke that says the Stone Age didn't end because *Homo sapiens* ran out of stone, becomes real here. Like flint and puddingstone before, oil is mighty useful, and, like those rocks, much of it may remain unused. It would be great if we could with impunity produce and consume the remaining oil in our present insouciant style, but calculations suggest otherwise.

Rocks and their messages, like the proof in the puddingstone, may be implacable; but the man-made discipline of economics is not. Economics can be changed, in response to what rocks tell us. The subtitle of Eugene Schumacher's classic (1973) work *Small is Beautiful* runs: "*a study of economics as if people mattered*".

Many might assume that we geologists must feel rather lofty and detached about climate change because we know that the planet has seen it all - and worse - before. I don't feel very lofty or detached. I am part of a large, tribal family and I have grandchildren. When our own children were young, I ran for Parliament – unsuccessfully - against a future Labour Prime Minister and a future member of a Conservative cabinet (Michael Ancram won). In the chilly church halls of Edinburgh South, I set out an earnest programme to deal with global as well as local concerns: hunger, thirst, pestilence, inequality and wickedness in high places. Were I to run for election again, I would add emphatically the warning that we can now read in those 55 million year old rocks. I reckon the undoubted evils against which I inveighed in the Seventies can only become even more pressing if, by our own hand, we create our own extreme warming event. The time in which we now live would then, sadly and justly, surely be known as the "Anthropocene".

We have received an important message from a warm planet. We can understand it, and we should respond - *as if people mattered*.

Acknowledgements:

I am indebted to Ted Nield and Nicky White for their trenchant advice on the form of this extended essay, which was originally published in three parts in Geoscientist, volume 18, numbers 6, 7 & 8 (June, July & August) in 2008. I thank Ted Nield and Carol Liddle for their help with the preparation of this version.

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New exposure of the Cretaceous-Paleogene unconformity and Paleocene-Eocene pebble bed in Paleogene outlier at Collier's End, Hertfordshire, UK.

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Hertfordshire Puddingstone
Icelandic plume
London basin
Paleocene-Eocene Thermal Maximum
Paleogene outlier

ABSTRACT

The Paleogene outlier at Collier's End, Hertfordshire lies on the northern rim of the London Basin. This small outlier has archaeological and geological significance. Silica-cemented concretions of Hertfordshire Puddingstone lie within a regionally mappable pebble bed. The first discovery of a Roman quarry to recover puddingstone for manufacture of querns was made in the outlier. A rare complete section from the Chalk Group up through the Paleogene was temporarily exposed in 2021 and is recorded here. The Paleogene shows features that may be associated with the Paleocene-Eocene Thermal Maximum (PETM). The chalk in the new exposure is Late Coniacian. This age provides further evidence of relatively deep erosion of the chalk in this area, as erosion of chalk at the crest of a regional dome preceded advances and retreats of the western shore of the Paleogene North Sea. These events may be linked to the early development of the Icelandic mantle plume.

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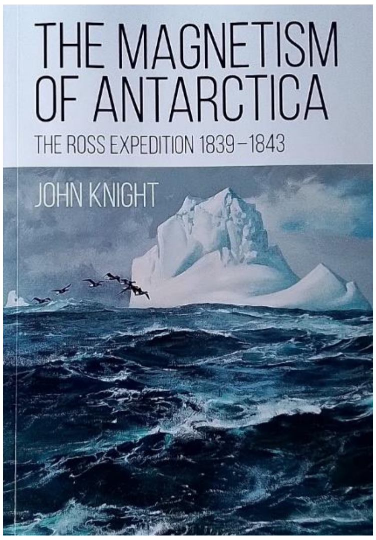
The magnetism of Antarctica
The Ross Expedition 1839-1843
By John Knight



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Reviewed by Dr Dave Brook OBE FGS
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The Antarctic expedition of James Clark Ross in HMS Erebus and Francis Crozier in HMS Terror is fairly well known to polar enthusiasts. While there are few books dealing only with this expedition, it is covered, at least in outline, in books about polar exploration. The voyage, the interactions with Sir John Franklin and his family in Tasmania and its major events and achievements are all summarised. Clear highlights were the rapid transit of the pack ice in the Ross Sea leading to the discovery of Victoria Land, Ross Island with its active volcano and the Ross Ice Shelf, the claiming of the area for Queen Victoria on Possession Island and the attainment of a farthest south record exceeding that of James Weddell in what became his eponymous sea, along with the less successful second venture into the Ross Sea and the later one to the Weddell Sea. The names of the ships and men of the expedition are prominent on the maps of the Ross Sea area and that of Ross, himself, has been added by posterity to the sea, the island and the ice shelf.

The subsequent fate of the two ships and the loss of Franklin and Crozier in a fruitless search for the North-West Passage is equally well known. Indeed, the 2 biographies of Crozier by May Fluhman (1976) and Michael Smith (2006) and, probably more significantly due to his high public profile as a TV personality, the biography of Erebus by Michael Palin (2018) has brought it to the attention of a wider audience. With the TV serialisation of The Terror, a fictionalised version of the Franklin expedition completes with its monster, Matthew Betts new biography of HMS Terror (2022) may have a similar effect.

This book presents a new examination of the expedition from a refreshing perspective. With a foreword by Philippa Ross, 3X great granddaughter to Sir James Clark Ross, it is written in 3 parts, the expedition, the sailors' stories and the ships' stories.

Part 1 opens with an evocative description of the Royal Naval Dockyard at Chatham, where the 2 bombships, HMS Erebus and HMS Terror were refitted for the Antarctic voyages, as it would have been in its mid-19th century heyday. Short introductory chapters describe the refitting, the aims and instructions from the Royal Navy and the Royal Society and probably the 2 most experienced ice navigators still active in the RN, in Ross and Crozier. The previous history of the ships and the contemporary voyages of Jules Dumont d'Urville and Charles Wilkes get a brief mention. The rest of Part 1 covers the expedition as a whole, with the island hopping down the Atlantic to Jamestown in South Africa, the Southern Ocean journey calling at Iles Crozet and Kerguelen on the way to Tasmania, where they spent the winter of 1840. The major discoveries in the Ross Sea are fully covered followed by a second winter in Tasmania and visits to Sydney and Bay of Isles in New Zealand before proceeding to a second, somewhat less successful entry into the Ross Sea, a potentially disastrous collision between the ships and the escape through the narrow gap between 2 icebergs before a winter in the Falkland Islands and a fruitless attempt to attain a furthest south in the Weddell Sea and the voyage home via Jamestown and Rio de Janeiro. I particularly enjoyed the descriptions of the excursions to study the natural history of the places visited by McCormick, the surgeon on Erebus, who was able to carry out the role he had hoped to undertake on the Beagle, where his frustration at finding that role being undertaken by the civilian scientist, Charles Darwin led to him leaving that voyage early. While McCormick made significant discoveries during these excursions, his work was generally over-shadowed by that of his more famous assistant surgeon, Joseph Hooker.

Part 2 gives details of the men who sailed the two ships, with information on their previous ships and those on which they served after this expedition. It includes the officers, warrant officers and petty officers with a few mentions of ordinary seamen. The number of men who had previously served with Ross and Crozier on their Arctic voyages illustrates the strength and spirit of the men involved. This is also reflected in the fact that 12 men from this expedition joined Crozier and Franklin in their search for the North-west Passage 2 years later and were never seen again.

Part 3 is the author's paean to the Royal Navy, from its very early beginnings under King Alfred the Great, through its growth under the Tudors and the defeat of the Spanish Armada, to its dominance as Britain became the major trading/imperial nation until the 20th century rise of the fleets of other nations and America becoming the dominant trading nation. The ships from which the men joined Erebus and Terror, or to which they subsequently moved are described briefly from their commissioning through to their end-days.

The muster lists for the two ships detail all those who took part in the expedition, however briefly, and indicate who deserted, who was discharged, who was invalided ashore, along with promotions/demotions, those who completed the voyage and the 5 accidental deaths and one death by natural causes.

Philippa Ross admits in her foreword that she has only dipped into her ancestor's book and not read it from cover to cover. I must confess that I've had the David & Charles reprint for over 50 years and I've not read it, partly because of its sheer bulk and partly because the standard Royal Navy style of reporting on 19th century expeditions can make for a very hard read. In contrast, this book is not a hard read at all. It flows quite beautifully with clear descriptions of the places visited, the investigations carried out and the discoveries made, much of which is not included in previous summaries of the expedition I have read. Parts 2 and 3 are a slightly harder read, reflecting the extent of the detailed research into Royal Navy records at the National Maritime Museum as well as other records. While there is regular mention of the magnetic observatories set up, there was , for me, one omission. In view of the book's title and the importance of the international collaboration under the German mathematician/physicist Carl Friedrich Gauss, whose name is synonymous with measurement of terrestrial magnetism, I would have liked to see an appendix summarising the magnetic work, detailing the observatories, their length of occupation and the extent to which the expedition was able to carry out the required measurements on the internationally agreed term days. This minor quibble does not detract from the value of this book as a sensitive and informative retelling of what is the most significant Antarctic expedition of the 19th century, renowned for its geographical and geological discoveries, for its important magnetic observations and for opening up the route to the South Pole.

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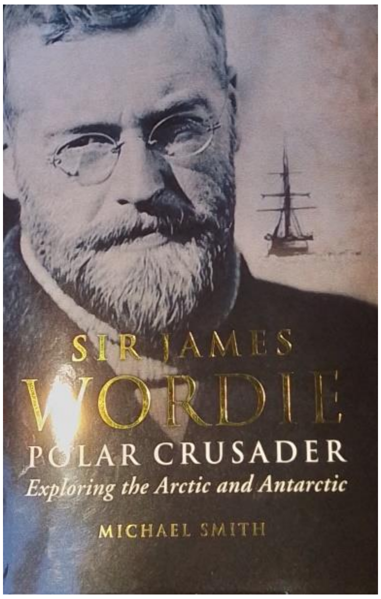
Sir James Wordie, polar crusader
Exploring the Arctic and Antarctic
By Michael Smith



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Reviewed by Dr Dave Brook OBE FGS
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This book will have been reviewed a number of times since its publication in 2004 but it is worth looking again at the life of the geologist who was a crucial link between the heroic age of polar exploration and the more modern era of the mid to late 20th century.

Not only was Wordie the geologist on the Imperial Transantarctic Expedition 1914-16 on the Endurance under the leadership of Sir Ernest Shackleton, but his first Arctic journey was to Svalbard in company with William Spears Bruce, who had led the Scottish Antarctic Expedition of 1902-04 on the Scotia.

Born in Glasgow in 1889, Wordie made his first Alpine climb at the age of 14 and his continuing attraction to the outdoors led to him gaining a BSc and MA with distinction in geology from Glasgow University, before becoming an advanced student at St John's College, Cambridge. In 1914, he joined Sir Ernest Shackleton's Imperial Trans-Antarctic Expedition. His Geological contribution was limited to examining pebbles swallowed by penguins and examination of a very limited area of Elephant Island but he provided revised definitions of the forms of sea ice for "South" and was later instrumental in ensuring that the scientific results of the expedition were published. The book quotes extensively from Wordie's diary to give a different perspective on the expedition and an appendix has an abridged version of his Weddell Sea log 27 September 1914 to 1 December 1916.

Wounded during the Battle of Lys in 1918, he was appointed lecturer in geology at Cambridge University in 1918. He joined Bruce's Scottish Spitsbergen Expedition in 1919 and the 2nd Scottish Spitsbergen Expedition in 1920 before sailing to Jan Mayen Island and making the 1st ascent of Beerenberg in 1921. Elected a Fellow of St John's College in 1921 and appointed Tutor in 1923, he maintained his association with the college, being elected President in 1950 and Master in 1952 until his retirement in 1959. Wordie led summer expeditions to East Greenland in 1923, 1926 and 1929, to West Greenland and Baffin Bay in 1934 and to Greenland and the Canadian Arctic in 1937. During these expeditions he successfully introduced a number of his protegees to polar exploration, including Augustine Courtauld and other members of Gino Watkins' Arctic Air Route Expedition and Vivian Fuchs.

James Wordie received numerous awards and served with distinction on the Discovery Committee, as Honorary Secretary of the Royal Geographical Society, Chairman of the Scott Polar Research Institute and on secondment to Naval Intelligence (the Polar regions) for Operation Tabarin and visiting Britain's Antarctic Dependencies in 1946-47. He played a significant role in enabling the successful ascent of Mount Everest as vice-chairman of the Everest Committee and chairman of the British Mountaineering Council and in supporting Fuchs as vice-chairman of the Committee for the Commonwealth Trans-Antarctic Expedition 1955-58 and chairman of the Brutish National Committee for the International Geophysical Year. He was elected President of the Royal Geographical Society in 1951 and made his last voyage to polar Territories in 1954, visiting the British North Greenland Expedition at Britain's Lake. Knighted for services to polar exploration and research in 1957, James Mann Wordie died in Ca Bridge in January 1962 at the age of 72.

Michael Smith has gained a sound reputation as a biographer of polar Explorers from the heroic age of polar exploration and this book goes a long way to cementing that reputation, while providing a link from that age to the modern era where vehicles and air transport play such a large role. The depth of Smith's research is clear to see in what is an excellent biography of a major player in 20th century geology and polar exploration.

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Ice Age Dublin

Adam Dawson FGS

All photos by the author

Figure 1. A trio of Giant Irish Deer (Megaloceros giganteus) skeletons at the National Museum of Ireland, Natural History (Dublin). The inset map (also from the museum) shows where Giant Irish Deer remains have been found in Ireland. This isn't necessarily where they all lived – the map just shows where they tended to die, be best preserved, and most easily retrieved in preserved form.

Introduction

We have been living near Dublin for the last two years, and one of the things that I came to realise soon after we arrived, is just how diverse the geology in this part of the world is.

From the fossilised *Lithostrotion* beds at Malahide to the relics of the Iapetus Suture just up the coast at Clogherhead, there is half a billion years of the earth's history to investigate, all within a short distance of Ireland's capital city. In my case, one of the features which struck me when exploring the magnificent beaches of the east coast was the impressive thick layer of glacial till which has been deposited on the bedrock, and neatly exposed by erosion at many points along the shore. This observation prompted me to learn a bit more about Dublin's Ice Age history.

A closer examination of the recent geological history of Ireland reveals that for perhaps as much as 90% of the last 1-2 million years, the island has been covered with ice up to 1000m thick – with perhaps just a few *nunataks* remaining unglaciated in the very highest mountainous areas. What's more, once you know where to look, abundant evidence – which includes the coastal till – of Ireland's recent Ice Age (Pleistocene) history can be found close to Dublin.

This article discusses some of the glacial features of the Dublin area. Much of the content was developed following an excellent field trip into the Dublin and Wicklow mountains organised by the Irish Geological Association (IGA) and led by Professor Peter Coxon of Trinity College. The IGA runs a number of fascinating field trips and I'd recommend the Association to professional and amateur geologists from anywhere in the world. Professor Coxon is a learned authority on Quaternary science, so I'd also definitely recommend his field trips to anyone who has the opportunity to attend one.

Ice Age

Figure 2. Glacial deposits overlying bedrock at Howth (left) and overlying heavily tilted Lower Carboniferous beds on the beach near Rush (right).

The reasons why the earth plunged into a cooler phase two million years ago are reasonably well established though some details may remain controversial. Leading models propose that geological sequestration of carbon over the last fifty million years, possibly combined with tectonic realignment of the landmasses, led to reduced greenhouse warming and changed oceanic circulation. Factors such as these together created a general global cooling trend. Eventually, temperatures may have become sufficiently low to allow minor changes in insolation resulting from the interplay of the Milankovitch orbital cycles, to tip the earth into the much colder oscillating glaciated phases we have seen in the last two million years.

In examining the glacial remains currently preserved in Ireland, it is important to bear in mind that Ireland may have been completely glaciated on as many as ten separate occasions over the last million years (as revealed by ocean core isotopic studies). As each successive glacial advance tends to erase the evidence of the previous one, most of the evidence that is visible today dates back to the most recent (Devensian – or Midlandian as it is known in Ireland) glacial advance. It started about 120,000 years ago and ended around 12,000 years before present. Even within this single glacial episode, there appear to have been warmer (interstadial) and cooler (stadial) periods. The last major cold period, which ended about 18,000 years ago, is known in Ireland as the Glenavy stadial.

Aside from the glacial deposits along the east coast, just to the south of Dublin is an extensive area of high ground – the Dublin and Wicklow mountains. In fact the highest summit, Lugnaquilla, is just 45km from Dublin city centre, and at 925m would be classed as a "Munro" if it were in Scotland. In common with similar high ground in mainland UK, evidence of recent glacial activity is well presented in these elevated areas. Further to the north of Dublin are the Cooley hills, which although slightly lower, still display some interesting remnant glacial features.

In the next sections, some of these features, which are all within easy reach of Dublin, are discussed.

Drumlins

Perhaps some of the most universally recognised glacial features are the hummocky "basket-of-eggs" drumlin deposits formed from glacial tills. They will be familiar to anyone who has explored the hills and countryside of the British Isles. They are abundant in Ireland, and in fact the word "drumlin" is derived from the Irish word "*droimnín*", which means "little ridge". Some of the more spectacular Irish examples are on the west coast, for example the flooded drumlin swarm which forms the islands of Clew Bay, but there are plenty closer to Dublin too. In fact, just an hour up the M1 motorway, in the Cooleys, there are some good examples. I first came across them when hiking from Ballymakellett to Carnavaddy, and you can see an example in the photograph. Eskers, too, are relatively common in Ireland and, like drumlins, they owe their name to an Irish word – in this case "*eiscir*", which means "ridge or elevation".

Figure 3. On the slopes of Carnavaddy, above Ravensdale on the Cooley peninsula, basket-of-eggs drumlin topography is visible in the valley.

Moraines

When the Irish ice sheet reached its maximum extent, the western and southern margins were bounded by ocean (the eastern flank was contiguous with the British Ice Sheet, which extended from Scandinavia). So the terminal moraines deposited at this time now lie offshore and so are not easily visible.

But as the ice retreated at the end of the Midlandian glaciation, the coastal tills were deposited, and terminal moraines were left by the corrie glaciers remaining in the higher ground.

Some excellent examples are visible today at Upper Lough Bray (pictured) and at Lough Nahanagan. There is a particularly good example of a medial moraine at Glendalough – site of St Kevin's sixth century monastic "city". It was deposited between the glaciers occupying the convergent Glendalough and Glendasan valleys.

Unsurprisingly, this ice also carved the valleys into a characteristic U-shape, and this can be seen particularly clearly in the upper Glendalough valley.

Figure 5. Glendalough monastic city, founded by St Kevin around 600 AD. It is sited on a medial moraine, at the confluence of glaciers which once occupied the Glendalough (left) and Glendasan (right) valleys.

Figure 6. Upper Glendalough valley, showing typical ice-carved U-shaped topography.

Lough Nahanagan

When the Turlough Hill pumped-storage hydroelectric power station was built in 1968, Lough Nahanagan – a small lough at the foot of Camaderry – was selected to be the lower reservoir, with a man-made upper reservoir at the top of the mountain. The facility has been fully operational since 1974 and as well as being a fascinating engineering project, it has also proven unexpectedly interesting to glaciologists. This is because, when water is pumped out of Lough Nahanagan to the upper reservoir, the lakebed is partially exposed and it reveals, in some detail, the remains of terminal moraines, deposited by a small corrie glacier on the slopes above the lough.

Figure 7. Terminal moraines in Lough Nahanagan. Deposited by small corrie glaciers during the Younger Dryas (Nahanagan Stadial) cold period 12,000 years ago.

The moraines have been dated and shown to have been deposited between 12,000 and 13,000 years ago. This must have happened much more recently than the main Glenavy stadial, which largely ended in Ireland about 15,000 years ago. They are in fact indicative of a short cold period, often known as the Younger Dryas but in Ireland as the Nahanagan Stadial, which affected the global climate around that time, and which is generally viewed as the last stage of the Pleistocene epoch before the current Holocene warm period began.

Ice core data from Greenland suggests that both the cooling at the start of this stadial, and the warming at the end, occurred very fast. In fact, the warming could have happened in as little as ten years, with temperatures in Ireland rising perhaps by as much as 8ºC. The Nahanagan Stadial must have been a fascinating period in Ireland's recent geological past. Much of the country would have resembled modern polar tundra, with small corrie glaciers (but probably not larger ice caps) in the higher mountains.

This event also precipitated the demise (in Ireland) of the Giant Irish Deer (*Megaloceros giganteus* – sometimes also known as the Giant Irish Elk). This magnificent animal is not exclusively Irish (and it isn't an elk) – its range extended as far east as Lake Baikal, in Siberia. But remains are particularly well-preserved underneath Ireland's abundant peaty deposits. The skeletons of over 100 deer, for example, have been retrieved from Ballybetagh bog, on the southern outskirts of Dublin. Three Irish examples are shown in the figure at the start of this paper.

It seems likely that the deer migrated into and out of Ireland on more than one occasion – advancing and retreating before and after the colder phases over a land bridge to continental Europe. This dry land was exposed from time to time, when ice caps started to form and sequester oceanic water, but before large ice masses completely smothered the whole of Ireland. But during the Younger Dryas, the land bridges had already disappeared. The ice caps that briefly expanded during this cold period were insufficient to cause sea levels to fall far enough for the bridges to re-form. So Ireland was an island, and the deer had no path of retreat as the climate cooled and food supplies dwindled. So they became locally extinct, though populations did survive until as recently as 7,000 years ago in areas around the Urals.

There has been speculation about what led to the sudden cooling and then warming before and after the Younger Dryas. Meteorite impacts have been suggested but the most likely explanation seems to be those changes in the salinity (and therefore density) of the north Atlantic, caused by inflows of freshwater, may have led to changes in the flow of oceanic currents. This could mean that the warming effect of the “Gulf Stream” may have declined, so Ireland experienced a climate more like that of other landmasses at similar latitudes, but which do not today benefit from warming currents. In this respect, the recent apparent reduction in the Atlantic meridional overturning circulation (AMOC), which may already have led to an observed lowering of sea temperatures in the north Atlantic, is interesting in the context of Ireland’s possible future climate.

Glacial Lakes

A simple calculation quickly shows that an ice cap 1000m thick and covering the whole of Ireland (which is roughly 400km long and 200km wide) must have contained at least $8x10^{13}$ (80 trillion) tonnes of frozen water. This means that when the earth warmed at the end of the Midlandian, a large amount of meltwater must have formed rather quickly and started discharging away from the ice caps and into the surrounding sea. This massive, sudden efflux probably accounts for some of the significant tills seen along the east coast and elsewhere in Ireland.

Figure 8. Glen Of The Downs – a prominent glacial meltwater channel eroded as Glacial Lake Enniskerry outflow escaped under the ice dam and eroded its way to the sea.

Aside from the tills, the meltwater has left its mark elsewhere on the Irish landscape. Perhaps the most obvious – and spectacular – features are the V-shaped meltwater channels which can be seen at a number of locations around Dublin. Two clear examples are at the Glen of the Downs near Kilmacanogue (pictured), and The Scalp, near Enniskerry.

These deep clefts (Glen of the Downs is up to 250m deep) in solid rock were carved by meltwater escaping from the large lakes which formed as the ice retreated. It seems likely that ice dams prevented the escape of meltwater, which eventually found its way through the ice to the bedrock. At this depth under the ice, the hydrostatic pressure would have been high enough for it to erode a path through the rock – still, presumably capped with ice – and out to the sea. It also seems likely that the same lines of weaknesses may have been exploited by meltwater in glacial periods prior to the Midlandian, with each successive round of melting and erosion carving the channels a little deeper.

Evidence for the glacial lakes still persists, in particular for Glacial Lake Blessington. Outflow from this large meltwater lake carved a number of deep channels – notably the Hollywood Glen (which nowadays has a road running through it, as does the Glen of the Downs), and the deep gorge at Poulaphuca. The latter is particularly spectacular but it is hard to visit today as it is sited under a busy road, and is partially blocked by the dam which retains the Poulaphuca reservoir.

Figure 9. Looking across the valley from the R756 road above Hollywood. Horizontal flat planes on the fields on the valley-side opposite are visible, representing the shoreline of Glacial Lake Blessington. They are about 60m above the surface of modern Poulaphuca reservoir.

In fact the modern reservoir today (which is just 30km from the centre of Dublin) represents a diminished footprint of the preceding, much larger, glacial lake. It is possible to get some idea of the size of the glacial lake from the road above Hollywood. Raised beaches, marking the level of the former lake surface, can be seen on the hillsides on the other side of the valley. Nowadays they are eroding and covered with vegetation, but the evidence is still visible (see photograph).

Conclusions

The Pleistocene, or “Ice Age”, is a fascinating period in the earth’s history. Not just because of the dramatic and evident impacts it had on the modern landscape, but also because it is chronologically accessible in a way that earlier periods in the earth’s deep history are not. The alignment of the continents was very much as it is now, and much of the flora and flora was the same. Further, there are still parts of the world – in the polar and high-altitude regions – which are in the grip of the Ice Age. So it is possible to imagine exactly how more temperate regions would have looked when the colder climate extended to lower altitudes and to regions further from the poles – for example to the land that is Ireland today.

The modern landscape around Dublin represents in many ways a microcosm of the post-glacial world. So, exploring the region makes a fascinating and extremely worthwhile project for anyone with an interest in natural history, and particularly for anyone who wants to learn more about how our modern landscape has been shaped the forces of ice in the relatively recent past.

A good place to start such an exploration would be Lough Nahanagan. It’s a beautiful, high-altitude spot, close to the Wicklow Gap and only just over an hour’s drive from the city centre. The engineering history of the area – with the pumped storage system – is interesting. But the lough itself, with the exposed terminal moraines from the last stadial, is even more remarkable. Unlike the main lengthy periods of glaciation, when the ice cap over Ireland must have been fairly static and perhaps, geologically, relatively uninteresting, the periods at the end of the glaciations, when glaciers were retreating, leaving visible moraines and creating massive glacial meltwater topographies, were active, dynamic, and left an indelible mark on the landscape.

But perhaps more than anything, Lough Nahanagan and the terminal moraines demonstrate that the earth’s climate is always changing – sometimes suddenly and dramatically. A clear reminder, if one were needed, that the current benign period which has allowed the human race to expand and thrive might be something of a climatic anomaly. It would be unwise to assume that anything about its future stability can be guaranteed in perpetuity.

Find out more

Wicklow in the grip of an Ice Age, INQUA 2019 Field Guide M:GL-6
By Pete Coxon, Fraser Mitchell and Patrick Wyse Jackson:
http://iqua.ie/publications/field-guides/
Irish Geological Association:
https://geology.ie/

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Minerals of Chipping Sodbury – Hampstead Farm Quarry

Stuart Wagstaff FGS
Past Chair HCNRG

© *Photograph by Stuart Wagstaff FGS*

Chipping Sodbury is a small market town in South Gloucestershire with a history of mineralogical importance. The area was once known for having the largest Celestine deposits in the world and was once the world's leading producer of this ore of strontium. This strontium mineralogy extends into Hampstead Farm Quarry and forms part of an array of mineral occurrences.

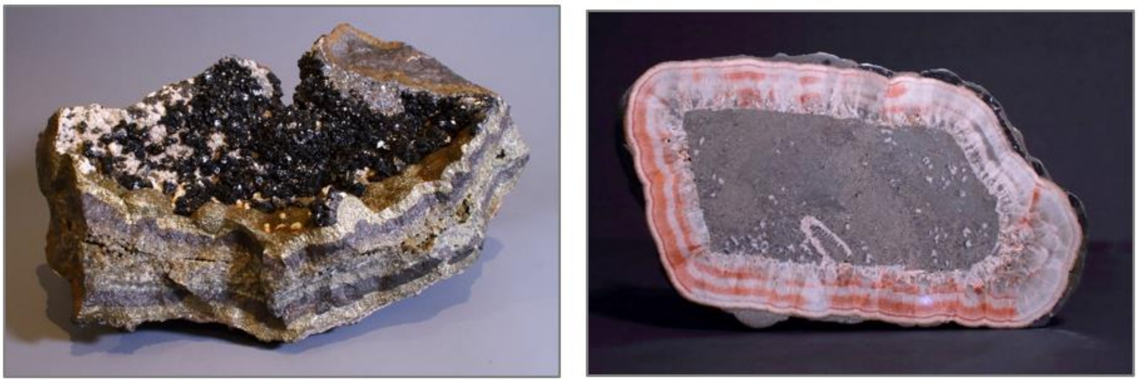
The quarry is operated by Hanson Group and is currently one of the largest quarries in Europe with a combined length of just under two miles. Quarrying started as far back as the Middle Ages and was an important producer of Lime. The quarry now largely produces aggregate for the construction industry and production is somewhere in the region of one million tons annually.

Geologically, the quarry lies on the eastern limb of a north - south trending syncline composed of carboniferous rocks. The rocks span in time from the Lower Carboniferous to the Middle Carboniferous and are unconformably overlain by Triassic Rocks. Some parts of the quarry expose karstic features produced during the Triassic period along with classic erosional surfaces. The rocks dip to the west with the lower section of the Carboniferous exposed on the eastern side of the quarry which is formed by the dip slope as seen in the picture above. It is believed that it is these lower rocks, which contain beds of black shales, are the principal contributors to the mineral assemblage seen.

The minerals in the quarry principally occur in open structures formed within the rocks such as cave systems, faults and joints. Such infilled caves and faults are shown in the photographs below.

© Photographs by Stuart Wagstaff FGS

The mineralogy is characteristically Mississippi Valley Type mineralization which comprises rhythmical cycles of banded sulphide deposits. The minerals were produced by warm fluids percolating through the rocks reacting with minerals in the black shales to produce acidic solutions. These acid solutions dissolved the rocks, leaching and concentrating various metalliferous compounds. Movement of these waters created supergene enrichment and evaporation led to crystallisation of minerals. The banded nature of the minerals is seen in the photos below.



© Photographs by Stuart Wagstaff FGS

The principal minerals found are; Pyrite, Sphalerite, Galena, Baryte, Calcite and Celestine (the pink banded mineral above) and many fine specimens have been produced. One of which, a lump in the region of 5 tons, is displayed in the Natural History Museum.

Collecting of these minerals and their preservation has been organised through The Russell Society, a group of largely amateurs and professional alike with a passion for the beauty of minerals. The groups is named after Sir Arthur Russell, a prominent Victorian mineral collector whos' collection forms the basis of the show cases in the Natural History Museum. We are open to new members and run a full collecting program through the summer months along with talks and meetings in the winter months. Interested in joining?

Visit: www.russellsoc.org

Thanks is also extended to the management of Hanson Group for allowing access and collecting of these minerals.

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Northern Home Counties Geological Connections Then and Now

Dr Tom Hose
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Geological study is all about making, the often seemingly tenuous, connections when telling the stories of the rocks; so too the stories of their discoverers. Should you visit High Wycombe, famous for its past furniture manufacturing, you might just begin to piece together a local connection between the town, a waterfall in the Scottish Borders, a notable Bedfordshire and three internationally renowned geologists, a piano company, and the British army. Yes, it is a bit like a question from Radio 4's 'Round Britain Quiz'!

Figure 1. Roderick Impey Murchison (1792-1871).

The locally connected internationally renowned geologist is Roderick Impey Murchison (1792-1871) (Figure 1) and graptolites are the link in the story.

Descended from a long-established Scottish Highlands family, Murchison was born in 1792 at Tarradale House, Muir of Ord in Ross-shire on 19th February. Aged just seven, he went to Durham School in 1799 where he remained for six years. Murchison then went on to the Royal Military College at Great Marlow (Figure 2) in 1805.

Figure 2. The Royal Military College at Great Marlow in 1805.

In 1807, aged fifteen, he was gazetted Ensign in the 36th regiment. In 1808, he landed with General Sir Arthur Wellesley's (1769-1852) – later the 1st Duke of Wellington – expeditionary army in Galicia, Spain. Literally, at just sixteen, he was carrying the colours of the 36th regiment into the battles of Roliça and Vimeiro in Portugal in the Peninsular War (1808-1814). Subsequently, under Lieutenant General Sir John Moore's (1761-1809) command in Spain, he took part in the retreat to Corunna and the final battle there. In the autumn of 1809, he became aide-de-camp to Lieutenant-General Alexander Mackenzie (c.1771-1853), his uncle, based at Messina in Sicily. The then Lieutenant Murchison returned home initially to barrack-duty at Horsham with the second battalion of the 36th regiment and then in Ireland, again as his uncle's aide-de-camp, at Amargh. On the 27th of January 1812, the now Captain Murchison became a Member of the Royal Institution, where he attended the lectures of Sir Humphry Davy (1778-1829). Following eight years service, and having come of age – thus inheriting his long deceased father's estate – in 1813, Murchison left the army. After enjoying a gentleman bachelor's leisurely lifestyle, he married Charlotte Hugonin (1788-1869), the only daughter of General Hugonin, of Nursted House in Hampshire on 29th August 1816 in the church at Buriton, also in Hampshire.

The newly married Murchisons spent two years in Europe, especially in Italy, after which in 1818 they resided in a substantial (Figure 3) townhouse, at Calgate – now marked with a blue plaque (Figure 4) – in Barnard Castle, County Durham. There he met with Sir Humphry Davy and several other notable scientists. In 1830, Murchison helped found the Royal Geographical Society. Prior to that, in the spring of 1826, he had been elected to the Royal Society. Its President, his old friend Sir Humphry Davy, told him he was so honoured not for the recognition of his scientific work, but because he was an independent gentleman with a taste for science who had plenty of time and enough money to gratify it. Having such considerable private means, Murchison also wholeheartedly threw himself into the life of a country gentleman and enjoyed fox hunting and shooting; he also took an interest in art and antiquities. Influential friends, such as Davy, aided by his wife eventually talked him into pursuing a more or less full-time scientific career. At that, time geology was the emerging science pursued by numerous gentlemen of means.

Figure 3. Townhouse, at Calgate.

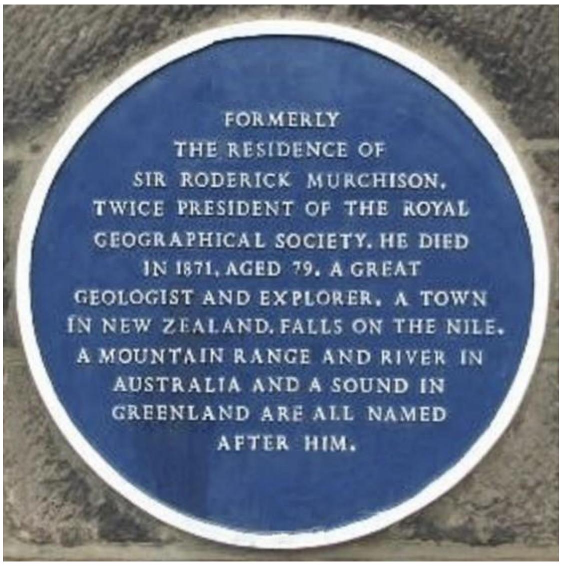


Figure 4. blue plaque in Barnard Castle, County Durham.

With his soldier’s field-craft training and Peninsular War campaign experience, it was natural that he should then choose to pursue his outdoor geological studies in the wilder parts of England and Wales. Hence, in 1831, aged 32, he began his great research into the mass of the previously geologically unknown ‘greywacke (that is, the Lower Palaeozoic) rocks’ underlying the Old Red Sandstone (that is, the Devonian) rocks in the Welsh Borderlands and South Wales. This was to find out of they could be grouped into a definite order of succession based upon their incorporated fossils. The result was the establishment of the Silurian system under which were grouped for the first time an extraordinary series of formations, each with their distinctive fossils other than and very different from those of the other rocks previously described in England. These researches, together with descriptions of the coalfields and overlying formations in South Wales and the English border counties, were embodied in ***The Silurian System*** published in 1839. This contained a detailed elucidation of the sequence of the ‘greywacke rocks’ and their fossils; it included landscape illustrations by Charlotte who had accompanied him on his field excursions. Likewise, the volume, ***Siluria***, first published in 1854 that went into several editions, also had such illustrations and covered the ever-widening regions that Murchison was by then incorporating in his Silurian realm.

Meanwhile, Adam Sedgwick (1785-1873) had been elucidating his Cambrian system. Murchison was involved in the unfortunate and bitter argument with Sedgwick over just which of the ‘greywacke rocks’ should be incorporated within the Cambrian and Silurian systems, It wasn’t until Charles Lapworth (1842-1920) recognised the Ordovician system that the controversy was finally laid to rest in the late 1870s. The controversy centred on how to make sense of the ancient ‘greywacke rocks’ (from the German mining term ‘grauwacke’, for grey, earthy, muddy rocks) that cover much of Scotland, and the upland areas of England and Wales in a somewhat chaotic jumbled succession. Sedgwick, a Cambridge University professor, had spent 30 years exploring the uplands of North Wales and the Lake District. Despite their confusing tangle of slates, sandstones and volcanic rocks that cross the region, he had identified a seemingly coherent rock succession that appeared to date back to the earliest origins of Earth. He named the Cambrian system after the Roman word for Wales. This was similar to Murchison’s elucidation of the succession, which he had called the Silurian after a Celtic tribe that once lived in the Welsh Borders, of mainly sandstone and limestone hills of South Wales and the Welsh borders – but clearly a younger sequence of rocks above the Cambrian.

However, neither Murchison nor Sedgwick could agree just where in the ‘greywacke rocks’ the boundary between the Silurian and Cambrian systems (delineated mainly then on their trilobite, crinoid and brachiopod fossils) should be drawn. Where the Cambrian finished and the Silurian began became not only a scientific dispute but also a bitter and personal rivalry, such that by the mid 1850s they weren’t talking to each other. Murchison even suggested Sedgwick was growing senile and Sedgwick accused Murchison of falsehood. Both men claimed the lion’s share of the ‘Greywacke rocks’ for their own systems. This split the geological community so much so that for some 20 years that the Geological Society banned any further discussion on the matter as simply too explosive.

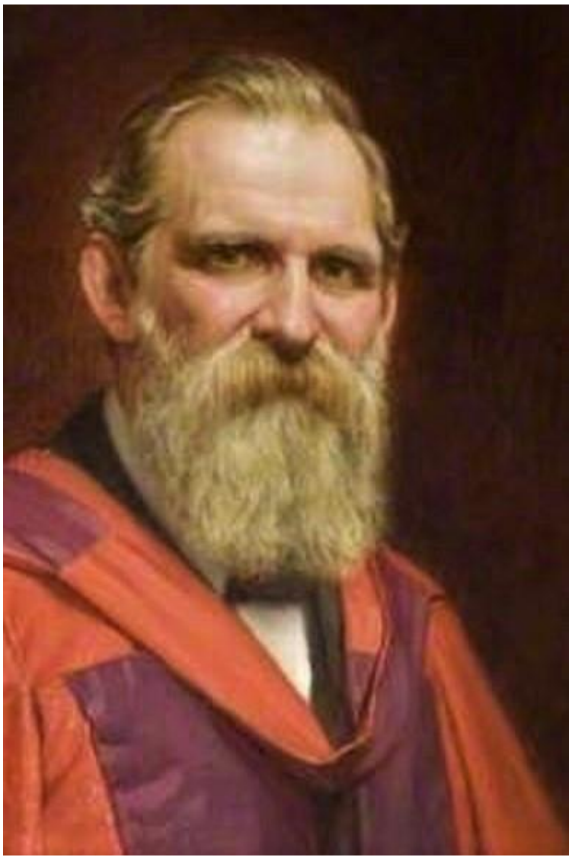


Figure 5. Lapworth.

Lapworth (Figure 5), then a school teacher, arrived in Galashiels in the Scottish Borders in the early 1860s and boldly (or is that bravely?) stepped into the Murchison-Sedgwick controversy in 1879. In exploring the hills around the town, he met local geologists who were surveying the region and discussing the Cambrian-Silurian controversy. The hills are composed of poorly exposed paper-thin shales and mudstones dipping and diving making determining their relationships, extremely difficult.

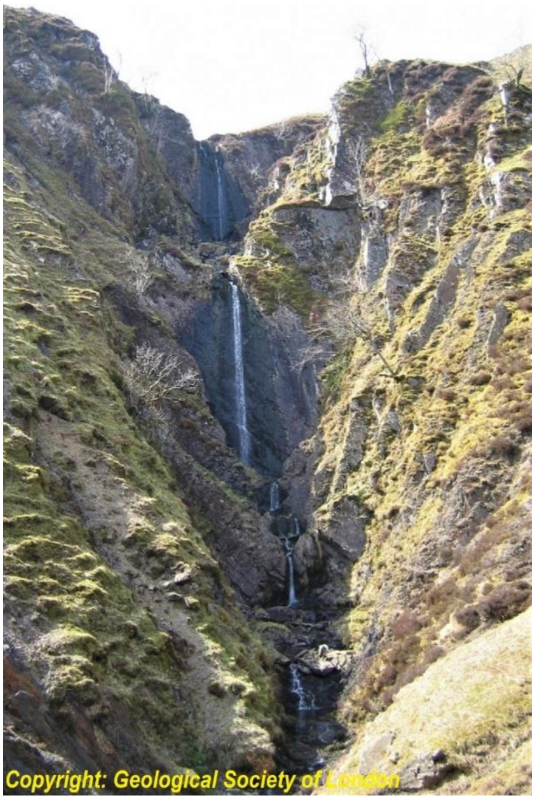


Figure 6. Dob's Linn where the upper waters of the Moffat have cut through the underlying rocks.

© Geological Society of London.

Fortunately, just off the road from Galashiels to Moffatt, near a remote shepherd's cottage at Birkhill is Dob's Linn (Figure 6) where the upper waters of the Moffat have cut through the underlying rocks. There, in the 1870s, Lapworth and James Wilson, a local journalist, elucidated the Ordovician (named after the last Roman-British tribe to inhabit northwest Wales) system, using the previously neglected fossils of graptolites (Figure 7). Over six years, between 1872 and 1877, they methodically collected by Lapworth and Wilson.

Figure 7. Graptolites. © National Trust for Scotland

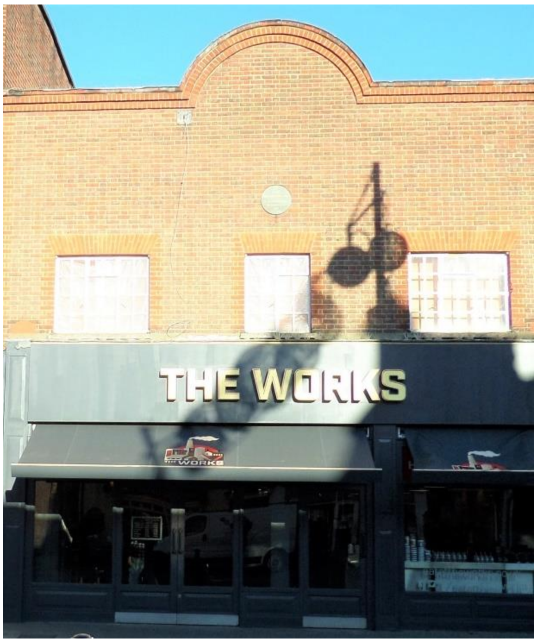
The task was made easier when Lapworth, with the help of his wife Janet, developed a 'geological waist coat' – a jerkin with a series of pockets down each front panel into which he carefully placed the delicate specimens. After a day's work, back at the cottage at Birkhill, Lapworth and Wilson, almost certainly together with Janet, unpacked and identified the graptolite fossils noting their find spots on hand-drawn maps. They eventually recognised a topmost band of mudstone, siltstone and black shale (the Birkhill Shale), a middle band of grey and black cherty shales (the Hartfell Shale), and a basal band of black cherty shale (the Glenkiln Shale). Lapworth named them, from the local river, as the three members of his Moffat Series.

Lapworth positioned his three graptolite-based formations within the disputed part of the Cambrian and Silurian boundary. He noted that his Birkhill Shale had an entirely different range of graptolites to those in his Lower Hartfell Shale and Glenkiln Shale. Indeed, the first neatly matched Murchison's topmost Silurian rocks. Further, his second two graptolite formations were clearly similar to the lowermost Silurian rocks. However, according to the graptolite evidence, there was a clear break in the fossil record between the uppermost and lowermost Silurian sequences; this marked a major planet-wide environmental change. Furthermore, there was an equally dramatic break in the fossil record between his second two formations and Sedgwick's topmost Cambrian rocks below. Finally, those two formations had a common unique fossil fauna completely different from the rocks above and below them – they must then represent a previously unknown and discrete geological system.

This conclusion was disputed by many in the geological establishment. It took 20 years for the British Geological Survey to accept the Ordovician as a legitimate geological system and a further 60 years before it was acknowledged by the International Commission on Stratigraphy. Dob's Linn is now a SSSI and the location of the internationally agreed boundary stratotype between the Ordovician and Silurian systems. The corresponding Cambrian and Ordovician boundary stratotype was taken in 2000 as Green Point in western Newfoundland, Canada.

In 1883, Lapworth was made the first professor of geology at Mason Science College, later the University of Birmingham, where he taught until his retirement in 1913. In June 1888, he was elected a Fellow of the Royal Society. He was, like Murchison and Sedgwick, awarded the Wollaston Medal of the Geological Society in 1899. In addition, like Murchison, he was elected President of the Geological Society for 1902-1904.

Meanwhile, Murchison had already achieved considerable recognition. He became director general of the Geological Survey of Great Britain in 1855. He had further presided over the Geological Society of London (and was a recipient of its highest award, the Wollaston Medal, in) the Geographical Society, and the British Association for the Advancement of Science. Knighted in 1846, he was made a KCB in 1863 and created a baronet in 1866. During the later years of his life a large part of his time was devoted to the affairs of the Royal Geographical Society, of which he was four times president – 1843-1845, 1851-1853, 1856-1859 and 1862-1871. Murchison died on 22nd February 1871 and was interred in London's Brompton Cemetery. Under the terms of his will the Murchison Medal and a geological fund, The Murchison Fund, to be awarded annually by the Geological Society of London's council were established.



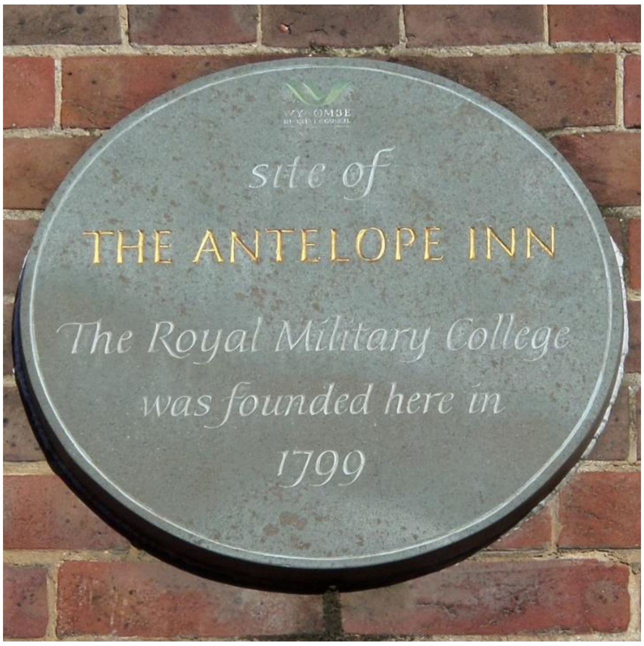


Figure 8.

Figure 9.

Now, turning to those local connections, particularly for Murchison, we can start in High Wycombe. A hospitality building (Figure 8), to the left of the Red Lion building, on the site of the long-demolished Antelope Inn bears a plaque (Figure 9) proclaiming that it was there that the Royal Military College was founded in 1799.

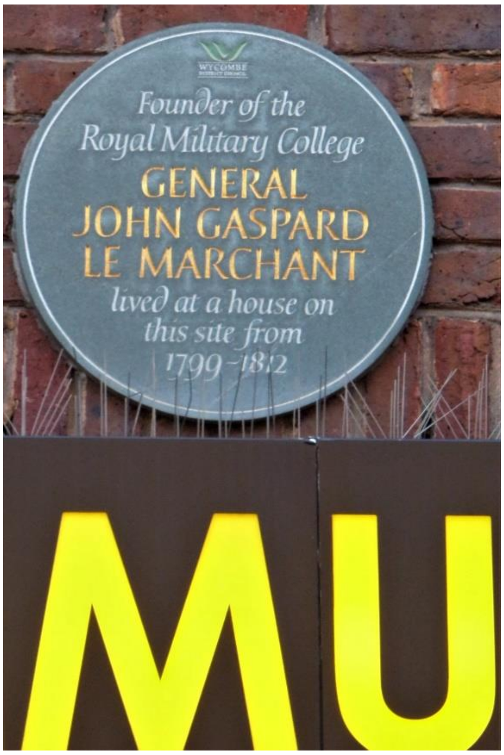


Figure 10.

Figure 11.

On the Frogmoor frontage (Figure 10) of The Chilterns shopping centre is a plaque (Figure 11) noting that was the site of a house in which General John Gaspard le Marchant (1766-1812), the founder of the Royal Military College, lived from 1799 to 1812.

Figure 12. John Hopkinson (1844-1919).

It was at that institution at Great Marlow that Murchison received his military training from 1805 to 1807. Meanwhile, Lapworth's stratigraphical employment of graptolites had been taken up by John Hopkinson (1844-1919) (Figure 12) who variously lived in St. Albans and Watford.

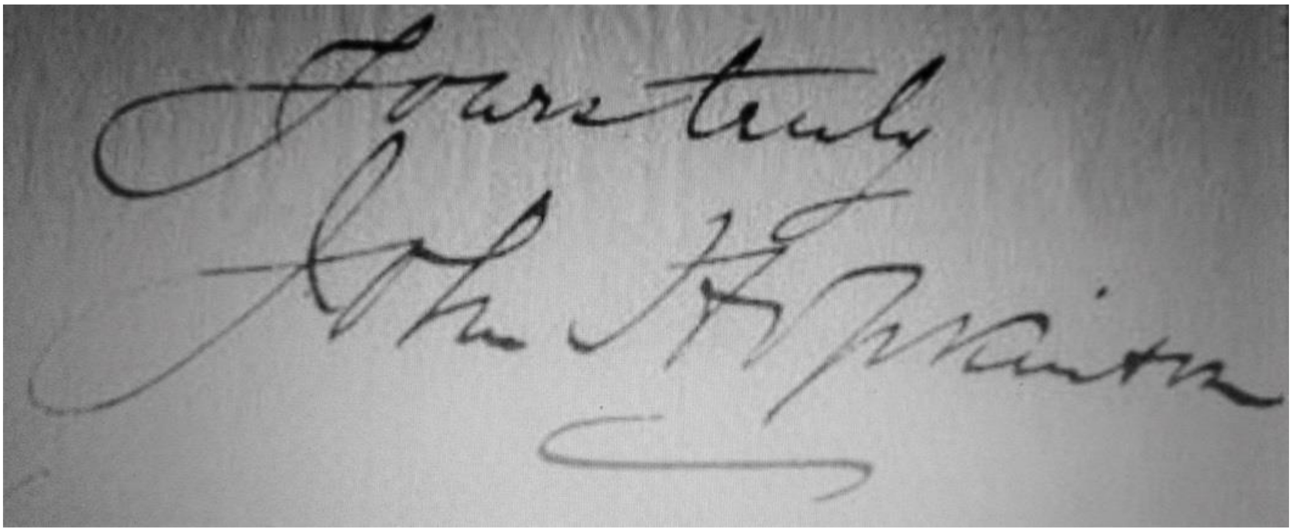
Hopkinson in 1886 – although his father had fully retired from the business in 1869 – inherited a Leeds-based music business (founded in 1835) and a London piano factory (established in 1846 and originally at 70 Mortimer Street) together with over half-a-dozen piano showrooms in upmarket parts of London. From 1886, Hopkinson Pianos went back into the music publishing business, running it alongside the piano-manufacturing business until 1895. Mechanisation and cut-price competition led to the lowering of workmanship standards in the piano industry; noting this, Hopkinson Pianos devised in 1912 a piano-making apprenticeship scheme in conjunction with the London Technical College. Hopkinson's educational endeavours extended beyond that of his London firm and employees.

Hopkinson was the principal architect, with fellow local naturalists, in the foundation of the Watford Natural History Society and Hertfordshire Field Club in 1875, which became the Hertfordshire Natural History Society and Field Club in 1879, and served as Secretary to both from 1875 to 1900. He was a Fellow of both the Geological Society and the Linnean Society. He was active in the Ray Society, being its treasurer between and 1902 and its secretary from 1902 until his death. An early member, from 1865, of the Geologists' Association, he was its Treasurer in the 1880s. He published numerous articles on geology, geomorphology and natural history in the Transactions of the Hertfordshire Natural History Society & Field Club. He was involved in the Geologists' Association cycling excursions examined in an earlier issue (No.18 - June 2022) of this newsletter. He led or co-led, from 1870-1911, and wrote the reports for some 32 of the Association's excursions; his only other contribution to the *Proceedings of the Geologists' Association* is a 1910 overview account of the geology of Middlesex and Hertfordshire. However, he published several graptolite papers, between 1870 and 1881, in the Geological Magazine. Significantly, Hopkinson jointly published a major paper with Lapworth, on the graptolites of the Arenig and Llandeilo rocks of St. David's in Pembrokeshire, in the *Quarterly Journal of the Geological Society* in 1875.

Meanwhile, Hopkinson corresponded with a wide circle of noteworthy contemporaries. For example, an 1887 letter of 7th November sent to Augustus Henry Lane Fox Pitt Rivers (1827-1900) survives. In it, he thanks the addressee for the copy of *Excavations in Cranborne Chase* that he was sent, provides information about 'ancient remains' in St Albans, and had included pamphlets regarding excavations in Hertfordshire and sketches of sites (now *both missing*) with it. Hopkinson also relates how he would like the Hertfordshire Natural History Society to prepare a list of the ancient monuments in its area because they included pre-historic archaeology in their investigations.

Figure 13.

The letter also confirms his address at the time as ‘The Grange’ (Figure 13) (at 16 St. Peter’s Street) in St. Albans; by 1914 he was living at ‘Weetword’ in Watford.



Yours truly
John Hopkinson

Figure 14.

It’s also nice to have something personal, including his handwriting and signature (Figure 14), from this local entrepreneur and scientist whose legacy, including the establishment of St. Albans Museum, is still to be found in his adopted home area. It’s to be lamented that there’s no formal recognition of

Hopkinson in either of his adopted towns. Equally, his wider contributions could be recognised in London since some of his firm's premises survive today. It's just a thought!

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An origin for the ferruginous sandstone fragments within the Gelasian (?) terrace at Grove Farm Chesham, Buckinghamshire

Nick Cameron FGS

Abstract

Quartz-rich, ferruginous sandstone fragments within a terrace, 160 metres above sea level at Grove Farm are interpreted as originating from the Reading Formation. Their composition, as has been described in the literature for the Lane End area near High Wycombe (Bucks), best fit fluvial derivation during the Paleocene from Lower Greensand 'carrstone'. Origins from either the Red Crag Formation or bog iron ore developed within the terrace are not favoured. The host terrace is regarded as Gelasian in age based on its elevation.

Introduction

Previously I described and amplified for this journal (Cameron and Hepworth, 2021) field investigations made by John Hepworth into the periglacial disruption as a slide of the Reading Formation exposed below a Pleistocene aged terrace in the former Meadhams Farm brick pit near Ley Hill (Bucks). This exercise formed just a small part of John's interest in puddingstones and sarsen geology and in this second article I examine by moving north a few kilometres to Grove Farm a further facet of those interests. This time the objective is the origin of the ferruginous sandstone fragments found within the northern continuation of the Pleistocene aged terrace.

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Figure 1. View WNW across the 160-metre surface towards Ashley Green and the high Chilterns. The enlargement highlights the abrupt jump in the height of the Chilterns surface across the Grim's Ditch Line of Hepworth (1998). Information on the now rejected view that this rise was cut as a cliff line during Red Crag deposition is available in Catt (2010, for example figure 5.14).

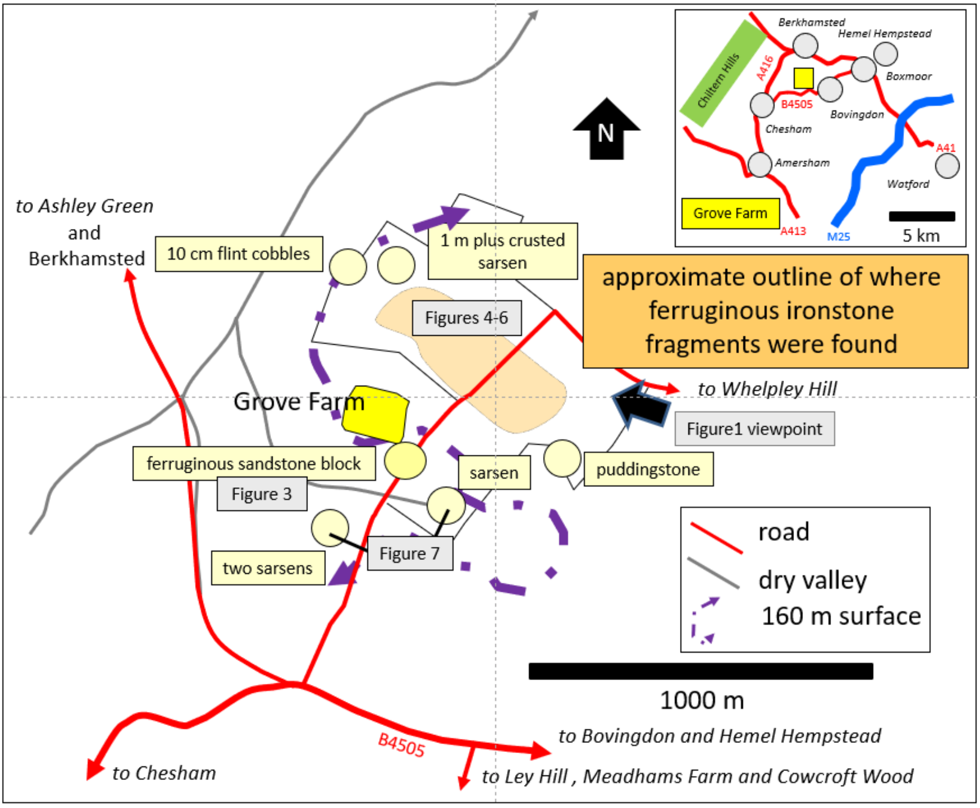

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Figure 2. Sketch positioning the 160-metre surface at Grove Farm and the ferruginous sandstones. The insert relates Grove Farm to nearby towns / villages and main roads.

The ferruginous sandstones

Some 25 years ago I found a 7-kilogram block of bedded, hard, medium grained, dark brown, ferruginous, quartz-rich sandstone lying beside a ditch in Grove Lane at the location indicated on Figure 2. Until recently it was treated as a geological curiosity with no relevance to the area's geo-history. This view changed when ferruginous sandstone fragments began to be found in nearby fields (Figure 2). The block which has maximum length of 28 centimetres is depicted in Figure 3.

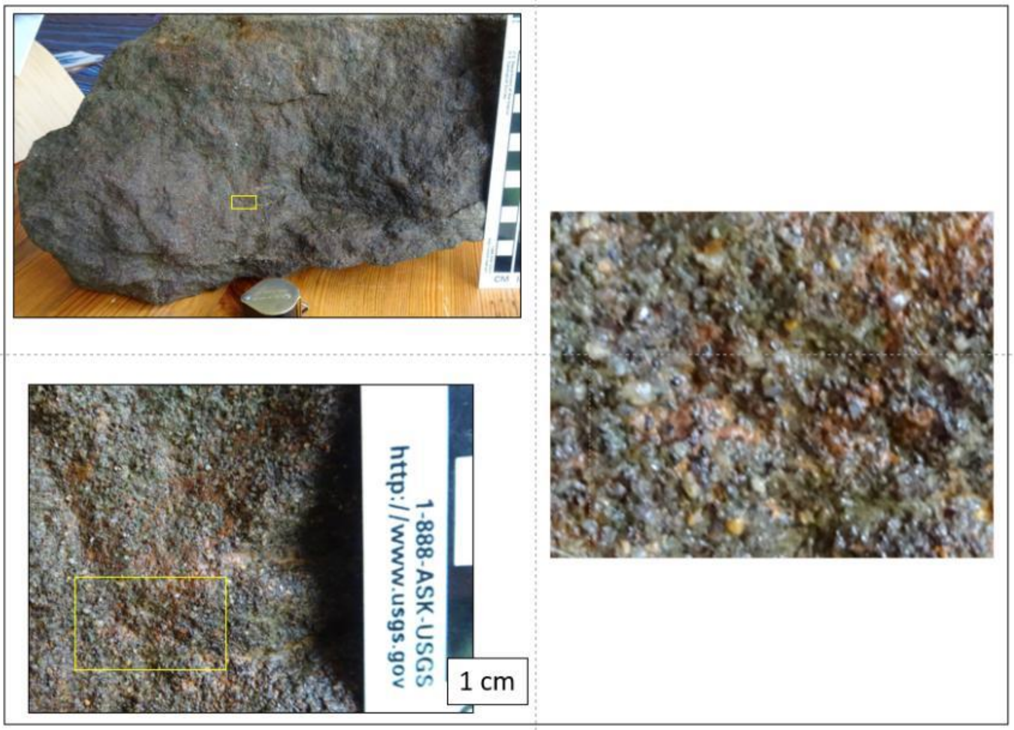

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Figure 3. Enlargements of the 7-kilogram ferruginous sandstone block. Their position on the block is outlined by the yellow bounded boxes. The scale bar is in centimetres. The abundant quartz is readily visible. Iron oxide veining in may be falsely giving the impression of low angle crossbedding.

So far ten brown, ferruginous sandstone pieces have been collected. They weigh between 20 and 150 grams and have a maximum length of 8 centimetres. Figures 4-6 illustrate these fragments. The sandstones are coarse grained to pebbly (up to 2-centimetre clasts) and rich in quartz, some of which is colourless. Grains are rounded to sub-rounded and many appear polished. Weathered flint is suspected. Iron-stained mudstone flakes are prominent. Smooth, up to 2.5 centimetre across, indentations on some samples may be the moulds of large mudstone clasts. A few samples appear to be the remnants of ironstone veins. Also present, and just visible on Figure 5, are barely millimetre sized, shiny black spheres. The impression is one of iron rich, oolite grains. Laterite pisoliths are another option, but these are typically much larger and browner in colour.

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Figure 4. The ten ferruginous sandstone samples. Figures 5 and 6 provide close ups of two specimens.

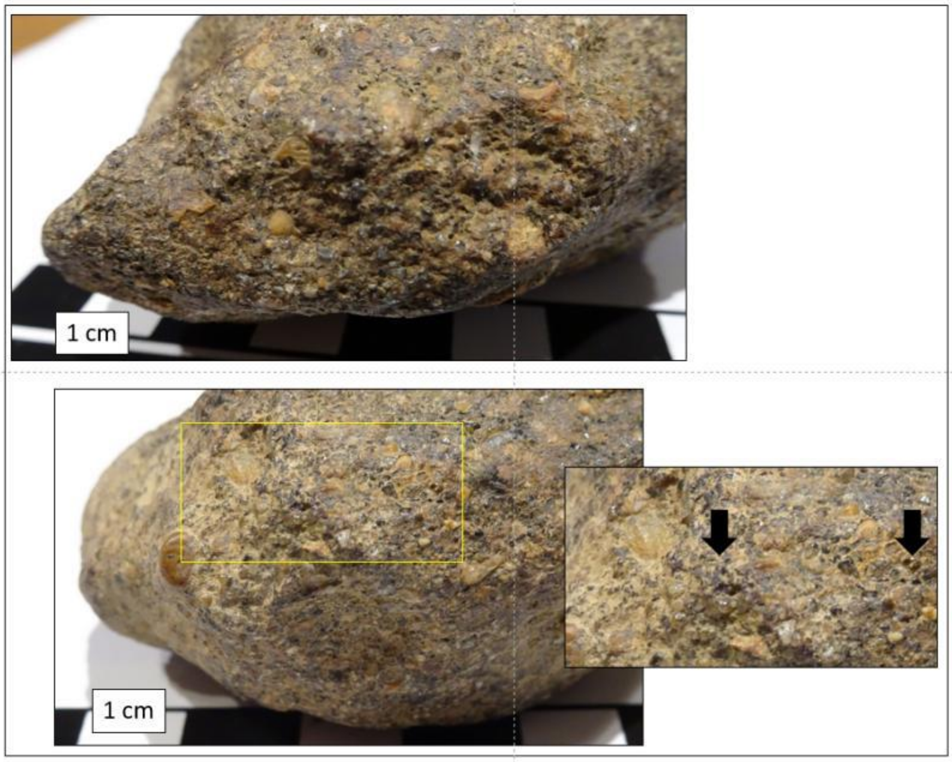

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Figure 5. Two views of the same specimen of ferruginous sandstone. Just visible are clear quartz grains and on the enlarged insert the black spheres. Some are these are located using the two black arrows placed on the insert. The yellow bounded box positions the insert's position on the sample. The scale bar is in centimetres.

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Figure 6. Close up of iron oxide veining in a quartz-rich, granular, ferruginous sandstone. The scale bar is in centimetres.

Hand lens comparison of the 7-kilogram block with the small fragments suggests, as shown by the figures, that all are lithologically related through the presence of clear, polished quartz and the black spheres.

Possible origins

Three origins for the ferruginous sandstones are considered:

1) Reg Crag Formation

Red Crag Formation fossils are present in periglacially disturbed boulders at Rothamsted (Herts, Dines and Chatwin, 1930). Their host is a medium grained, bedded, ferruginous sandstone, coloured pictures of which are supplied as plate 23 (page 80) in Catt (2010). Fossil pictures in Dines and Chatwin (1930, plate 1) hint by the scattered sand grains on the shells that the sandstones may be soft. Despite the absence of fossils and ferruginisation, intertidal sands and beach gravels (Catt, 2012) at Little Heath near Berkhamsted (Herts), some 13 kilometres WSW of Rothamsted, have long been associated with the Red Crag Formation. The Little Heath Tertiary outcrop viewed from Grove Farm forms a positive rise 4.5 kilometres to the NNE across the Bulborne valley. The outlier's crest stands some 10 metres above the Grove Farm surface.

2) Reading Formation (Lambeth Group)

White quartz rich sands and gravels with lydite (hard, pre-Cretaceous, black radiolarian cherts) and sandstone fragments were once exposed in the Lane End area near High Wycombe (Sherlock et al., 1922). These beds were regarded as unusual by Wooldridge (1925) as they are developed in an otherwise normally silt-clay dominated section. As such these coarser sediments represent the entry of a fluvial regime into a predominantly, depositionally quiet marginal marine basin. Sherlock et al.

(1922) suspected Lower Greensand (Aptian) sediments supplied the sands and gravels. Others were of the same opinion with Wooldridge and Ewing (1935) concluding the source for the sands and gravels was the Lower Greensand of the Farringdon region of Oxfordshire. There the Ferham Sand Member consists of '*reddish-brown, ferruginous, cross-beaded, shell fragmental, medium- to coarse grained, clean sandstone. There are scattered pebbles, bands of conglomerate grit and minor horizons of mudstone*' (British Geological Survey, undated).

3) Pleistocene bog iron

Oxidation by exposure to the air or contact with the roots of growing vegetation of ferrous iron-bearing ground waters results in the precipitation of ferric oxides and the accumulation of iron pans. Pictures of iron cemented gravels formed by this process and used in the construction of church walls in Hertfordshire and Surrey are provided by the Hertfordshire Geological Society (undated) and Nield (2020). Post-formation, periglacial disruption of any pans would allow the formation of isolated rock fragments.

Discussion

Sumbler (1996, page 117) observed that the drainage fabric for the South East was established during the Paleogene as the east-west elongated, London Basin began to subside and the proto-Thames began to deliver sediment from beyond the Tertiary confines of the basin: as an example John Hepworth and I found centimetre sized lydite within the terrace exposed immediately east of High Wycombe at the time of the M40's construction. Given this long-term, west to east drainage configuration, a Reading Formation rather than Red Crag Formation derivation for the ferruginous sandstones, despite their proximity to Little Heath, provides for now a simpler model for their origin.

Their hardness, when combined with the absence of ferruginisation in true puddingstones and sarsens (Hertfordshire Geological Society, undated) supports the Lane End model for a pre-Reading Formation origin. Supply as rock fragments from 'carrstone' (Wikipedia, undated) within the Lower Greensand, in the way suggested by Wooldridge and Ewing (1935), represents the most satisfactory origin, especially as no other candidate lithologies are reasonably available. However, this option, regardless of the exact Lower Greensand source location, requires the loss during the Paleocene of the Chalk cover from the Lower Greensand. It also requires the absence of a Chalk escarpment during Reading Formation deposition to enable pre-Chalk sediment to reach what are now Chilterns plateau settings. However, as Wooldridge and Ewing (1935) observe '*the Chalk cover north-west of the London Basin, must have been locally breached in early Eocene times, permitting the contribution of Lower Cretaceous and Jurassic material to the Eocene sediments*'.

Additional support for an ultimate Lower Greensand origin is provided by the similarity between the observed polished black spheres in the ferruginous sandstones and the description of '*dark coffee-coloured and well-rounded goethite grains*' in the 'Red Sands' of the Woburn Sands Formation (Lower Greensand, Shephard-Thorn et al., 1994).

The bog iron option is discounted for two reasons:

1) the presence of iron oxide veining, illustrated for example in Figure 6, requires multi-stage, iron mobility. Such histories result in the Lower Greensand 'carrstone'. They are less likely in Pleistocene created iron pans.
2) No free quartz has been noted in the field soils where the ferruginous sandstones were collected. This observation makes it unlikely that sufficient quartz existed loose within the terrace to allow the quartz concentrations observed in the ferruginous sandstones.

The disparity in size between the 7-kilogram block and the ten other ferruginous sandstone samples provided another reason for initially continuing to reject the former as indigenous. This possibility was discarded when kilogram-sized blocks were found scattered across the 160-metre surface. Present are a 35-centimetre long, standard puddingstone block and three 20 to 25-centrimetre long, indurated, sarsen-affinity, sandstone cobbles (Figure 7). All three of the cobbles contain quartz and black lithics. Also recorded are a rounded, crusted, metre plus sized sarsen, and abundant 10-centimetre sized, flint cobbles. Their locations are marked on Figure 2. These finds supply additional evidence from Grove Farm of Reading Formation origin sediments, but this time preserved by early Eocene silicification as described by Hepworth (1998).

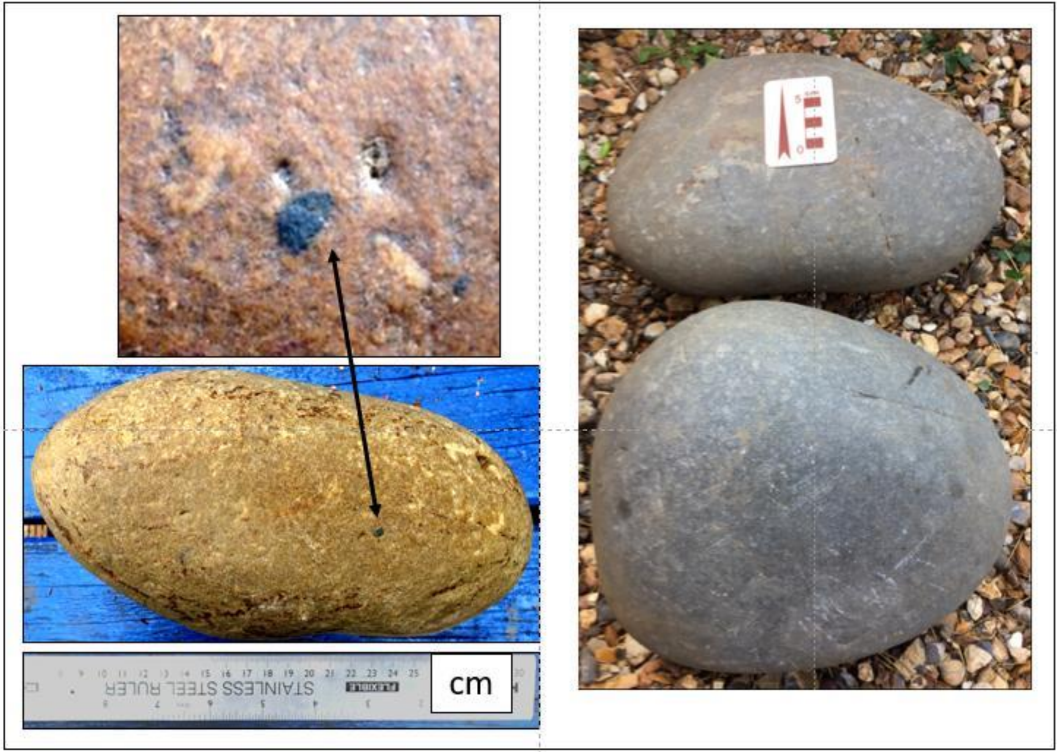

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Figure 7. Hard pebbly sarsen-affinity cobbles. They are quartz rich and contain black lithics (possibly lyddite). When, where and how rounding was acquired are unknowns. My suspicion is that the rounding may one day provide evidence for currently unrecorded Chiltern events, for example during the Neogene.

Some years ago, I found a lightly pinkish stained, quartzite cobble reminiscent of those found in the Triassic aged, Bunter Pebble Beds. This was also dismissed as non-indigenous, but after discovering from the literature the realities for Lower Greensand sediment delivery to the Reading Formation basin, this quartzite may become yet another natural component of this increasingly lithologically stimulating, 160-metres terrace.

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Scotland’s North-West Highlands – roadside geology from the North Coast 500: the Mesoproterozoic aged, Bay of Stoer (Sutherland) impact surge blanket

Nick Cameron FGS

Abstract

Presented are observations, made during a short geology driven tour around Scotland’s North Coast 500 route of the unique for this country, Mesoproterozoic aged, Bay of Stoer (Sutherland) surge blanket which was created by meteor impact. The succession, which is directly accessible from the NC500, is hosted within Stoer Group sandstones and red mudstones and consists, as detailed by the literature, of 10-12 metres of welded, de-vitrified glassy breccias capped by interpreted air fall, gravelly sandstones. The underlying, then newly deposited, Stoer Formation sandstones are injected and disrupted by the by the basal surge. The impact site remains debated.

Introduction

Just before Christmas 2022 an invitation arrived to visit family living on the Black Isle just north of Inverness. This to my geological mind immediately became the perfect opportunity to extend time in Scotland by revisiting the North-West Highlands. With so much more to experience than the geology, my wife agreed, albeit I must admit rather less whole heartedly, to accompany me. Our route was the North Coast 500 (NC500) which snakes for much of its length through the North-West Highlands. There in June this year we were presented, not with those often rabbit hole sized outcrops characteristic of where we live, but with mountain sized swaths of geology. The question soon became, with so much to excite a geologist, what could be the focus for an article on the richness of rocks and structure available from the NC500. The front runner was the superb geology and scenery associated with the Moine Thrust, but contenders were the new roadside cuttings on the A832 southeast of Gairloch presenting a magnificent section within the perplexingly positioned, Paleoproterozoic aged, Loch Maree Group and the Mesoproterozoic aged, surge blanket that defines the meteor impact created, Stac Fada Member of the Stoer Group. In the end, the cataclysmic geology of the Stac Fada Member exposed at the Bay of Stoer could be the only winner. To put the Stac Fada Member into its geographical context, Figure 1 combines the visited location with the GeoIndex Onshore map base available digitally from the British Geological Survey (BGS) together and the route of the NC500. Figure 2 then positions the impact's position within the Caledonian and older geological history of the North-West Highlands.

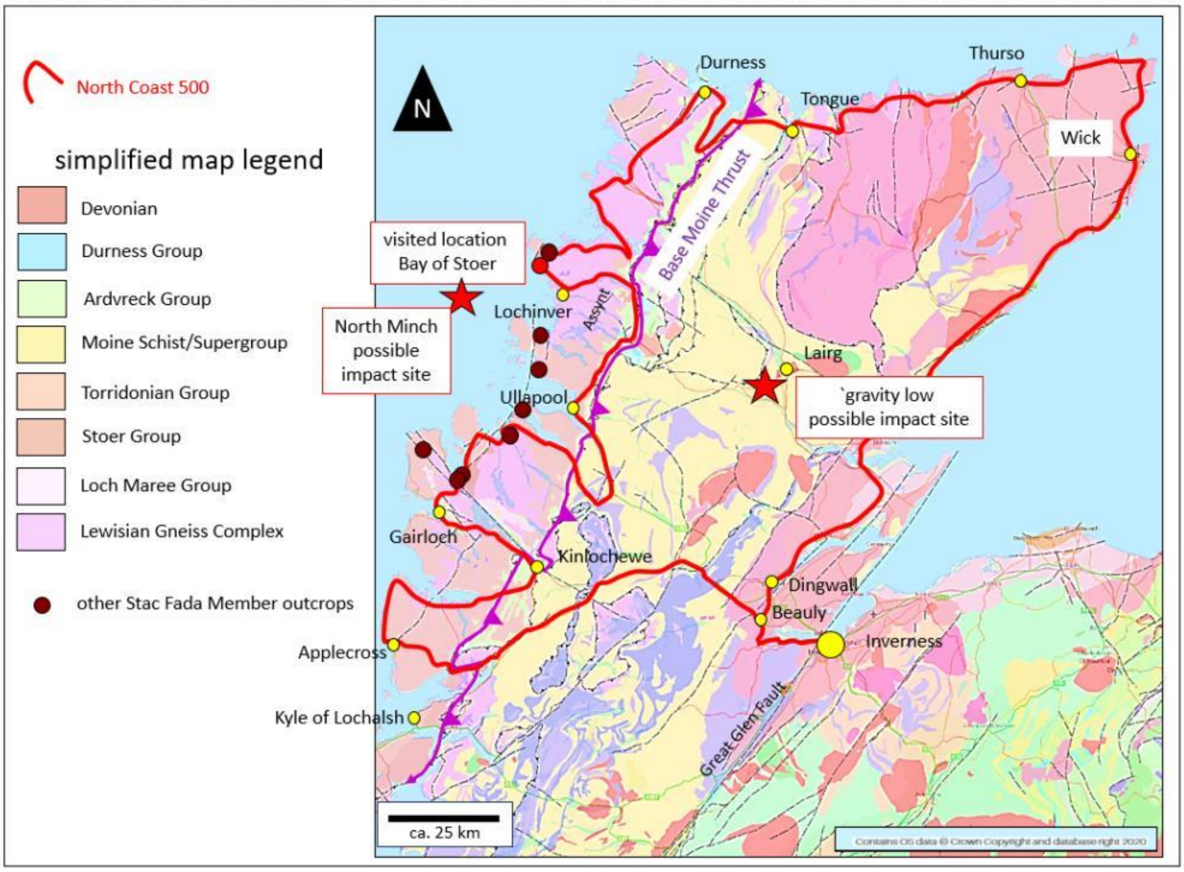
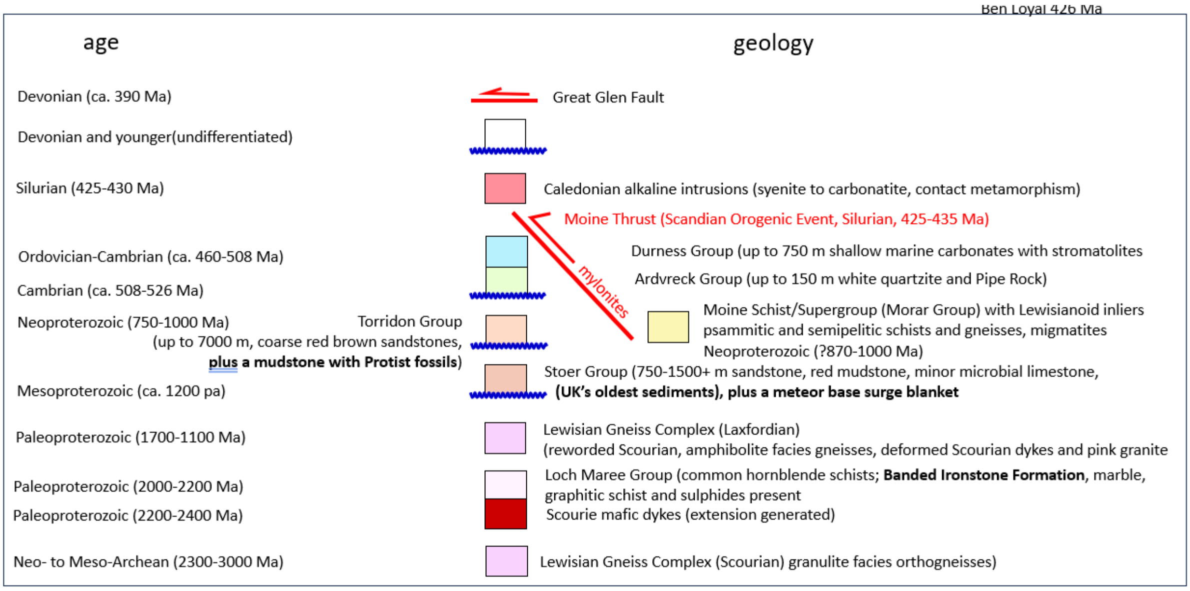


Figure 1. Location of the Stac Fada Member (Stoer Group) impact deposits. The complete geological legend is available at the referenced BGS site. The primary road network progressively appears as the transparency of the geological overlay is increased. Collins sell an excellent NC500 pocket road map which shows all roads and helpfully names peaks.



Ben Loyal 426 Ma

age		geology
Devonian (ca. 390 Ma)		Great Glen Fault
Devonian and younger(undifferentiated)	☐	
Silurian (425-430 Ma)	🟥	Caledonian alkaline intrusions (syenite to carbonatite, contact metamorphism)
		Moine Thrust (Scandian Orogenic Event, Silurian, 425-435 Ma)
Ordovician-Cambrian (ca. 460-508 Ma)	🟦	Durness Group (up to 750 m shallow marine carbonates with stromatolites
Cambrian (ca. 508-526 Ma)	🟩	Ardvreck Group (up to 150 m white quartzite and Pipe Rock)
	mylonites	
	🟨	Moine Schist/Supergroup (Morar Group) with Lewisianoid inliers psammitic and semipelitic schists and gneisses, migmatites Neoproterozoic (?870-1000 Ma)
Neoproterozoic (750-1000 Ma) Torridon Group (up to 7000 m, coarse red brown sandstones, **plus a mudstone with Protist fossils**)	▨	
Mesoproterozoic (ca. 1200 pa)	▨	Stoer Group (750-1500+ m sandstone, red mudstone, minor microbial limestone, **(UK's oldest sediments), plus a meteor base surge blanket**
Paleoproterozoic (1700-1100 Ma)	▨	Lewisian Gneiss Complex (Laxfordian) (reworded Scourian, amphibolite facies gneisses, deformed Scourian dykes and pink granite
Paleoproterozoic (2000-2200 Ma)	☐	Loch Maree Group (common hornblende schists; **Banded Ironstone Formation**, marble, graphitic schist and sulphides present
Paleoproterozoic (2200-2400 Ma)	🟥	Scourie mafic dykes (extension generated)
Neo- to Meso-Archean (2300-3000 Ma)	▨	Lewisian Gneiss Complex (Scourian) granulite facies orthogneisses)

Figure 2. The Stoer Group tabulated in relation to the Caledonian and older geological history of the North-West Highlands. This table was prepared from multiple sources, but primarily those released to the web by the BGS using their earthwise source. The highlighted text illustrates unique geological features of this region.

The Stac Fada Member (Stoer Group) at Bay of Stoer

The Stac Fada Member is a lithological misfit, 10-12 metres thick, entrained within the pervasive sandstones and red mudstone dominated Mesoproterozoic aged, Stoer Group. Initially this unique horizon was interpreted as related to welded, pyroclastic (lahar) flows, but following the discovery of shocked quartz and chromium, nickel and cobalt abundances characteristic of meteorites, it now unequivocally established as a meteor impact generated, ejecta blanket and is, as such, for this country unique. There is a growing literature detailing the geology, but perhaps most useful for introductory purposes is the blog prepared by Rob Butler and available on You Tube. This blog is especially insightful as it includes dramatic satellite images from Mars of ejecta blankets thrown out from 3.8 billion years old, impact craters formed when Mars was still wet and hosted a geomorphology analogous to that of the Stoer Group. Other references include the geological excursion guidebook prepared by Goodenough and Krabbendam (2011) and undated Geological Society and Oxford University blogs. More detailed information can be discovered on Google by searching using words such as Stoer and impactite.

By combining our foreshortened, strike viewpoint from the southeast of the outcrop (Figure 3) with the direct view, close-up images in Butler's blog, the impact succession can be visualised as beginning with a welded, basal surge breccia (see area A on the above figure) whose momentum disrupted and dismembered, from left to right in this case, by hot injection the underlying, then newly deposited and still moist sands (area B on this figure). Above are dark coloured, massive welded breccias containing abundant distal to this site sandstone and to a lesser extent Lewisian blocks, all set within a matrix of flattened to shredded, now devitrified glass (area C on this figure and Figure 4). The cap was observed to contain parallel bedded gravelly sandstones interpreted to be rich in air fall lapilli (Figure 5). This uppermost horizon from the literature has a low mounded surface that is transgressed by Poll a'Mhuilt Member sediments (this contact is hidden from the Figure 3 viewpoint).

Figure 3. Updip view of the Stac Fada Member. The base is interpreted using images in Rob Butler's blog. The weather had been unusually dry all Spring and water supply for some was problematic.

Figure 4. Welded surge breccia containing, in the top right corner, a fractured, Stoer Group sandstone block. The ring provides the scale. This picture was taken by Ewan Innes.

Figure 5. Interpreted, air fall, lapilli rich, gravelly sandstone in a float block located close to Figure 4. The ring supplies the scale.

The impact site remains uncertain. One possibility is just offshore in the North Minch (Figure 1, Amor et al., 2019), another is the centre of the large gravity low to the southwest of Lairg (Simms et al., 2019 and Simms, 2015). The crater is thought, as discussed in Butler's blog, to be some 10-15 kilometres wide and perhaps 1-2 kilometres deep. As noted in his blog, deposition began within minutes of the impact. Though the resulting surface destruction was large as revealed by the spread of the Stac Fada Member (Figure 1), algal life in the form of laminates is present in the overlying Poll a'Mhuilt Member (Krabbendam, 2011, figure 32).

Access to the Bay of Stoer impact site

Location 9 on figure 29 in Krabbendam (2011) positions the Stac Fada Member outcrop on the northwestern side of the Bay of Stoer. Ready access is available from the NC500 as its route, defined here by the B869, runs northwest through Stoer from Lochinver. In good weather there are outstanding views back eastwards towards the classic Torridonian peaks that dominate the landscape of Assynt (Figures 1 and 6).

Figure 6. Suilven (right) and Canisp viewed from the NC500 east of Stoer. The foreground is the once glaciated surface of the Lewisian Gneiss Complex. The vertical gneiss lies within the Laxfordian aged, Canisp Shear Zone (Watson et al., 2011, figure 20).

Parking is available along the south side of the sheep-proof, walled cemetery west of the road close to location 10 on figure 29 in Krabbendam (2011). Almost opposite, across the road, a wide grassy track leads to the beach from where a lesser path runs north-westwards some 500 metres on grassland, mostly just above the low cliff line. The going is easy, though it will be far less so when wet, windy or both. There is a small stream which when in flood could prove tricky to cross. Both the OS Loch Assynt 1:50,000 (Landranger 15) sheet and Google Earth show this steam and the rock ledge that forms the Stac Fada outcrop as it juts southwards offshore and extends inland as a low ridge. Descent to the outcrop could be tricky and required no longer available to us agility. For refreshment and perhaps recuperation, Flossies beach store is a short distance by road to the south of the parking place. However, opening may be seasonal.

The impact site can be busy because of its geological importance. Hammering is discouraged, but I note polished breccia stones, traded as suevite, for use in jewellery is for sale on the web. For us, just savouring apocalyptic geology was sufficient compensation. And from now onwards, we can experience meteor impact movies knowledgeable of their true reality.

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Field meeting report on the geological and geoarchaeological aspects of Londinium (Roman London) on two hills walk, led by John Wong FGS

Rudy Domzalski FGS and Richard Trounson FGS

All photos by the authors ©

On Sunday 5th November 2023, John Wong FGS led a seven-hour guided walk (include half an hour lunch stop) of the Londinium (Roman London) in the City of London from St Paul's Cathedral to Aldgate in memory of Home Counties North Regional Group member John Pulsford FGS CGeol.

Below is a description of the geology and archaeology of the walk in the order we visited, along with a brief historical context at the start.

The remains of the City Wall (Roman Londinium wall) can be found from the Tower of London in the east to the Old Bailey in the west the City of London. The remains along this stretch covers an intermittent distance of approximately 2 miles. The City Wall was built in c.200 AD by the Romans some 150 years after they had arrived in Britain. During the Saxon period the wall began to fall in decay, however between the 12th and 17th century the wall was repaired and built upon. The 17th century marked a rapid time of expansion to the city of London thus the defensive purpose of the wall was not required from the 17th century onwards. For much of the 18th century the masonry of the wall was taken and by the 19th century much of the wall had disappeared. Through recent construction work some of the remaining wall has become visible again thanks to preservation of these newly found archaeological sites.

On this field trip John led us from Saint Paul's Cathedral via the Barbican area, the Roman Amphitheatre at the Guildhall, Roman Temple of Mithras, Cannon Street, Roman Thames foreshore south of Upper Thames Street, to the Tower of London and Aldgate looking at selected Roman wall sections. However not every Roman site on this walk was visited as there were time constraints.

Before the walk started at the western end of Saint Paul's, John gave an appreciation of the late John Pulsford, a participant in a number of the Group's field trips, which was followed by two minutes silence. John then gave an introductory talk describing the geology of early Londinium. He said it was set on two hills made up of Pleistocene Brickearth or loess, now called (in this context) the Langley Silt, which was so important in the construction of Roman London. The silt was favoured for the making of bricks because it required much less mixture of other materials than clay, and fused at lower temperatures, enabling high-quality bricks to be made effectively with more simple kiln technology. It was also suggested that these two hills, besides being near the Thames for water, provided their own drainage streams and also defensive positions for early Londinium. John was to ridicule on several occasions during the walk an archaeological image of Roman London, widely displayed near relevant sites, which showed the entire Square Mile area as completely flat and low-lying!

Aldersgate, City Gate

Figure 1: © Roman London City Gate.

This gate (figure 1) was built in the 4th century by the Romans to defend against the increasing number of invading Saxons coming from across the North Sea. It was built from sandstone foundations, Kentish Ragstone building blocks and wood (as will be described in later Roman sites of this walk), creating a secure gate with a platform for catapults. All that remains of this Roman gate is shown in the above photo which depicts a rectangular foundation seen here below the vegetation. The remains of the Roman and Medieval gate here do not show much as they were bombed during the 2nd World War, along with buildings on top.

St Giles Cripplegate Tower

Figure 2: © Medieval defensive tower.

The medieval tower shown in figure 2, represents the Northwest section of the Roman and Medieval defences of London. In 1211-1213 a new defensive ditch was built around the wall and soon a series of towers like this one were built along the western side. In peacetime the towers were rented out for several uses and some used by hermits. This tower may have been used for this purpose as in the C13th the chapel to the hermitage of St James in the Wall was built nearby.

The walk continued to the site of Cripplegate, which would have been the Northern entrance to Londinium, however the gate was completely demolished in 1760.

City Wall and St Alphage Gardens

The gardens (figure 3) are named after a former church on the site, now also demolished, which was dedicated to St Alphage (or Alphege), an early 11th century Archbishop of Canterbury who was martyred in 1012 at Greenwich by a drunken band of Danes after refusing to agree to the payment for his ransom of a large sum from church funds. He was first beaten with bones, and then polished off by an axe, the first of five Archbishops of Canterbury to meet a violent death.

Figure 3. © St Alphage Gardens.

This part of the wall, shown in Figure 3, has a Roman base with medieval brickwork later added. It forms part of the Northern defences of Londinium. The medieval brickwork was added in 1477. It was the first time on the walk that we could use our hand lenses on the masonry as the wall was accessible. The two photos below show a macro photo taken of the cement and stone blocks.

Figure 4: © Kentish ragstone.

Figure 5: © Roman cement with inclusions.

Figure 4 shows the construction stone of the Roman wall. This is a Kentish ragstone, which is a sandy limestone or limey sandstone found in Kent in the Hythe formation in the Lower Greensand. One of the participants in the fieldtrip pointed out that transport from Kent would have been relatively easy with the river access, making it cheaper for transportation. This could be a reason why much of the Roman wall was built with Kentish Ragstone. Figure 5, on the right shows the Roman cement with small angular pebble inclusions. It is surprising to think this cement has lasted over 1800 years and holds as the base of the Medieval wall.

London Roman Amphitheatre

When the Guildhall Art Gallery was being built in 1988, archaeologists with the Museum of London discovered the remains of the Londinium Amphitheatre. It is now on public display beneath the Guildhall, its location and size being also marked by a circle engraved on the flagstones lying above.

Figure 6: © View of left side of the entrance to the stage of the amphitheatre.

Figure 7: © View of the right side of the entrance to the stage of the amphitheatre.

Figures 6 & 7 above show the entrance to the stage of the amphitheatre. You can see the rooms where the fighters/actors or even animals would have been made to wait before their entrance. Figure 7 shows the wooden remains of a door to one of these rooms. Next to the door you can see some tiles built in the wall which would have been made from the Langley silt (Brickearth sourced from Londinium's two hills). Also, just above the tiles there is a large sandstone block amongst the Kentish Ragstone limestone building blocks. We were able to inspect similar blocks at closer quarters later in the trip. However, John drew our attention to the glauconitic content and fine graining of the Ragstone, which he said was a sign that the stone had been quarried from more easterly outcrops of the Hythe Beds.

Temple of Mithras

The temple was initially excavated in the aftermath of second world war bombing, with the archaeologists not knowing what they had found. It was the discovery of a sculpted head of the god Mithras on the last day of excavation which provided the identification of this Temple to Mithras, a very secretive cult during the Roman period. It is located beneath the Bloomberg Space and has an immersive display with sound in the form of Latin chants and special lighting. Again, the building stone is a sandy limestone; Kentish Ragstone.

Figure 8: © View of the Temple of Mithras during the presentation with changing light effects.

Figure 9: © View of sandy limestone (Kentish ragstone) used as foundations of the Temple.

Tower Hill Roman wall

After visiting the Mithraeum, we walked down to Upper and Lower Thames Street, where we saw 2000-year-old timber from the Roman wharves. A piece is attached to the bell tower of St Magnus the Martyr Billingsgate, close to where the wharves would have been in Roman times.

We then walked up to the Monument, and after a stop for lunch re-joined Lower Thames Street and walked past the site of the Old Billingsgate Market and the Custom House towards the Tower of London. There we came to a further section of the Roman Wall.

This part of the Roman wall near the Tower of London extends to 14.5 feet and is built from Ragstone with tiles supporting the masonry. It was a good opportunity to get a group photo in front of this section of wall, which is below along with close ups of the Kentish Ragstone building stone, Roman cement and a Roman tile taken on this part of the wall.

Figure 10: © Group photo in front of the Tower Hill Roman wall.

Figure 11: © Parts of the Tower Hill wall from left to right; Kentish ragstone building block, Roman cement, Roman tile.

Similar Section of the Londinium wall

The wall survives here to a height of 35 feet shown in the two photos below. The lower section 14.5 feet is Roman and is comprised of the tiles (from Langley silt) and Ragstone found on much of this walk. You can see some of the red sandstone which forms the base of the wall. The wall was extended in medieval times and the difference between the Roman and Medieval wall is clear with the linear regular masonry of the Roman wall compared to the irregular masonry of the Medieval wall as shown in Figure 12. Figure 13 shows the wall in line with the Tower of London in the background.

John explained that the Roman wall had long been thought to run around the site of the Tower of London enclosure, but in fact it ran through it, fragments of it having recently been found in the Wardrobe Tower.

Figure 12: © Medieval wall above the Roman wall

Figure 13: © View of the wall leading to the Tower of London.

Londinium Wall section in Vine Street

The last section of the wall we visited was in Vine Street. This is beneath what used to be Emperor House but now is postgraduate student accommodation called "The City Wall at Vine Street", it is shown below in Figure 14.

Figure 14: © The city wall at Vine Street.

A section showing the outer part of the wall with a base pavement is preserved in a display area downstairs in the building, which is open to groups of the public by appointment. This provided what was perhaps the best view of the wall's construction in the trip.

You can see the usual Ragstone, brickearth tiles and regular masonry. The original wall would have been 2-3 metres thick, faced with this masonry and filled with rubble.

However, what is perhaps particularly interesting is the reddish-brown soil found on this site and shown in the photo. It is Langley Silt which is still in situ amidst the roman wall construction.
A film which is played in an adjacent viewing area sets out the history of the locality surrounding this section of the wall.

Conclusion

We saw as many sites as time would allow us to, and we saw evidence of the local Brickearth (Langley Silt) beneath London being used to make the Roman tiles. This is probably a reason that Londinium was built on these two hills of Brickearth, amongst other explanations. The Kentish Ragstone used extensively in the Roman masonry was probably used due to ease of access and low transportation costs. The ground immediately beneath the heavily built on surface of the City is mainly comprised of Langley Silt overlying the London Clay. This is a simple geological base but has produced a vast array of archaeological structures dating from Roman times.

This was a very pleasant walk in London which did not cover everything which is available to see along the wall. However, John has mentioned that he may lead the Londinium walk part 2!

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Report on lecture by Dr Colin Serridge on ‘Some aspects of natural and anthropogenic halite (salt) karst subsidence in north Cheshire’ help on Zoom on Tuesday 28th March 2023

Adrian Marsh FGS

Dr Colin Serridge opened his lecture by reminding the large Zoom audience of the nature of geohazards such as those posed by halite karst: ‘*A geological hazard (geohazard) is the consequence of an adverse combination of geological processes and ground conditions, sometimes precipitated by anthropogenic activity. To understand geohazards and mitigate their effects, expertise is required in the key areas of engineering geology, hydrogeology, geotechnical engineering, risk management, communication and planning, supported by appropriate specialist knowledge*’ from Geological hazards in the UK: their occurrence, Monitoring and mitigation – Engineering Geology Special Publication 29 (Ed. D.P. Giles and J.S. Griffiths, 2020). Karst areas of Britain fall into four broad categories with increasing solubility and dissolution rates from Limestone (Carboniferous and Jurassic), Chalk (Cretaceous), Gypsum (Permian & Triassic) to Halite (Triassic). Colin (Edge Hill University) and Anthony Cooper (BGS) have been studying (Serridge and Cooper 2022 - https://doi.org/10.1144/qjegh2022-081) aspects of halite karst in recent years and its importance has been highlighted by the route selection for HS2 Phase 2b being aligned through part of the north Cheshire halite basin.

Beneath typically around 30m of mixed glacial deposits, two distinct halite units are present in the Sidmouth Formation of the Triassic Mercia Mudstone Group in Cheshire:

- Upper – Wilkesley Halite Member (up to 300m thick)
- Lower – Northwich Halite Member (up to 200m thick, thinning from East to West Cheshire) – underlies the Bollin Mudstone Member and is overlain by the Byley Mudstone Member.

Colin’s lecture concentrated on north Cheshire within a triangular area broadly delineated by Lymm, Northwich and Knutsford in which there is relatively flat topography and a concentration of lakes, locally termed ‘meres’. These were mainly formed naturally by dissolution of halite after the last Devensian glaciation. Natural halite dissolution induced by the retreating Devensian ice sheet, followed by the establishment of the natural pre-anthropogenic hydrogeological regime caused brine movement, ‘brine runs’, towards low areas where brine springs, locally referred to as ‘wiches’, developed. This term is captured in local place names coinciding with these locations such as Nantwich, Northwich and Middlewich. Under the natural hydrogeological regime, a point of stability was reached during the post-glacial period where supersaturated brine capped the halite deposits and prevented further significant dissolution.

Anthropogenic brine extraction, initially of the natural brine springs, dates from pre-Roman times; later becoming the main industrial salt producing areas in Cheshire, particularly in the late 19th to early/mid-20th centuries, when a flourishing salt and associated chemicals industry developed. Salt was extracted from both underground mines (Winsford Mine, 1928-present, is the last remaining operational mine) and through widespread brine pumping from deep borehole wells into evaporation pans where the salt was recovered. The most successful brine extraction arose from wells located along lines of pre-existing natural brine runs. However, little engineering consideration was given to the implications of this extraction, hence it is termed ‘uncontrolled’. Latterly, ‘controlled’ brine extraction was practiced in zones where the halite is capped by a significant thickness of mudstone and a stable cavern can be formed through engineered freshwater injection and brine extraction. Some of these caverns have since been used for gas storage.

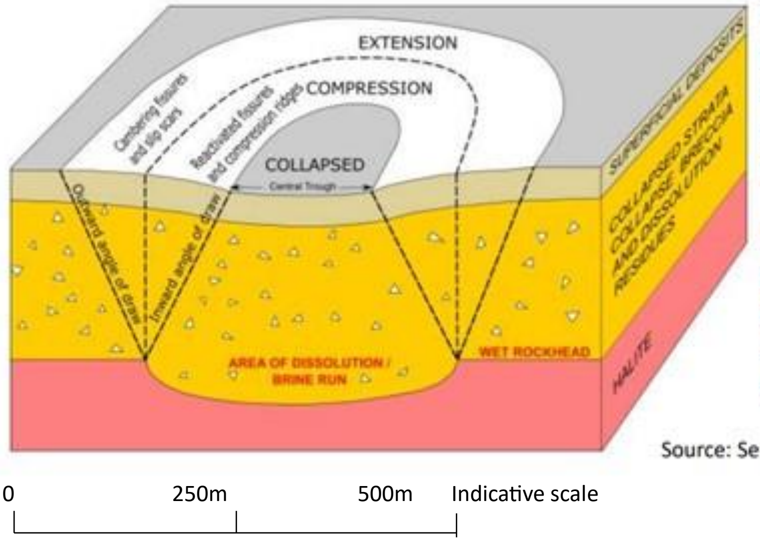
The industrial brine extraction contributed to further subsidence, enlarging some of the meres and formed the new mere of Melchett Mere. In addition, distinct long linear water-filled subsidence features, locally termed ‘flashes’, developed through uncontrolled ‘wild’ brine extraction along brine runs. From the 1950s uncontrolled brine pumping declined with the last brine extraction recorded at New Cheshire Salt Works, Wincham closing in 2006. The engineering legacy of brine extraction has been substantial, with catastrophic building collapses in towns such as Northwich and widespread subsidence related problems. However, responsibility for the cause of surface subsidence was very difficult to establish in the context of large numbers of independent brine pumpers and the considerable distances between pumping and subsidence. This led to the setting up of the Cheshire Brine Subsidence Compensation Board (CBSCB) under a 1952 Act. The CBSCB still acts today providing compensation for brine pumping related subsidence affecting land and property.

Colin has studied the surface expression of the dissolution process with particular reference to the characteristic features of three meres, Rostherne, Melchett and Tatton, using historical surveys, maps, photographs and light detection and ranging (LiDAR) Interpretations. Similarities between the natural and anthropogenic subsidence features are present, which can be separated only by temporal evidence of their formation. All three meres are surrounded by landslip scars related to the subsidence, as illustrated in the photograph in Figure 1 behind the parked car at Melchett Mere. Melchett Mere did not exist before anthropogenic brine pumping and developed mainly between 1927 and 2003. Further evidence of the subsidence is provided by leaning mature trees around Melchett Mere, as illustrated in Figure 2.

Fig. 1: Tension scars visible in extension zone on eastern edge of Melchett Mere subsidence depression

Fig. 2: Subsidence induced leaning trees (remnants of Long Wood) at the northern end of Melchett Mere

The historical and field studies have helped substantiate a subsidence process model for the characteristics of mere formation/enlargement, as shown in Figure 3.



The features of subsidence caused by natural salt dissolution or brine extraction which are similar to long-wall coal mining subsidence.

Monoclinal subsidence zone shows a transition from extension to compression as subsidence expands before settling in the collapsed position

Source: Serridge and Copper, 2022

Fig. 3: Block diagram subsidence model for Melchett Mere

Statistics on the main three meres studied are given in Table 1

Mere	Surface area, ha	Maximum depth, m	Source
Melchett	c. 8-9	11.6	Bennion et al (2010)
Rostherne	c. 48.7	31	Serridge and Cooper (2022)
Tatton	c. 32 (1.6km long)	12	Scott (2014)

Table 1: Physical dimensions of selected meres

Former brine pumping at Northwich, Plumley and possibly Agden is implicated in the formation of Melchett Mere and reactivation of natural subsidence at Rostherne and other Knutsford Group meres. Brine run linkages between these abstraction areas and the subsidence areas cross the route of the proposed Phase 2b of the HS2 railway between Crewe and Manchester.

Investigation of salt subsidence features may benefit from a wide range of techniques, such as:

- Desk studies including historical map and air photography interpretation
- Remote sensing including airborne and ground-based LiDAR
- Building damage surveys
- Geophysics including microgravity, resistivity tomography and passive seismic
- Boreholes and associated monitoring

On the basis that industrial brine pumping has now ceased, care is still required to avoid any potential reactivation of dissolution. Water from buildings and other hard surfaces should not be allowed to soak away into halite karst areas, it should be managed. Furthermore, structure foundations in some areas may be at risk from future subsidence, where robust raft foundations may be required to cater for any on-going residual subsidence.

In summing up, Colin stressed the following main points:

- It is evident that historic uncontrolled (wild) brine pumping has accentuated many of the natural subsidence features occupied by the north Cheshire meres;

- Most of the meres in north Cheshire are natural and largely of post-glacial age, with the exception of Melchett Mere which is completely anthropogenic;

- Despite cessation of wild brine pumping in 2006 there is still the possibility of continued natural dissolution and metastable cavities being present;

- Whilst induced brine runs can be recognised in some locations by subsidence damage or mere (lake) enlargement, without further investigation precise routes remain unclear; and

- Presence of any potential metastable ground has implications for infrastructure development.

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Report on lecture by Gerald Lucy ‘The Story of Essex in Rocks’ held on Thursday 4th May 2023 at the offices of Pell Frischmann in Bishops Stortford

Adrian Marsh FGS

Gerald Lucy describes himself as an amateur geologist with a particular interest in the geology of Essex. From his lecture, it is apparent that this is a classic case of British understatement. His passion for and knowledge of the subject shone through in his narrative and wide selection of slides of landscapes, geological sites and associated fossil and rock specimens from across the county of Essex.

Era	Period or Epoch		Approx. age in millions of years	Geological formations in Essex
Caenozoic	**Quaternar**	**Holocene**	0.01	Recent peat and alluvium
		Pleistocene		River terrace deposits

			0.45	Boulder clay (till) and glacial gravel
			1	Kesgrave (Thames) sands and gravels
			2	Norwich Crag (Chillesford sand)
	Pliocene		2.5	Red Crag
	Miocene		10	*No evidence of rocks of this age in Essex but derived Miocene fossils are found in the Red Crag*
	Oligocene		20	
	Eocene		50	Bagshot Sand
				Claygate Beds
				London Clay (includes the Harwich Formation)
	Palaeocene		55	Lambeth Group (Woolwich and Reading Beds)
				Thanet Sand
Mesozoic	**Cretaceous**		80	Chalk
			100	Gault and Upper Greensand (beneath Essex)
	Jurassic		150	*No evidence of rocks of this age beneath Essex with the exception of Jurassic Oxford Clay in a graben (a sunken part of the crust bordered by faults) beneath east Tilbury*
	Triassic		220	
Palaeozoic	**Permian**		250	
	Carboniferous		300	
	Devonian		400	Shales and mudstones dating from these periods occur at depth (about 300m) beneath Essex
	Silurian		420	
	Ordovician		450	*No evidence beneath Essex, however boreholes have not been drilled deep enough to confirm*
	Cambrian		500	
Pre-Cambrian	**Precambrian**		Age of Earth 4,600	

Figure 1: Summary of geological formations in Essex

The talk was structured chronologically through the formations summarised in Figure 1, starting with a discussion of the Devonian and Silurian basement underlying the county at around 300m depths. In the latter part of the nineteenth century, the discovery of a deep coalfield near Dover stimulated the search for coal in East Anglia. This led to the sinking of a deep borehole at Weeley, near Clacton in 1896. The borehole penetrated the deep Palaeozoic basement rocks at a depth of over 330m and not the younger Carboniferous coal measures that had been hoped for. But sections of these deep Essex 'basement' rocks were brought to the surface for the first time, with a core sample from the bottom of the borehole now at Colchester Natural History Museum. Examination in recent times of various strands of evidence relating to the notable Colchester earthquake in 1884 has indicated that it arose from movement at depth in this Palaeozoic basement.

Above the Palaeozoic, Essex sits in the London Basin, a syncline or trough of Chalk filled mostly with London Clay. The London Basin syncline trends SW-NE through Essex such that Chalk is exposed in the area around Purfleet on the southern flank of the basin and then more extensively across the northern fringe of the county and beyond into Suffolk and Norfolk. Although not exposed, Gault and Upper Greensand are present beneath the Chalk. Various quarries in the Chalk have yielded a good range of fossils including shark teeth (Figure 2), notably at Saffron Walden in the north and Chafford Gorges Nature Discovery Park near Thurrock in the south. The latter site also exposed Brickearth used for brickmaking and Thanet Sand.

Figure 2: Sharks tooth fossil in flint

Figure 3: Cemented Lambeth Group shelly beds

The Lambeth Group is part of the now obsolete 'Lower London Tertiaries' used in the past to describe Palaeogene deposits beneath the London Clay in the London Basin, especially where the Lambeth Group and the Thanet Formation are difficult to separate, as in Essex. In some places, this may include the Harwich Formation and there would be equivalents to Thanet Formation, Lambeth Group and Harwich Formation. Thanet/Lambeth Group exposures generally sit inside the northern and southern limits of the Chalk, plus a few inliers within the London Clay outcrop. The Lambeth Group is a complex mixture of sands, clays and shelly beds of estuarine origin, with cemented shell beds present locally, as encountered during the construction of the M25 in Essex (Figure 3).

London Clay dominates the 'solid geology' across Essex with extensive coastal exposures where many fossils have been collected including sharks teeth, lobster and nautilus shells, indicating an Eocene coastal/shallow marine palaeo-environment, together with an early horse bone fossil found at Harwich interpreted to indicate that land animals trapped on large rafts of vegetation floated out to sea (such rafts are a feature of some major tropical rivers today). The LC cliffs at Wrabness on the Stour estuary contain layers of volcanic ash associated with the opening of the North Atlantic Ocean. The LC is overlain by Claygate Beds and Bagshot Formation Sands, the latter notably present around Brentwood and Billericay, indicating a continuation of shallow marine conditions.

Any Oligocene and Miocene deposits have since been eroded, with fossil megalodon large tooth (Figure 4) derived from the Miocene found in the LC at Dovercourt, Harwich. However, Pliocene deposits consisting of Red Crag Formation are present in the north east of the county above the Stour estuary in the form of coarse-grained, poorly sorted, cross-bedded, abundantly shelly sands. These beds feature the unique gastropod, the left-handed whelk Neptunea Contraria (Figure 5). Fossils originally buried at depth within the Red Crag tend to be absent as they have been dissolved away.

Figure 4: A tooth of Carcharodon megalodon from Dovercourt, Essex

Figure 5: Left-handed whelk Neptunea Contraria

The second half of the lecture was almost entirely devoted to the Pleistocene, which Gerald split into before and after the Anglian glaciation, with the timescale summarised in Figure 6. In Essex two 'new' warm stages (Purfleet and Averley) are now recognised within the Woolstonian cold/glacial stage.

Epoch	Age in years	Stage	Climate	Oxygen isotope stages	Archaeology
Holocene	0 10,000	Flandrian	Present interglacial	1	**Neolithic** **Mesolithic**
Pleistocene	20,000 80,000	Devensian	Glacial	2 – 5d	Neanderthals become extinct Modern humans (Homo Sapiens) arrive in Europe
	120,000	Ipswichian	Warn	5e	
	150,000	Unnamed stage	Cold or Glacial	6	
	200,000	'Averley'	Warm	7	**Palaeolithic**
	250,000	Unnamed stage	Cold or Glacial	8	
	300,000	Purfleet	Warm	9	
	350,000	Unnamed stage	Cold or Glacial	10	Neanderthals (Homo Neanderthalensis) evolve from Homo Heidelbergensis
	400,000	Hoxnian	Warm	11	
	450,000	Anglian	Glacial	12	
	500,000	Cromerian	Climate of early stages uncertain	Pre-Anglian stages	Boxgrove, Sussex Homo Heidelbergensis
	2.6 million	Early Pleistocene stages			First evidence of humans in Britain (Norfolk) c. 800,000 years?
Pliocene			Cool		

Figure 6. Geological timescale of the Ice Age in Britain (not to scale)

The earliest Pleistocene deposit present in Essex is the Warley Gravel (Warley is a suburb of Brentwood) of the Early Pleistocene Epoch (>1.5 million years old?) and now equated to the Stanmore Gravel Formation. The earliest evidence of early hominids in the region is around 0.8 million years BCE in Norfolk. At that pre-Anglian time the river Thames flowed across central Essex (Figure 7) and was joined by the river Medway near Clacton. There was no English Channel then with England still joined to mainland Europe.

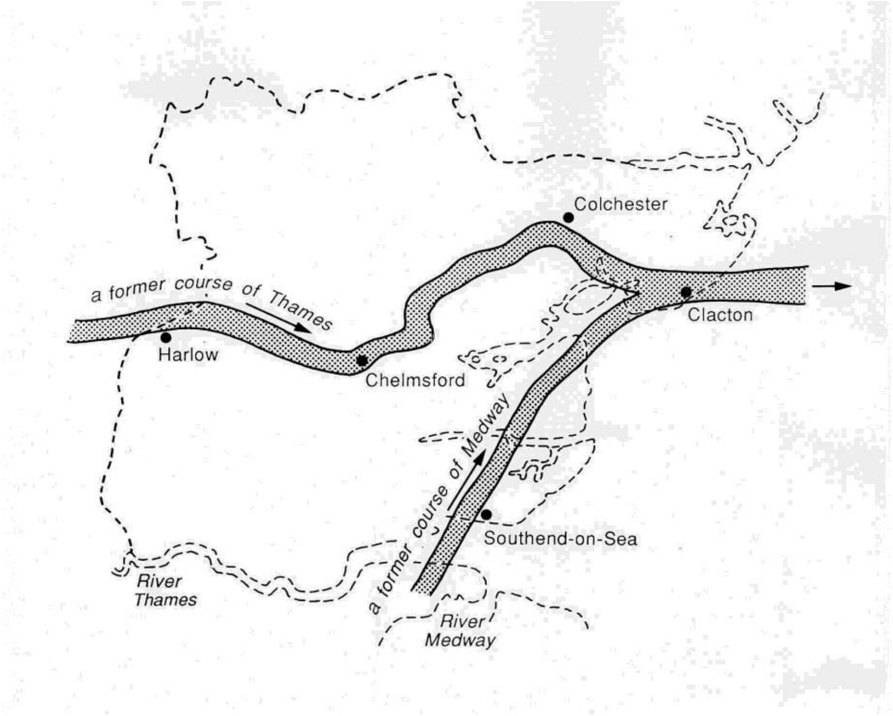

Figure 7: Routes of the Thames and Medway before the arrival of the Anglian ice sheet 450,000 years ago.

Considerable archaeological evidence of early hominid occupation of Essex has been found, including ‘Clactonian Man’ with relatively crude flint tools and the earlier ‘Purfleet/Greys Man’ with more advanced tools. This suggests that pre-homo sapiens development did not follow a linear progression and probably consisted of waves of tribes with different cultures migrating in relation to changes in the climate and associated sea levels/land boundaries.

The Pleistocene deposits have been a rich source of interesting geological specimens, including large boulders of Hertfordshire Pudding Stone and Sarsenstone and flint fossils. Some of the gravel clasts have travelled a long way to reach Essex, including Tuff originally from the Snowdonia region of north Wales, and Cornish igneous rocks transported along a Triassic river flowing from Brittany into the English Midlands and then later picked up by the palaeo-Thames. In terms of fossils found in quarries, the ‘Ilford Mammoth’ was found in 1863 (now in the Natural History Museum) and the ‘Averley Elephant’ found in 1964 in a channel alongside mammoth bone remains. Periglacial features include patterned ground near Harlow reflecting fossil ice wedges.

Gerald’s closing remarks concerned the story of the Ashdon meteorite (subsequently sectioned, Figure 8). This 4.5 billion years old rock fell into a field in 1923 at an estimate velocity of 18km/sec and was witnessed by a farm labourer who reported that the earth had spouted like water after the impact. The stone was subsequently found at a depth of two feet. The stone passed through various ownerships before eventually being donated to the British Museum. In recent times, Gerald and friends set out to mark this story by erecting a signpost at the point of impact (Figure 9).

Figure 8: A tooth of Carcharodon megalodon from Dovercourt, Essex

Figure 9: Left-handed whelk Neptunea Contraria

The meeting concluded with a lively Q&A session.

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Report on lecture by Gábor Somodi on ‘Fracture Network Charaterization in the Granite Host Rock of National Radioactive Waste Repository of Hungary’ held on Zoom on Thursday 31st August 2023

Adrian Marsh FGS

Following a national radioactive waste repository site options and selection process in the 1990s, the preferred site for low and medium-level waste was chosen at Bataapati in southern Hungary, shown in Figure 1. The surface facilities of the repository were opened in October 2008 and the underground facilities four years later in December 2012. This latter ceremony took place in two stages: first at the western incline to the repository and then at the entrance to the storage chamber, some 250m below ground. The Bataapati facility and its licences will eventually allow for the disposal of some 40,000 cubic metres of radioactive waste. The first disposal chamber can accommodate 4600 drums of waste contained in 510 reinforced concrete containers. Waste drums will be stacked at a depth of 200-250m below the surface (0-50m above sea level) inside caverns, outlined in Figure 1, within the Mórágy Hills that are composed of Variscan granitoid rocks.

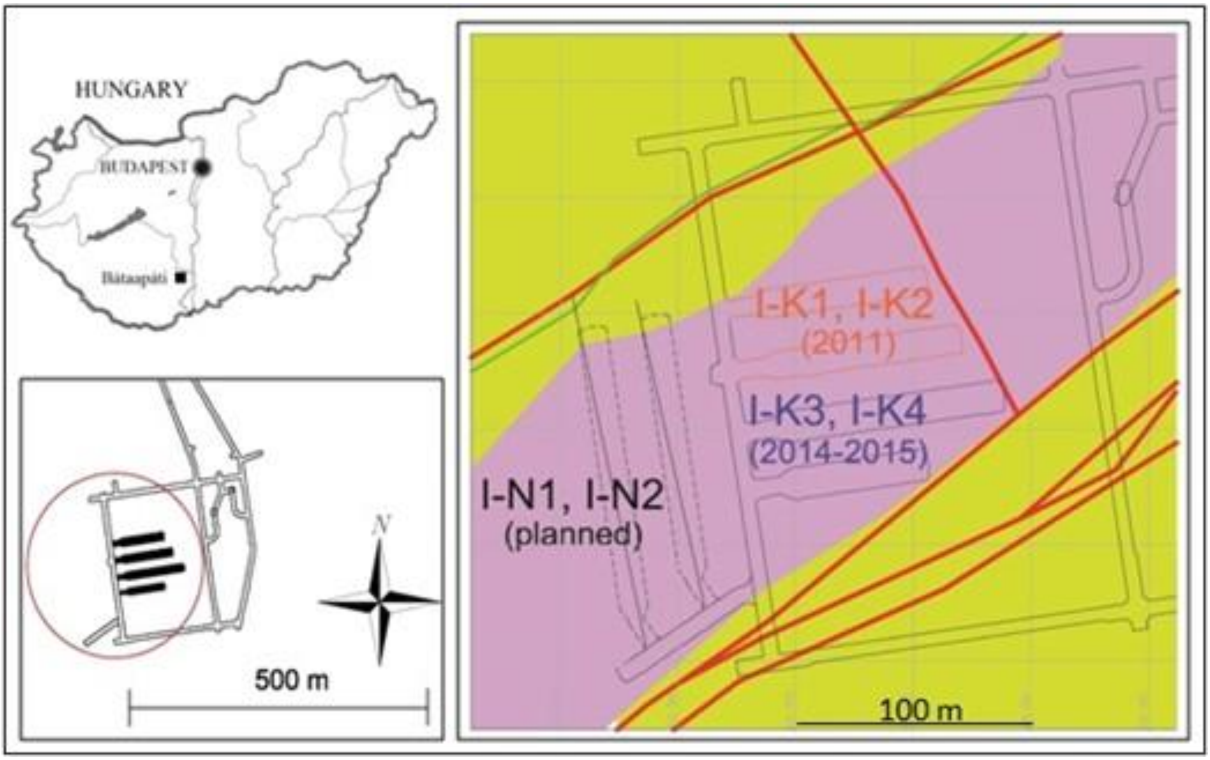

Figure 1: Schematic view of the National Radioactive Waste Repository (NRWR) at Bátaapáti, Hungary

By way of geological background, part of the Mórágy granite complex crops out at the surface or is partly covered by Neogene and Quaternary deposits. In the south, the complex is bordered by sedimentary sequences from the Triassic age. The northwest borderline is defined by the Mecsekalja shear zone, which is composed of highly deformed Variscan metamorphic rocks. Within the granitoid massive itself, a typical monzogranite dominates, although a more mafic monzonite body and numerous aplite dykes have been identified. The granite exhibits a slight foliation as a result of multiphase metamorphism. Several brittle deformation events caused fracturing of the rock complex following its post-metamorphic evolution. The prevailing dip direction of discrete fractures interpreted from acoustic borehole logging is northeast, with dip values ranging from 70^0 to 80^0. Fractures that strike east–northeast to west–southwest with a steep southern dip have been identified as well. The fractures themselves are filled with minerals of hydrothermal origin (calcite, dolomite, clay minerals, quartz and chlorite), deposited essentially from Ca- and Mg-rich subsurface solutions under a wide temperature range in several phases (Toth and Vass, 2011).

Gábor has been involved in the Bataapati project team and as a mature PhD student, having previously gained an MSc and over 16 years geotechnical engineering and earth sciences project experience both within Hungary and internationally. The geological and geotechnical investigations for the project provided useful information about the fracture geometry of the rock masses. A very detailed description of granitic host rocks provided probabilistic data for Discrete Fracture Network (DFN) models. However, in some aspects of data collection there are significant differences between rock mechanical and hydraulic properties, and coupled DFN models demonstrate that mechanical properties of a rock mass can affect their hydraulic behaviour. The project site information on the fracture system geometry was obtained from surface mapping, underground mapping and borehole logging. Underground mapping used both 3D photogrammetry and original rock mass classification mapping consisting of Q Rating, Rock Mass Rating (RMR) and Geological Strength Index (GSI) providing important parameters such as orientation, size and intensity. However, there is a significant range of published approaches to the calculation of GSI values within different rock masses. This is illustrated in Figure 2 (from Vásárhelyi et al., 2016) presenting a brief analysis of the measured and calculated GSI values, comparing seven different qualitative methods in the highly disturbed granitic rock applied to the field data collected in the 3rd research tunnel.

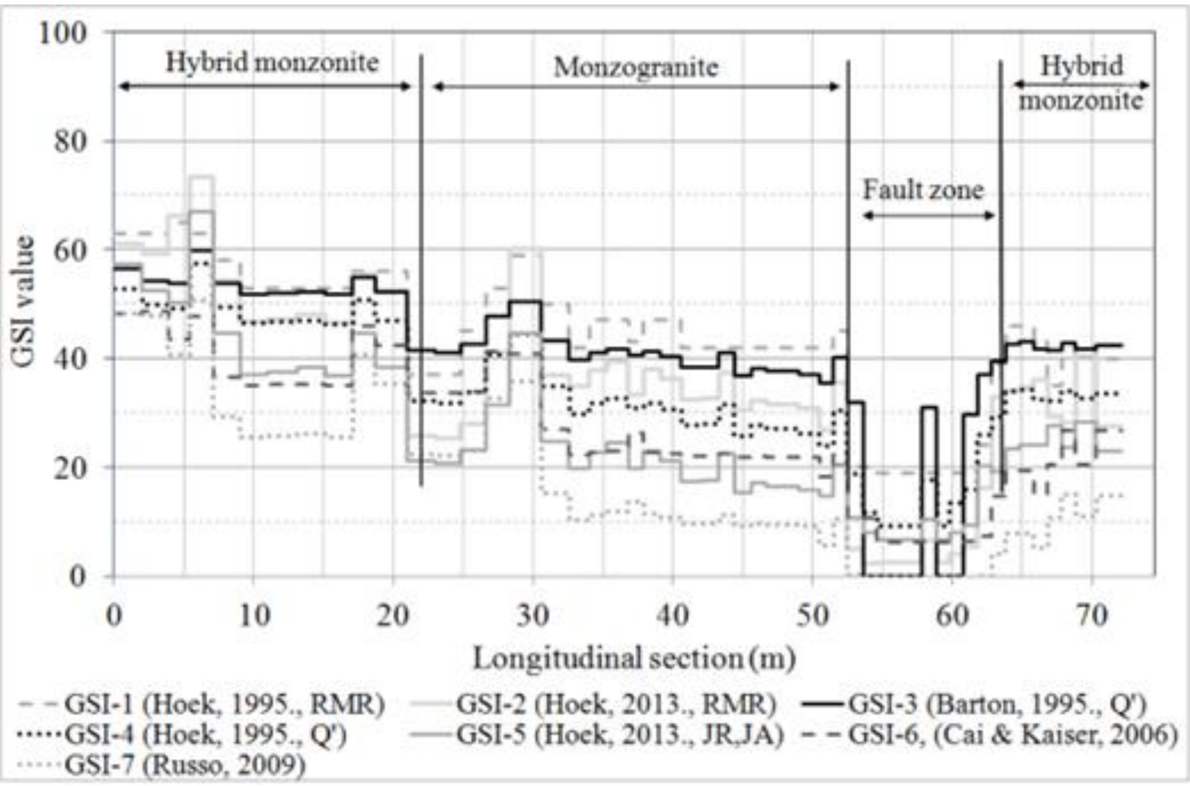

Figure 2: Calculated GSI values along the longitudinal section of the 3rd research tunnel.

Gábor and colleagues' investigation is focusing on fracture density data originated from tunnel face mapping of granitic host rocks exposed during the drill and blast tunnelling works, as illustrated in Figure 3 (from Somodi et al, 2016).

Two different approaches were applied for describing fracture density, original Rock Quality Designation (RQD) and fractal-based parameter (D). The results have shown that the RQD and Fractal D parameters are weakly related to tunnel size and this result is connected to the fracture sets and fracture population. Within the overall project study area there are significant variations in the host intrusive granite geology, including hybrid monzonites composed mostly of plagioclase and alkali feldspar, monzogranites of biotite granite, numerous aplite dykes and fault zones, all affected by metamorphism. Each has unique patterns of fracture networks that apparently both RQD and Fractal D methods can characterise as distinct rock domains. Hence, for generating and validating fractal based DFN models these can be a good solution, whilst rock mass classification methods are useful for describing mechanical behaviours of rocks. We found that applying RQD data, as confirmatory parameter for the DFN models of Mórágy Granite, can lead to a false approach if it was calculated as a summary of fracture sets in tunnel size. Widely used rock mass classification data is a useful approach to understand the spatial variations of fractured rock masses. Although it has limitations in applying it in couple based DFN models.

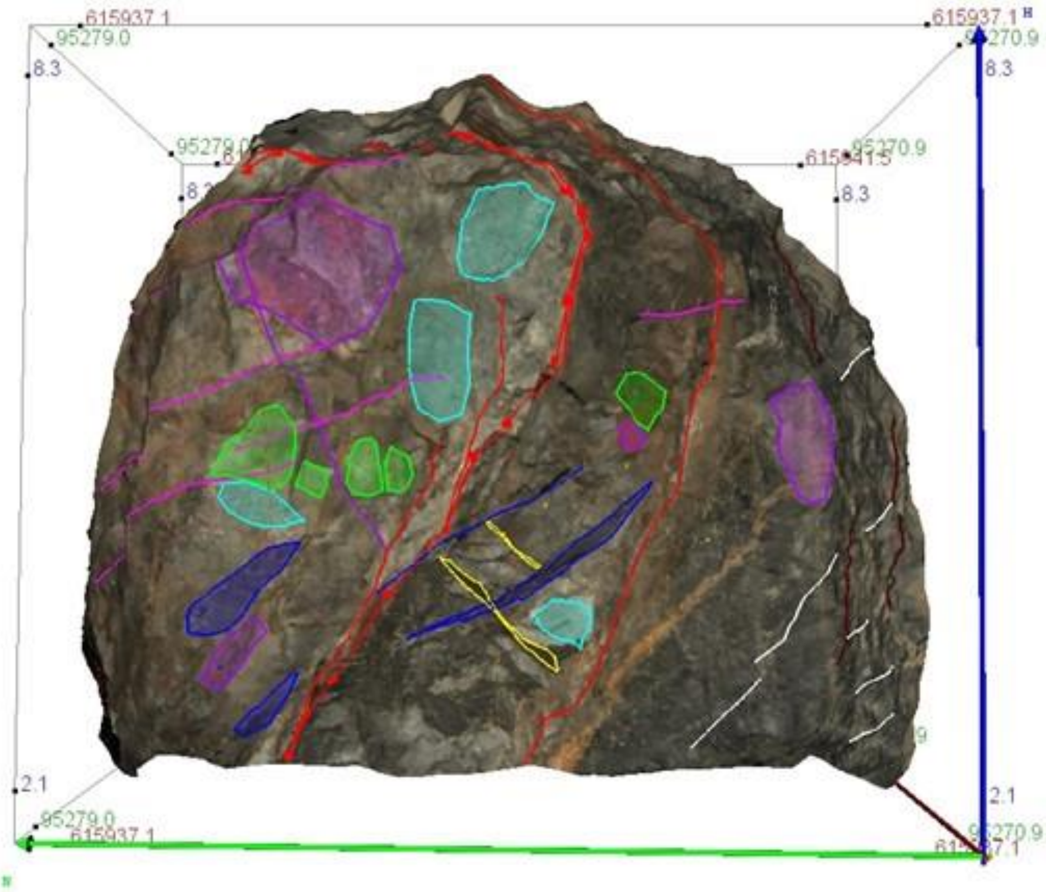

Figure 3: Analysed tunnel face in class III rock mass (RMR = 58; Q = 0.451)

Gábor also discussed the links between structural fracture network characterization and hydrogeological behaviours. The orientations, sizes, intensity, spatial locations and transmissivity of fractures at different scales were previously studied in two hydraulic domains: 1) more transmissive zones, and 2) less transmissive blocks, as shown in Figure 4 (from Benedek & Molnár, 2013). Based on the evaluation of these properties, a conceptual model was developed for the fracture system. The hydrostructural concept suggests that the complexity of fracture orientation and intensity increases with distance from more transmissive zones to less transmissive blocks but fracture size and transmissivity decrease. It also suggests that these parameters vary continuously between different hydraulic domains and that different parameters are strongly intercorrelated. The complex interpretation of the fracture system studied can provide direct inputs for hydrogeological models but can also provide conceptual information for the development of the geosphere module in safety calculations.

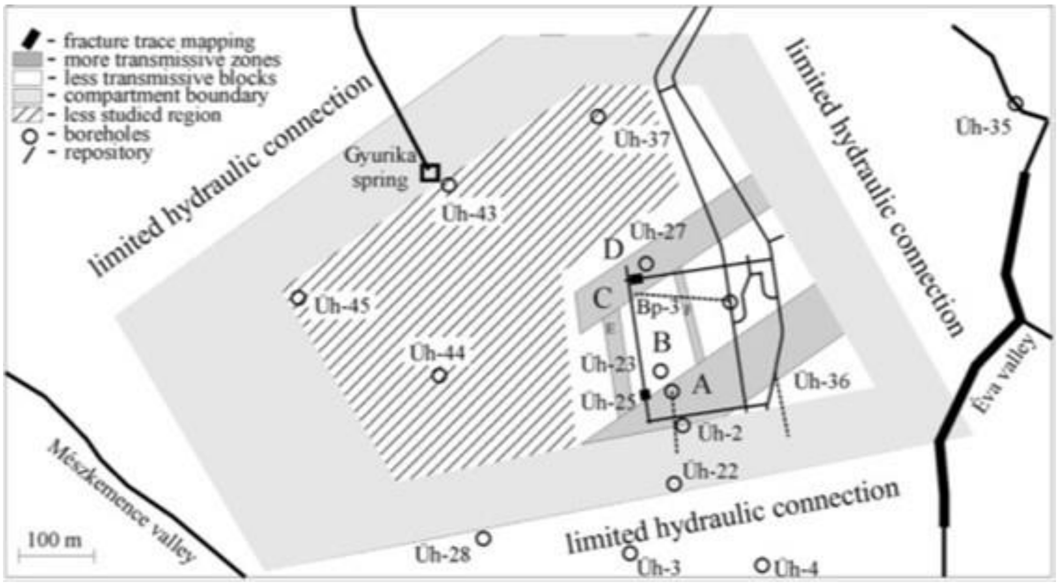

Figure 4: Generalized map of the study area. A, C, E, F indicates the more transmissive zones (MTZ), and B and D are the less transmissive blocks (LTB)

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Report on lecture by Kathryn Price on 'Ancient Rivers, Early Humans: The River Thames 500,000 - 1 million years ago' held at RSK, Hemel Hempstead, on Wednesday 24th January 2024

Adrian Marsh FGS

Kathryn set the scene in her lecture for her doctoral research project by outlining some of the changes that the Anglian glaciation (~450 kilo annum, KA) brought about that affected early hominin populations. Pre-Anglian southern/central England contained three main river systems with associated populations:

- Bytham – 'Pioneer' coastal/estuarine occupation
- Thames – Minor occupation but not yet contextualized
- Solent – Minor occupation

The Anglian glaciation effectively destroyed the Bytham and most of its related Pleistocene deposits, and pushed the course of the Thames further south, especially the lower reaches. Importantly, sections of pre-Anglian river terrace deposits in the middle reaches of the Thames survived.

In England, research to date has found evidence of sporadic hominin occupation of coastal sites in the pre-Anglian period 500-600KA, including notably at Happisburgh in Norfolk (MIS 25/21, MIS=Marine Isotope Stages dating system) with low artefact numbers of around 200, and at Pakefield in Suffolk (MIS19/17) with only 32 artefacts found to date. These artefacts fall into the category of 'Core & Flake' technology and reflect low 'pioneer' populations moving into the region. However, at around 500KA evidence indicates a distinctive shift to more continuous/settled occupation, e.g. at Barnham, West Sussex (MIS 11) and Devereux's Pit, Icklingham, Norfolk (MIS 11?) where recovered artefact numbers have run into thousands and hand axe technology is more advanced indicating substantial migration into the region and resident populations. These new behaviours have been associated with the influx of Homo heidelbergensis from Europe, as revealed in the Eartham Pit excavation at Boxgrove, West Sussex.

Hence, the evidence to date indicates that the earliest hominin occupations of north-western Europe remained in coastal environments. However, this assertion is the subject of current research and debate. Did populations venture inland, e.g. using rivers as routeways, or were inland occupations restricted by technological or other behavioural limitations? These questions provided the research context for Kathryn's PhD literature studies, fieldwork and laboratory research. She has distilled this into a practical methodology for the middle reaches of the Thames comprising studying:

- Museum artefacts from the intermediate/higher Thames terraces. In Britain and beyond in Europe, the artefacts recovered from Pleistocene deposits do not show a simple technological progression and sophistication with age, rather it appears some populations made big advances whilst others remained satisfied with very basic tools.
- Archives and historical maps to improve contextual information. This included accessing relevant Historic Environment Records (HERs), where there are over 80 HER centres in England maintained and managed by local authorities.

- Geological borehole data, mainly from BGS records, to reassess older river courses and terrace levels (from the age of Westland Green Gravels up to the Black Park Gravels). Much of this output was captured in GIS format, see Figure 1.
- Prospective fieldwork sites for accessibility and suitability. Once shortlisted, sites were also reviewed to see if the terrace elevation was consistent with the published ‘gravel train’ designation in the literature (e.g. Gibbard, 1985 and 1994) and British Geological Survey mapping.

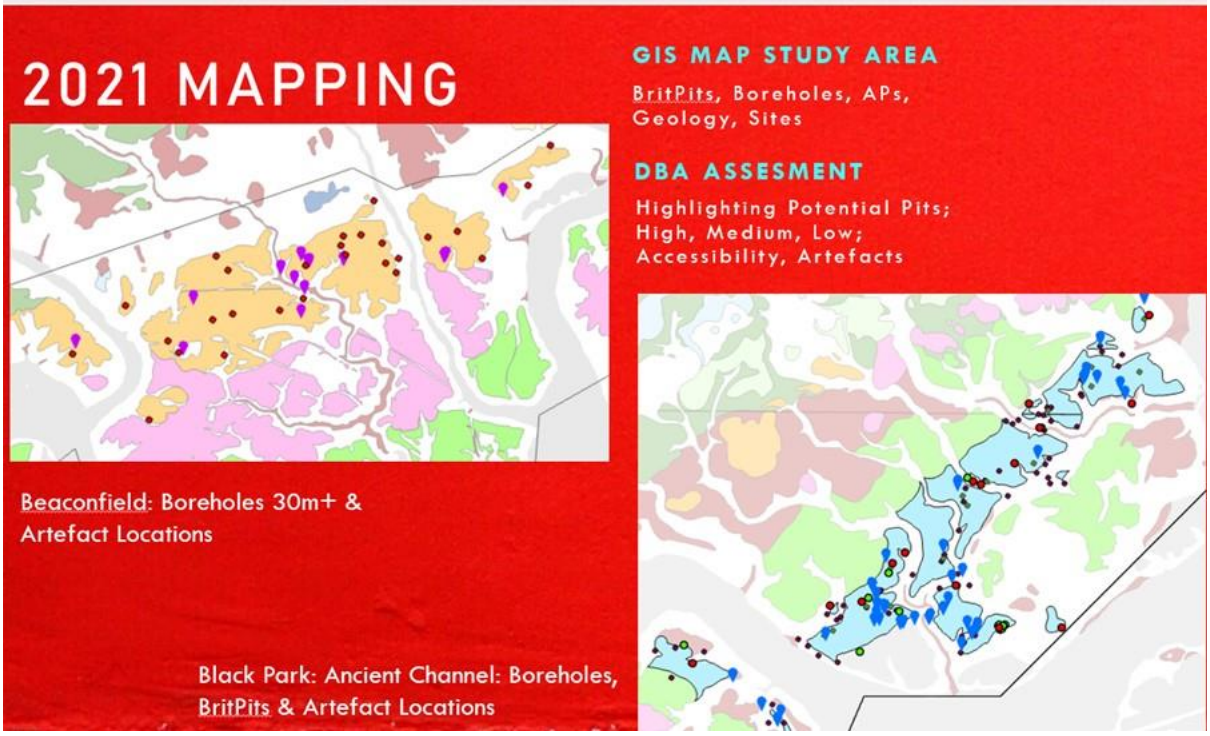

Figure 1: Examples of GIS mapping and data layers compiled.

Kathryn’s five key findings from the mapping and site reconnaissance can be summarised as follows:

- Number of shortlisted sites – 139 in total including from HERs and 39 ‘new’ sites, with far fewer in the higher terraces. A different context for artefact discovery was prevalent in the HER data.
- Number of previously found artefacts - 700+ now stored in 10 museums, of which around 80% are covered in the literature, with an indication of possible occupation in the higher terraces.
- Fieldwork sites - Potential locations identified in each terrace.
- Terrace mapping – Several incidences arose of incorrect terrace age designation, based on the site reccy and literature, leading Kathryn to make some reassignment of individual terrace remnants’ designations, with associated implications for the archaeology.
- Borehole coverage – scant or absent in the Westland Green and Satwell Gravels and distinctly uneven distribution elsewhere reflecting many factors such as the extent of urban/infrastructure development and interest in quarrying for sand and gravel. This emphasized the need for fieldwork in the higher terraces, and possible additional BHs.

Kathryn’s fieldwork, supported by her supervisors, other university specialists and several volunteers, is being carried out over three seasons (2022-2024). The aim is to expose the full depth of the terrace deposits wherever possible, which typically overlie Chalk or Lambeth Group strata. Then meticulously clean up and record the face lithology, obtain samples for particle size analysis, and excavate bulk samples for coarse sieving on site to obtain clasts over ~25mm for suspected artefact identification. Typically, up to 1+ tonnes of materials were sieved by hand on each site for this purpose and interesting clasts bagged for more detailed laboratory examination. The elevations of each section are being captured by GPS survey, the stratum dated by Electron Spin Resonance (ESR) dating and photogrammetry undertaken of the deposits, as illustrated in Figure 2.

FIELDWORK 2022: CAVERSHAM HEATH GOLF CLUB

Terrace	Age (approx)
Westland Green Gravel	1.5 mya
Satwell	1.4 mya
Beaconsfield	950,000
Gerrards Cross	860,000
Winter Hill	500,000
Black Park	450,000 ★

Figure 2: Some of the fieldwork techniques used.

Kathryn still has more fieldwork and analysis to complete, but the early indications are that hominins were present on the then paleo-Thames river terraces dating from the Black Park (450KA) and Winter Hill (500KA) periods, with some of the artefacts recovered in her fieldwork shown in Figure 3. Interestingly for geologist, these pale brown and grey flints are significantly weathered when perhaps we are used to seeing fresh, typically black coloured flint artefacts in literature and museum collections. To date in her work, no artefacts have been definitively identified from the much older Gerrards Cross Gravels (~850KA) and preceding higher terraces. However, artefact finds by others are scattered across parts of these older terraces. Are these artefacts signalling a hominin presence in the higher terraces? What role may have been played by geological processes, such as solifluction, in redistributing artefacts in the soil profile through the subsequent glacial/inter-glacial cycles?

If hominins were in the Thames middle reaches pre-500KA, what technology were they using and what does this tell us about them and the environments they are living in? Conversely, if hominins aren’t here, what is this telling us, e.g. was initial colonisation dependent on the more oceanic climates and wider, collectable food resources, e.g. shellfish, found in coastal areas? Did these early 'pioneer' populations move inland but leave few artefact traces? Furthermore, was inland occupation dependent on more advanced technologies, e.g. clothing, shelter, fire, better food acquisition techniques, e.g. hunting, and implicitly improved social cooperation?

	
Black Park Gravels (~450KA)	Winter Hill Gravels (~500KA)
Caversham Heath Golf Club	Burnham Beeches

Figure 3: Examples of artefact finds in two of the younger terraces.

Hopefully, Kathryn will be able to update HCNRG members over the next year or so as her final fieldwork season progresses, particularly in the critical Gerrards Cross and Beaconsfield Gravels.

Adrian Marsh who is one of Kathryn’s volunteer helpers.

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Report on lecture by Dr Eimear Deady on ‘Critical Raw Materials (CRMs) – A national-scale assessment of the geological potential for CRMs in the UK’, held on Zoom on Wednesday 24th April 2024

Adrian Marsh FGS

The UK probably will need up to around three times the current supply of a range of metals and other materials by 2050 in order to make the transition to a net-zero economy and society. This was one of the central messages in Eimear Deady’s presentation. To what extent can the UK itself supply these based on the current knowledge of our geology? This was the essence of the brief given to the British Geological Survey (BGS) by the Department for Business & Trade-funded UK Critical Minerals Intelligence Centre (CMIC). Eimear was the lead author of the BGS team that delivered the study and report published in 2023 entitled ‘Potential for Critical Raw Material Prospectivity (in the UK Decarbonisation and Resource Management Programme Commissioned Report CR/23/024, available on the BGS website).

Eimear commenced her talk by giving a short update on BGS's activities and expanding role post-Brexit, with staff numbers anticipated to rise from around 600 to 800 in the coming years to provide government and other customers with expert advice and services on topics such as climate change, decarbonisation, resource management and geohazards.

Critical raw materials (CRMs) are those commodities that are economically important and at risk of supply disruption. Many CRMs are essential for the technologies that will enable decarbonisation of the global economy, such as electric vehicles and renewable energy infrastructure. The UK critical raw materials list (Lusty et al., 2021) classifies those commodities that are most important to the UK's economy, and which have the greatest risk of supply disruption (Figure 1). The CRMs identified as being of elevated or high criticality include the essential raw materials for lithium-ion batteries (lithium, graphite, nickel, manganese, and cobalt); the rare earth elements (REE, e.g neodymium, dysprosium and praseodymium), which are used in permanent magnets that are a key component of generators in wind turbines and motors in electric vehicles; tellurium for solar panels; and silicon, gallium and germanium used in semiconductors.

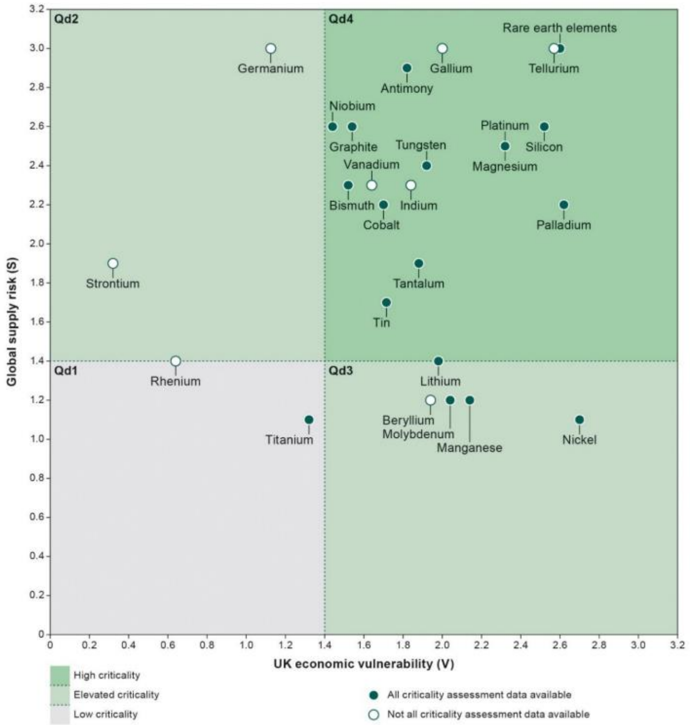
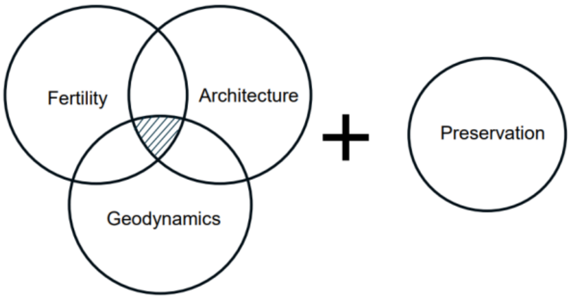


Figure 1 Critical raw material matrix for the UK, from Lusty et al., 2021. CRMs plotting in the top right quadrant are considered to be highly critical for the UK.

Global institutions such as the World Bank (Hund et. al., 2020) have concluded 'Ambitious climate action will bring significant demand for minerals' …because clean energy technologies need more materials than fossil-fuel-based electricity generation technologies. Modelling various energy technology scenarios through to 2050 projected to be required to meet net-zero, results in demand for minerals rising from a current figure of around 50 million tons to somewhere between around 100 to 180 million tons, or a two to possibly three-fold increase. More widespread and effective recycling and activities like reprocessing existing mine wastes will provide part of this increase but the bulk of these resources will need to come from more mining. With an eye to global politics and associated economic factors, the UK government wishes to reduce its reliance wherever possible on importing the critical materials in favour of identifying alternative sources in the UK that could be developed in future.

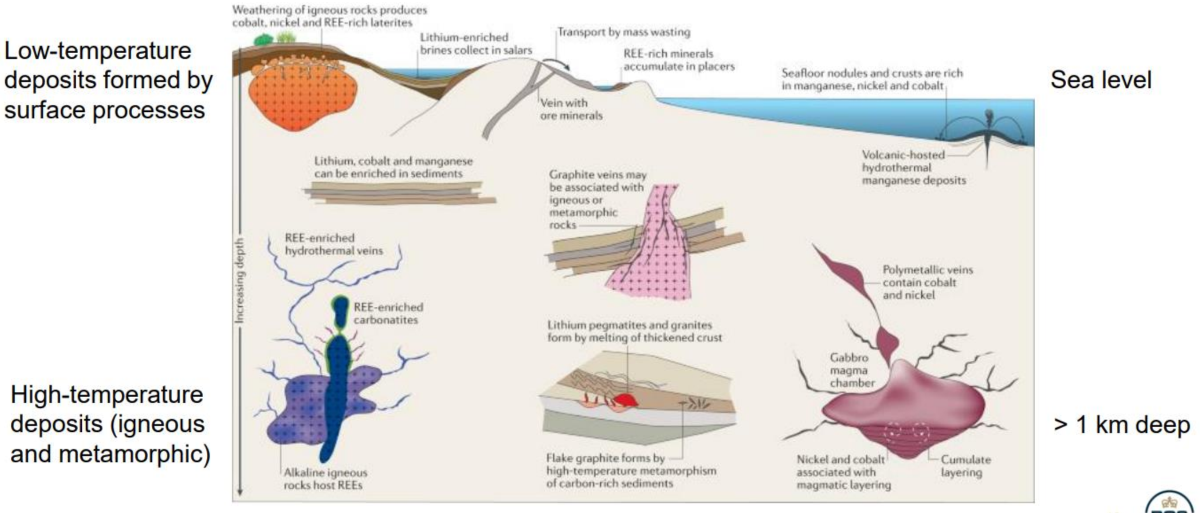
The methodology adopted for the study was based on a 'Mineral Systems Approach', which is a concept that considers all mineral deposits are formed by a combination of particular geological processes (McCuaig et al., 2010), as shown in Figure 2, together with the vital element of subsequent preservation.



*'A **fertile** ore-component source in a suitable **geodynamic** setting with favourable linked lithosphere and crustal **architecture** for ore-fluid migration to a trap site, with suitable post-mineralization tectonic processes to ensure **preservation**'* (Kelley et al., 2021).

Figure 2. Mineral Systems Approach concept.

Generations of exploration for and mining of mineral deposits has helped identify their main sources, as illustrated below, although in the past the minerals we need now for the energy transition were not always considered economically important.



Pell et al. 2021 Nature Reviews Earth and Environment

Figure 3. Illustration of different types of mineral deposits.

For BGS, adopting the mineral systems approach in practice involved identifying essential processes for ore deposit formation in the UK and translating that into mappable target criteria, based on available data and substantial in-house expertise. The natural abundance of CRMs in the earth also varies enormously so that major mined commodities, centre, dark green in the Figure 4, needed to be shown with potential co- and by-product commodities and their primary geological process of formation.

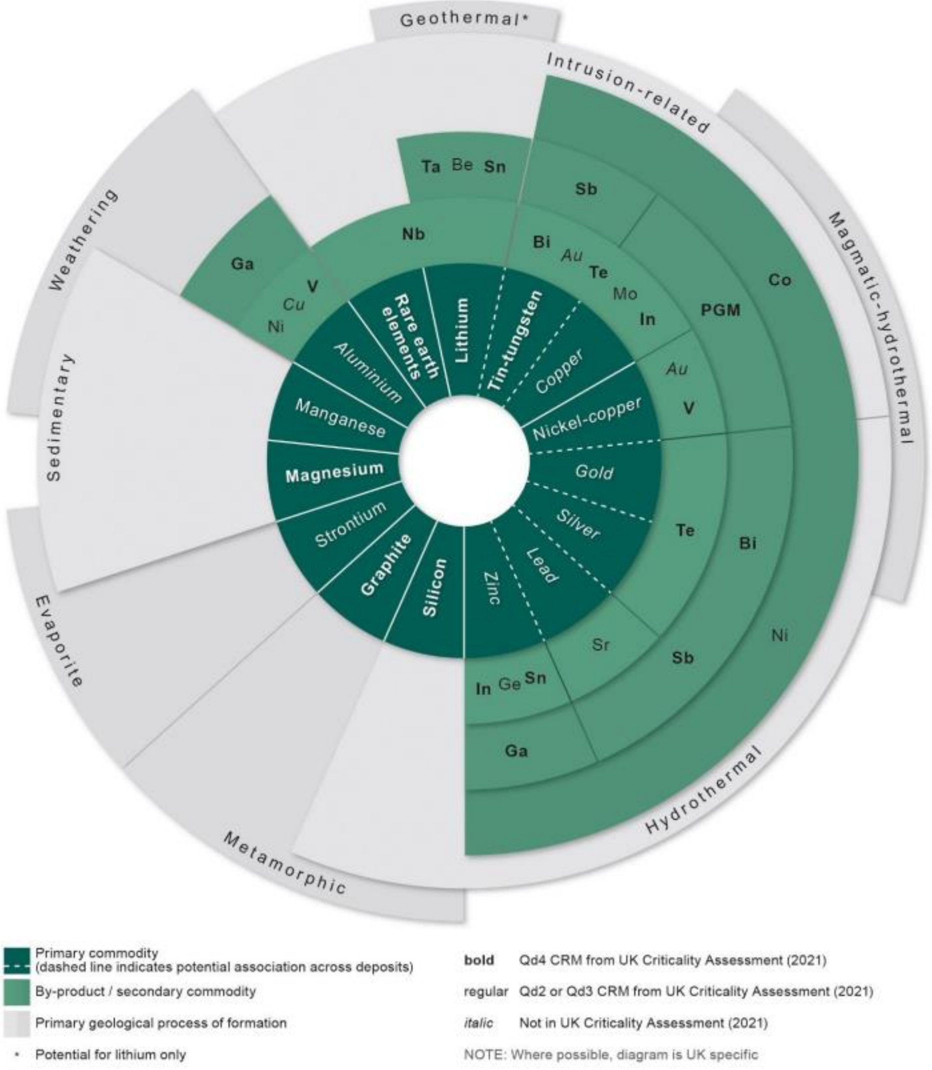


Figure 5. Delineated 8 key areas in the UK that are prospective for a range of critical raw materials.

Data sets accessed ranged across geological, geophysical and geochemical information accumulated over a long time, but did not include any new commissioned surveys. Eimear also stressed that no account was taken of potential future constraints on mining, such as working in protected areas, e.g. national parks and SSSIs, social license to operate, or regulatory and planning requirements. Only where detailed datasets were available across the whole of a region to be assessed could data-driven prospectivity modelling be carried out for each specific mineral system. Elsewhere, they had to take a knowledge-driven prospectivity assessment.

Each commodity was assigned to a series of mineral systems with distinct geological attributes and grouped where geologically appropriate, e.g. nickel-platinum group elements and vanadium. Expert geologists then identified the mappable target criteria for those mineral systems and the available datasets used to map geographic areas that meet those criteria.

The full set of mapped results for each CRM can be seen in ‘Potential for Critical Raw Material Prospectivity in the UK’ Deady et. al. (2023). However, the vast majority of the prospectivity results fall into just eight UK regions as shown in the figure below.

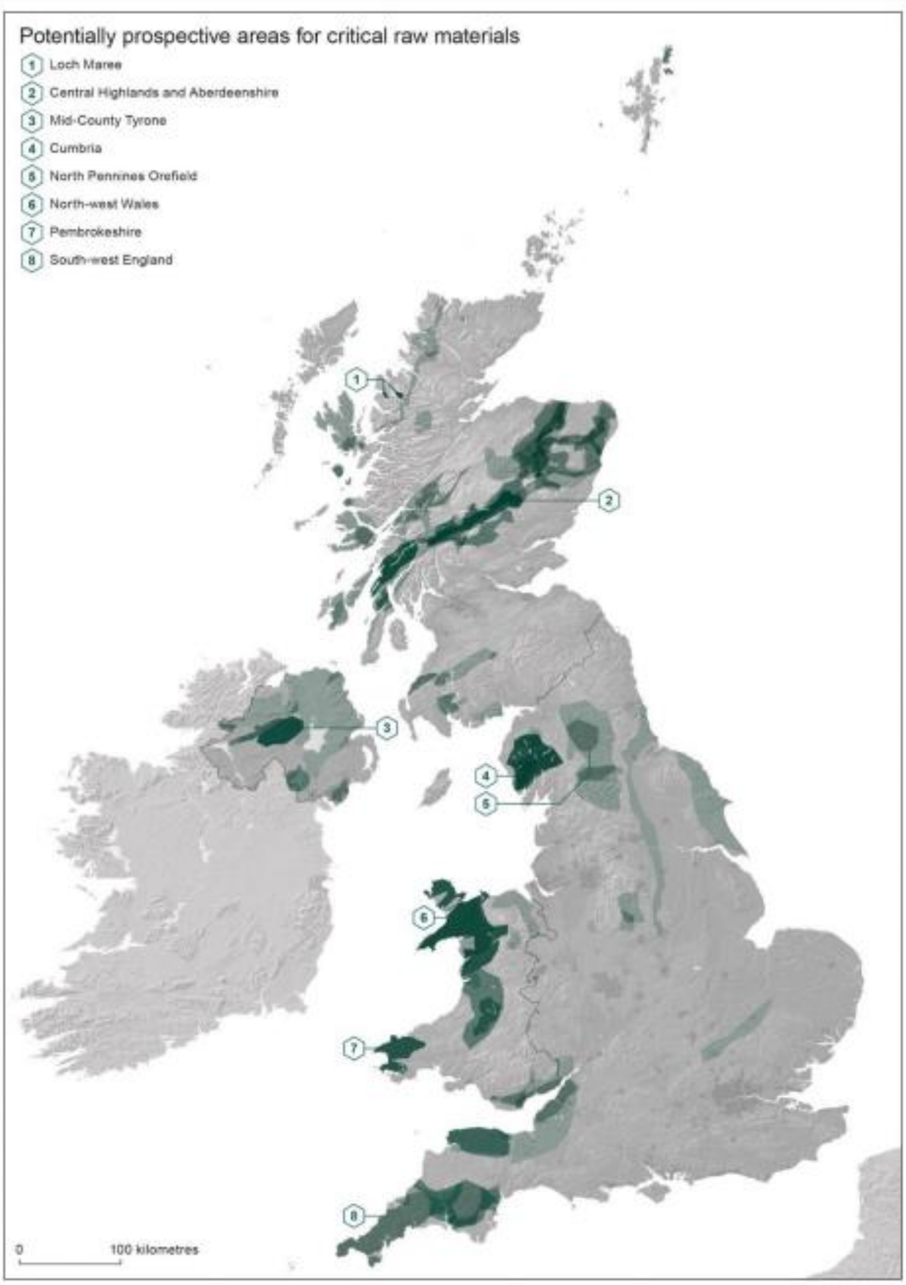


Figure 5 Delineated 8 key areas in the UK that are prospective for a range of critical raw materials.

The maps presented do not represent areas where deposits of critical minerals are guaranteed to be found; they simply represent areas where the geological criteria have been met and thus there is potential for deposits to occur. It is also important to note that mineral deposits could be found beyond the identified prospective areas, where localised geological conditions are suitable.

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Report on hybrid lecture by Dr Matthew Hooper and Ian Dunkley on ‘Northamptonshire Ironstone: Geology, mining and legacy land’ held in-person at the offices of Soiltechnics Ltd and on Zoom on Wednesday 25th September 2024

Adrian Marsh FGS

Matt opened the lecture with an overview of the global tectonic scenario through the Early (~200Ma), Mid (~170 Ma) and Late (~150 Ma) Jurassic Epochs, over which time the huge Pangea continent was breaking up with shallow seas across much of what is now Europe. Towards the end of the Jurassic, the Atlantic Ocean was opening to the west of Britain. The Northampton Sand Formation (NSF) in which the ironstone formed is of Aalenian Age, the first of the four ages within the Mid Jurassic Epoch.

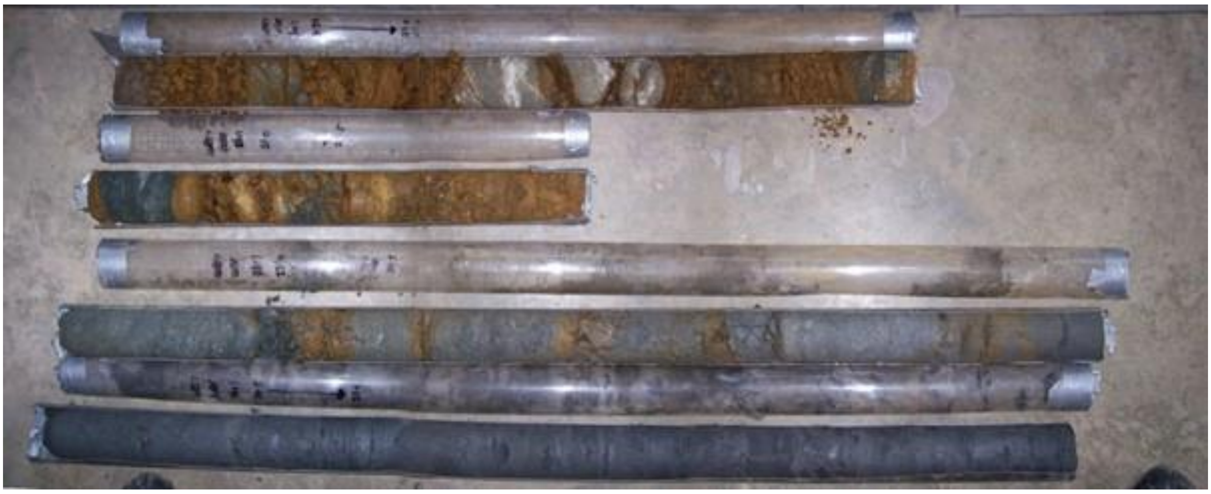
The evolving continental and marine environments through the Jurassic resulted in a wide range of sedimentary deposits now being present in England encompassing mudstones, sandstones and limestones. The factors that combined to form the NSF ironstones included:

- Deposition in a shallow marine extensional basin during a period of extensive continental change, although the core of the London-Brabant Massif remained an island to the south east of this basin;

- Continental divergence that drove climate change from a relatively arid to a humid, more seasonal, environment which increased weathering and erosion; and

- Weathering that allowed the concentration of iron in sea water to increase from a likely kaolinite source which under reducing conditions allowed the formation of ooids and iron matrix of the deposits.

The resulting NSF ironstones are a sandy, berthierine-ooidal and sideritic ironstone, typically displaying a box-stone structure. The deposits are generally around 4m to 8m thick, with a typical core section shown below. The rock is greenish grey where fresh, weathering to brown limonitic sandstone.

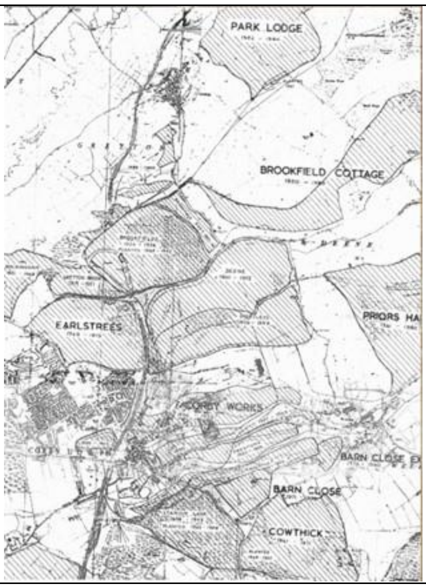


Ian then continued the talk on the extraction and use of NSF as a building stone and for its iron content. The box-stone jointed structure of the NSF made it widely quarried, certainly since Saxon times, across England under many different local rock names historically, e.g. Brixworth Stone, Eydon Stone and Wellingborough Stone. Ian then ran a short quiz for the audience showing a series of pictures of buildings constructed with stone asking which ones were of NSF origin. This served to highlight the range of NSF stone colours, with the two non-NSF Mid Jurassic stones spotted by some. An excellent example of Eydon Stone was illustrated in the picture below of Home Farm farmhouse, Partridge Lane, Eydon.

Ian moved onto iron ore extraction, steel-making and its legacy. Although NSF ironstone had been quarried for iron-making on a relatively small scale in the east Midlands since pre-Roman times the deposits were not ideal with a relatively low iron content, typically no more than 30% to 35%, and high phosphorous content. However, the invention of the Bessemer process in 1856 by Sheffield-based inventor, Henry Bessemer, changed this. The Bessemer process is a method for mass-producing steel by blowing air through molten pig iron, removing impurities, and adjusting the carbon content to achieve the desired properties.

The 'Blast Furnace' process relies on the fact that oxygen from the air reacts with the carbon and other elements, such as phosphorous, in the molten iron, burning them off and leaving a more purified and homogeneous product. The first blast furnace in the region was at the Wellingborough ironworks but this was soon eclipsed by the major iron and steel works developed at nearby Corby, latterly named Stewart and Lloyds, which finally closed in 1980, having processed some 94 million tons of iron ore mainly extracted from opencast mines around the local area.

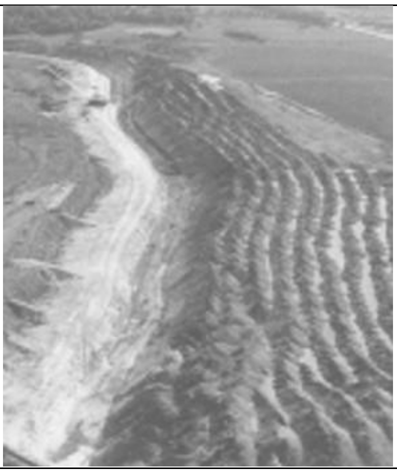
Corby steelworks c. 1937



Opencast mines around Corby

Opencast mining was carried out at scale across the region ultimately with large dragline excavators removing the overburden of mainly glacial deposits (typically 8m to 10m thick) to expose the NSF ironstone which was excavated by a slightly smaller machine that loaded directly into railway wagons on temporary track. The spoil of glacial materials and overlying Jurassic strata was dumped behind the face and formed characteristic unconsolidated 'hills and dales' terrain.

Earlstree pit c. 1958, 10m to 20m deep



‘Hills & Dales’ spoil heaps

There was a limited amount of underground mining, notably one major ‘pillar and stall’ mine at Irthlingborough in the 1930s, now sealed up but still causing settlement and collapse issues as the pillars tended to be robbed out as miners withdrew from a worked-out area.
Ian outlined several other legacy issues:

- *Total/differential settlement when building on backfilled quarries* – the universal practice of loosely dumping excavated materials to backfill the quarries has and continues to cause settlement problems with all types of subsequent buildings. The fill was not compacted and contained a varying proportion of large rocks with associated bridging voids, which decades later are still prone to differential settlement. Various ground improvement techniques have been tried, e.g. surcharging, dynamic compaction and pre-inundation with water, but the depth and nature of the fills often renders these techniques incomplete. Houses and other structures have been constructed on raft foundations, which helps but still can suffer differential settlement. House-builders working in the area tend to have their preferred foundation designs but still have to resort to remediation by injection grouting on occasion to rectify tilts.

- *High Arsenic concentrations in near-surface soils* – total As concentrations often exceed 50mg/kg but these soils can be more appropriately assessed using a bio-availability test that can then allow >100mg/kg total As to remain in situ, whereas in the past capping layers were required.

- *Hazardous dust* – during the decommission, demolition and reclamation of the steelworks and associated infrastructure by the local council dust containing elevated levels of various toxins, e.g. heavy metals, was released both at the works sites and from lorries transporting waste to a landfill outside the town. This became the subject of a very protracted legal process concerning alleged health impacts and birth defects affecting local residents, which the council lost and decided not to appeal but paid compensation in the end. The dust receiving landfill near Rockingham remains.

The event rounded off with a lively Q&A session and wider discussions amongst the audience.
HCNRG is grateful to Soiltechnics Ltd for hosting the event.