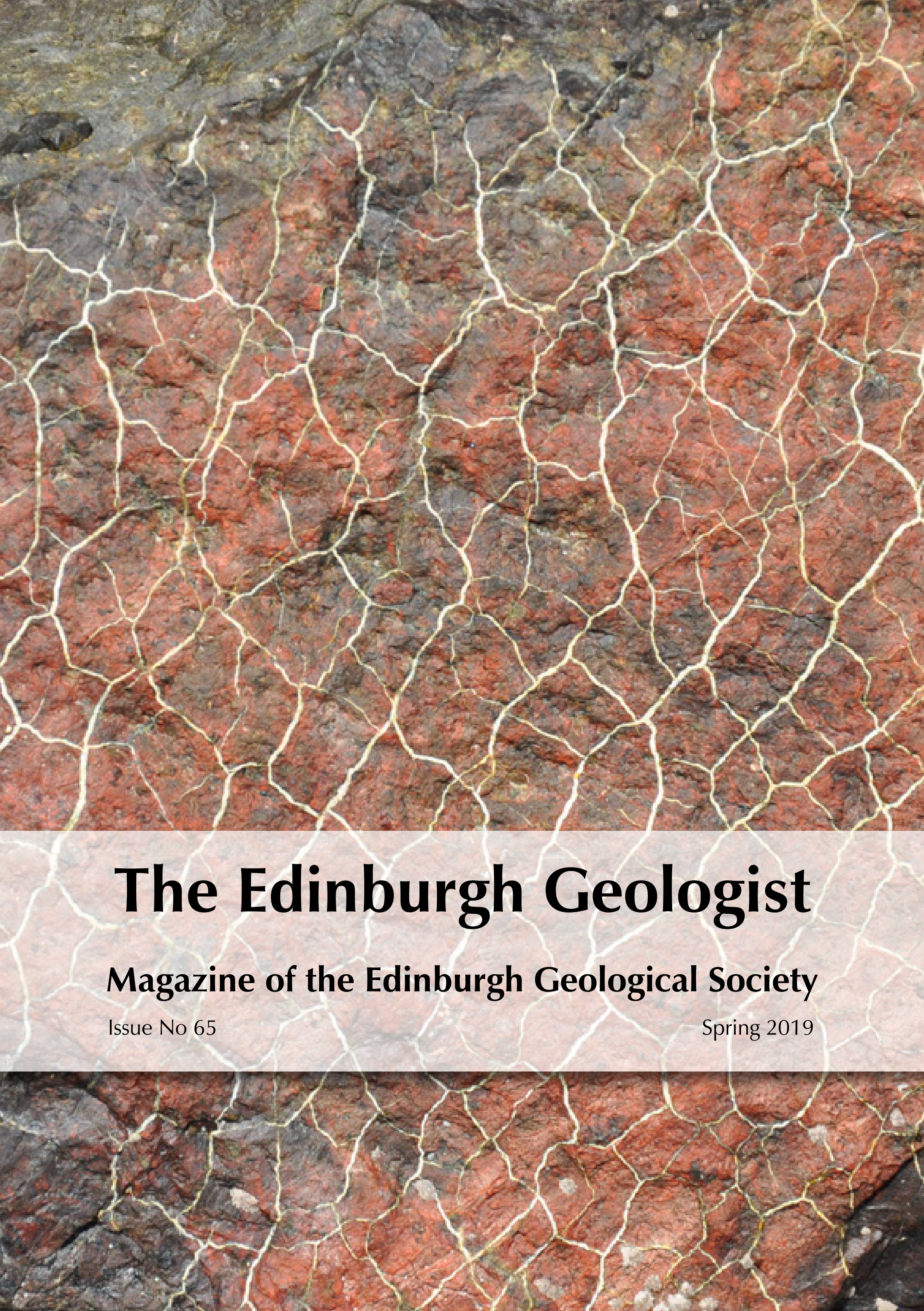

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Cover Illustration

Serpentinite cut by a network of carbonate veins, part of the mantle-crust transition in the Lizard Ophiolite exposed at Coverack, Cornwall. Image ©Beverly Bergman. x1. For more on the Cornish geology seen during the Edinburgh Geological Society's 'long excursion' in 2018 see the article by Beverly Bergman and others on page 13.

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From Pangaea to the Anthropocene by way of South Uist, Cornwall and Glasgow

An editorial ramble by Phil Stone

One of the many delights of geology is the way in which unexpected connections crop up in unlikely places. Our first article in this issue of *The Edinburgh Geologist* was initiated by a chance discovery in an Outer Hebridean library on the Isle of Benbecula, yet interacts neatly with one of my own recent encounters in a disused quarry in the village of Kirtlington, about eight miles north of Oxford. Visiting friends in that area, I was taken to see a local geological trail, set up in the old limestone quarry which, from 1907 to 1928 had been worked for cement production. But the surprise came, not from the Middle Jurassic (Bathonian) rocks, but from the dedication plaque at the beginning of the trail that acknowledged the 'renowned Scottish geologist W Stuart McKerrow' (Figure 1). Stuart hailed from Glasgow but spent his academic career at Oxford University.

Figure 1 The dedication plaque to Stuart McKerrow at the beginning of the Kirtlington Quarry geological trail, near Oxford.

From the perspective of Scottish geology, Stuart McKerrow is probably best known for his initiation of the 'accretionary prism' model that explained development of the Ordovician to Silurian, Southern Uplands terrane in terms of subduction of the Iapetus Ocean at the margin of Laurentia. With his background in palaeontology, he had also been one of the first to show the sequential merging of faunas as the Iapetus Ocean narrowed. Appropriately enough, the centrepiece of his memorial plaque is a reconstruction of the Pangaea supercontinent, with the north of Scotland nestled into the south-east coast of Greenland.

Stuart's involvement with the quarry at Kirtlington started with his palaeontological work on brachiopods early in his career, hence the contrasting views of, I think, a rhynchonellid brachiopod on either side of the Pangaea map. He bought a house in the village in 1979 and thereafter campaigned successfully for the quarry to be recognised as a local nature reserve and SSSI: it is estimated that a thousand students of geology visit the quarry annually. But now the invertebrate fauna has been eclipsed by vertebrates, with the quarry yielding remains of dinosaurs, sharks, crocodiles and plesiosaurs and, it is claimed, the quarry is amongst the richest mammal-bearing localities of Middle Jurassic age known anywhere in the world. All of which sounds rather like a piece of Scottish geology that has recently acquired much significance for its vertebrate fauna, the Middle Jurassic of Skye. How apposite if Stuart McKerrow, a palaeontologist from Glasgow, is commemorated in southern England's equivalent of the Bathonian succession around the Trotternish peninsula. Perhaps unsurprisingly, shallow marine to coastal lagoon environments are represented in both areas.

Oceans apart but geologically united

Now, keeping Pangaea in mind, can you quickly make a connection between Lewisian gneiss and the Magna Carta signed by King John of England in 1215 AD? Probably not, beyond acknowledging that neither arose until considerable pressure had been brought to bear. But our first article describes a much more benevolent association in a detective story pieced together by Jean Archer that takes us from South Uist to Washington D.C., following the trail of a grand diplomatic gesture. Crucial to Jean's account is the palaeogeography of the Precambrian supercontinents Rodinia (complete about 750 Ma) and Pannotia (complete about 580 Ma — Figure 2), wherein Scotland's North-west Highlands terrane lay close to what is now southern Greenland. Its unification with the rest of Scotland as the history of the Iapetus Ocean unfolded is a story that owes much to Stuart McKerrow's seminal contributions. His memorial illustrates the Pangaea supercontinent (formed about 300 Ma), the break-up of which left the North-west Highlands behind as the opening of the Atlantic Ocean carried Scotland apart from Greenland and North America. Jean's story derives from the perceived geological connection between Scotland and the United States, rather than Greenland, but in context we can let that pass.

It's now commonplace for the Lewisian Gneiss Complex to be cast as an outpost of North American geology,

Figure 2 A reconstruction of the palaeogeography of the Pannotia supercontinent at about 580 Ma. The red 'ladders' show the rift zones that developed into the Iapetus Ocean. BGS image.

but it was not always thus. We now smile smugly when thinking about the initial American reaction to continental drift and celebrate the championing of the cause by the likes of Arthur Holmes — not least, and recently, in *EG64*. Another name that should be celebrated for the same reason is Alex. (he always signed himself Alex.) Du Toit, the South African geologist whose seminal book *Our Wandering Continents* (1937) was for many years a solitary and influential beacon for the ideas of continental drift.

Du Toit dedicated his book to the memory of Alfred Wegener 'for his distinguished services in connection with the geological interpretation of our Earth'. Wegener, who had ignited the continental drift debate, had died in 1930 on an expedition to Greenland, but despite Du Toit's expressed admiration, he must have despaired at some of Wegener's ideas. For example, not content with correlating the solid geology in his continental reconstruction, Wegener also noted a correspondence in the extent of glacial deposits on either side of the North Atlantic Ocean. From that, and displaying little regard for the geological timescale, he deduced that the North Atlantic must have opened since the retreat of the Quaternary ice sheets. Such an unlikely circumstance made it very easy for his opponents to dismiss continental drift in its entirety.

We can stay with the themes of closing oceans and the development of Pangaea into our second article but move south from the Early Palaeozoic Iapetus Ocean to the Late Palaeozoic Rhenohercynian Ocean, the ocean that separated Avalonia from Gondwana. As the Iapetus Ocean closed, bringing the Avalonia and Baltica continental plates to the margin of Laurentia, the Rhenohercynian Ocean opened behind Avalonia as it moved away from its original position at the margin of Gondwana. Eventually, in its turn, the Rhenohercynian Ocean closed and by the end of the Carboniferous, Gondwana was reunited with Avalonia to complete the supercontinent of Pangaea. Whereas the remains of the Iapetus Ocean can be found in the Caledonian orogen across Scotland and northern England, the remains of the Rhenohercynian Ocean form part of the Variscan orogen that extends from central Europe across to the peninsula of south-west England. And it is there, to Cornwall, that our second article takes us in the company of the participants in the EGS 'long excursion' of 2018, coordinated by Beverly Bergman.

Hot rocks and warm water

Cornwall clearly has some fascinating geology: Devonian marine strata variously deformed, the enigmatic Lizard ophioilite, the Early Permian Cornubian granites and their associated mineralisation. The granites at outcrop are a bit like the tips of icebergs, in that they are but the visible cupolas of a huge buried batholith. The Cornubian granites also produce a lot of heat and the extent of the batholith is dramatically shown by a heat-flow map of the region (Figure 3). It's an aspect of the geology that has often been considered in terms of geothermal energy potential, and perhaps its time has finally come. If all has gone to plan, as you read this issue of *EG* what was billed as the UK's deepest ever borehole (projected depth of 4.5 km) should be making good progress near Redruth, on the northern flank of the Carnmenellis pluton.

Sadly, Scottish granites are not so hot. Whilst the Cornubian granites commonly generate in excess of 120 milliWatts per square metre (mWm^{-2}) with wide areas showing in excess of 100, the best Scotland can manage, from a small area of the Cairngorm granite is about 80 mWm^{-2}. But that

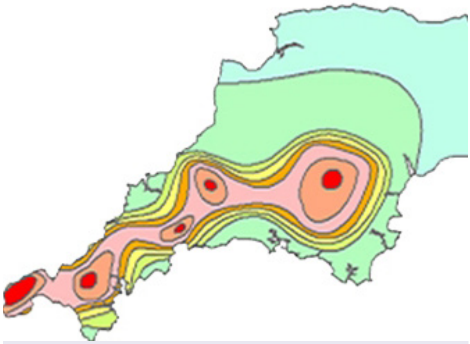


***Figure 3** A heat-flow map of Cornwall produced by the British Geological Survey. In the red areas the maximum heat-flow exceeds 120 milliWatts per square metre (mWm^{-2}), whereas the pale blue area has a regional background heat flow of about 50 mWm^{-2}. Compare with the geological map on page 13.*

doesn't mean Scotland is without geothermal potential, as explained by Alison Monaghan in our third article. It is hoped that the warm(ish) water in abandoned coal workings can be exploited for neighbourhood heating schemes via a heat pump system, and Alison describes a pilot project underway in Glasgow that aims to test the concept.

It's a remarkable turn-around in the face of anthropogenic climate change when coal mines become a source of renewable energy. And the speed of that turn-around was brought home to me when I recently came across a picture of Bilston Glen colliery, in the Midlothian coalfield just to the south-east of Edinburgh, under construction in 1956 (Figure 4). At the time it was predicted that the mine would have a working life of 100 years, but this proved unduly optimistic; production started in 1963 and the mine closed in 1989. The site is now occupied by an industrial estate and no trace of the colliery remains. In its place is a very different range of Scottish industry — Stoats Porridge Bars, Stewart Brewing and Macsween Haggis amongst others.

Of course, the scene at Bilston Glen is a familiar one across all of the once-productive Scottish coalfields so it's appropriate that one of our book reviews is concerned with the geological controls on mining in the East Neuk of Fife — and complements geology with a fascinating account of the social history that the industry generated. Another book review introduces metamorphism and shows that there is much more to it than is demonstrated by those old, hard, Lewisian rocks of northern Scotland.

Whither the Anthropocene?

Having touched on anthropogenic climate change I expect that, given its wide publicity and broad cultural

***Figure 4* Bilston Glen colliery under construction in 1956. BGS image P001468.**

assimilation, you have got used to living in the Anthropocene. Perhaps you even saw it performed by Scottish Opera earlier this year.

But wait: the final word on these arcane matters of nomenclature is usually pronounced by the International Union of Geological Sciences (IUGS) and a formal decision was expected last year. Would the Holocene be declared at an end, and a brave new world begun? That result was widely expected, but instead IUGS declared that the Holocene was in fact still up and running and, going further, divided it into three divisions, the last of which continues to the present day. So, since 4250 years ago, we have been in a stage called the Meghalayan. To quote from *New Scientist*, 28 July 2018, p. 24: “This age is defined by a mega-drought that caused a number of civilisations, including Mesopotamia, to collapse. It is named after the north-eastern Indian state of Meghalaya, where a stalagmite was recovered from a cave that provides chemical evidence of the drought.”

Somehow, I don’t think that will be the end of the story. In general, the finer divisions of geological time arouse little public excitement, but in terms of the wider understanding of geological events and the science of where we are now, the concept of the Anthropocene has proved invaluable. As an example of its explanatory value I can offer one of my 2018 Christmas books, indeed it’s one of the most satisfying geological books that I’ve come across recently. The main title, *Timefulness*, might conjure-up ideas of New Age meditation but the sub-title should prove irresistible—*How thinking like a geologist can help save the world*. The author, Marcia Bjornerud, is a structural geologist at Laurence University, Appleton, Wisconsin, and is clearly a fan of Hutton and Lyell; her second illustration is a sketch of the unconformity at Siccar Point. She vividly and succinctly contrasts the processes enduring through ‘deep time’ with their abrupt acceleration by the unintended consequences of human activities, hence the Anthropocene. Quite apart from championing the cause of long-term thinking if the issues of anthropogenic climate change are to be first appreciated and then addressed, the book is an excellent ‘grown-up’ introduction to geology and its comprehensive importance. The author’s concluding call to arms has an understandable North American bias, but it doesn’t take a genius to make the trans-Atlantic correlations. Recommended!

A special stone for a very special pedestal

By Jean B Archer

'The material for the base of the Parliamentary gift to Congress of the Magna Carta was obtained from the pegmatitic gneiss at Ardivachar Point' (Black 1977).

This enigmatic statement caught my eye whilst I was browsing through the pages of an unpublished geological report on the Outer Hebrides reached down from the reference shelves of my local library, a few miles from Ardivachar. The claim appears over the names of three well-known geologists, but when was the gift made and under what circumstances? Ardivachar Point (*Rubha Aird na Machrach*) is at the north western corner of the Isle of South Uist, but apart from that geographical fact all else was obscure. I was intrigued. After embarking on several false lines of enquiry a chance encounter with an islander — Billy MacPhee — set me off on the correct trail. The Magna Carta was the British government's gift to the USA on the occasion of the Bicentennial of 1976.

The gift entailed a year-long loan to Congress of one of only four known original copies of Magna Carta signed by King John in June 1215. It was to be replaced at the end of the bicentennial year by a replica Magna Carta, worked in gold. To contain first the original Magna Carta, and then its golden replica, architect turned goldsmith Louis Osman (1914–1996) was commissioned, on the recommendation of the Goldsmiths' Company, to create a fitting showcase. There is no mistaking the magnificence of this golden *object d'art* which sparkles with gemstone insets and enamelled detail all worked into a plethora of symbolic motifs appropriate to a document held in just as high esteem in the USA as it is in the UK (see https://www/aoc.gov/art/commemorative-displays/magna-carta-replica-and-display).

With only a year to work on this major commission Osman lost no time in completing a design in which his 'golden box' would stand on a mushroom-shaped pedestal carved in a stone that would match the Virginian sandstone flooring and walling of the Rotunda in the Capitol Building. The pedestal would have a polished stone table top, but where might there be found a suitable British stone? That

The Magna Carta display case and pedestal—following conservation in 2010 and flanked by the team that installed the display in the Crypt of the Capitol Building, Washington D.C. Courtesy of the Architect of the Capitol.

is where Ardivachar Point came to the goldsmith's notice as the source of a rock that he came to call Eygon Pegmatite.

Osman required the pedestal to possess a symbolism appropriate both to the event and its location. He therefore sought geological advice. That much is on record; Osman's biographer refers to his 'corresponding with eminent geologists' (Moore 2006). In my search for their identity the records of the Goldsmiths' Company were of no assistance, but another likely source of information was one or other of the authors of the above-mentioned geological report. However, Janet Watson had passed away in 1985, Rod Graham denied all knowledge of the gift to Congress, while the third author, Raymond (Ray) Dearnley, was remarkably difficult to trace.

In 1968 Ray co-authored with Frederick (Fred) Weir Dunning a paper in which they identified the Ardivacher rocks as an early (Scourian) part of the Lewisian Gneiss Complex essentially unscathed by Laxfordian reworking. In 1975 Fred held the post of Curator in the South Kensington Geological Museum which was a likely place for Osman to have turned for geological advice. When I approached Fred about his knowledge of the Magna Carta gift he was approaching the end of his life and unable to help (he passed away on 12 April 2018).

Wendy Cawthorne of the Geological Society, London, Library interested herself in the search for Ray. She made the breakthrough when she discovered, from the Geological Survey's *Annual Report* for 1976, that Ray had indeed served as Osman's advisor. Furthermore, she found that the *Report* outlined reasons for Osman's selection of Ardivachar stone. Besides aesthetic appearance, Ardivachar rocks were described at the time as the oldest in the UK having 'pre-drift geological linkage with the USA' (Anon 1977) — so making them a combined token of liberty and former unity.

Wendy had a further success when she traced and established contact with Ray Dearnley. In a face-to-face encounter, Ray reminisced about his association with Osman. Ray told a veteran of the Lewisian, Douglas Fettes of BGS, and myself that he had discussions in London with Osman and then travelled north with him in his 'campervan' to view the oldest rocks in the British Isles in a geographic location closer to North America than most other parts of Great Britain. Together, in the summer of 1975, they inspected various locations where outcrop interrupts, and helps stabilize, the long, remarkably straight, beach and dune-lined Atlantic coastline of South Uist. Their search came to its happy conclusion on the rocky foreshore at the northern termination of the long beach which is home to the launch pad of Uist's missile range, and which terminates in the rocky foreshore on the southern approaches to Ardivachar Point.

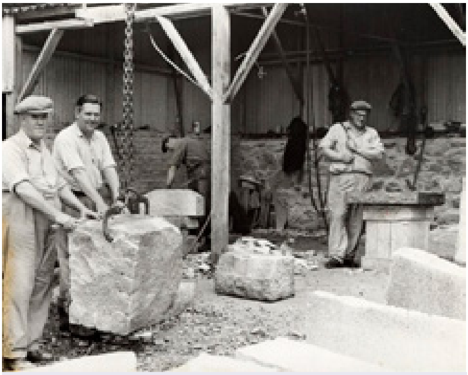
Ray returned to Ardivachar with Osman and a film crew led by Jon Schorstein (1949–1978) who was commissioned to shoot a documentary on the making of the Magna Carta gift. The South Uist footage, which Ray viewed in London in Osman's company, is now seemingly lost along with the rest of the never completed film. Ray also disclosed that he recommended a Millstone Grit quarry near Huddersfield operated by Johnsons Wellfield Ltd as the source of stone for the massive, mushroom-shaped Magna Carta pedestal. Osman opted for another, similar-looking, York Stone (sandstone from West Yorkshire). This was Coal Measure Sandstone from the Bolton Woods quarry near Bradford, then operated by the long-established firm of Waterhouse Denbigh which also fashioned the pedestal. In recommending York Stone, Ray had led Osman to material which, by all accounts, is an excellent match of the Virginia Sandstone flooring and walling of the Rotunda in the Capitol Building.

Ray took no part in the removal of the stone from Ardivachar and from

Contactor Donald Joseph Peteranna sizing-up the boulder preparatory to its removal from the Ardivachar foreshore. From original photograph in the possession of Duncan Campbell — the operator of the digger seen in the background.

the Outer Isles. I spent some time hunting for the site of extraction before I knew that the stone was not cut from country rock, but was selected from one of the numerous boulders strewn on the Ardivachar wave-cut platform. Ronald John MacEachan, who lives close by the shore, told me the stone was about the size of his kitchen fridge and had been removed from the foreshore by Uist Builders Ltd.

The founder and managing director of Uist Builders, the late Donald Joseph Peteranna, proved to be a rich source of information which I now very gratefully acknowledge. He recalled borrowing from Askernish Quarry (now MacCaulay Askernish) the digger normally used to lift rock blasted from the quarry face. The digger, operated by its usual driver (Duncan Campbell), cleared a track across the foreshore to a boulder some three tons in weight and hoisted it onto the back of a waiting lorry. The boulder was then transported by sea and land for cutting and polishing in the stonemason's yard of J & A Milligan at Creetown, in Dumfries and Galloway. There, the boulder was first sliced along cut-lines oriented at a high angle to the rock's gneissose foliation/banding to ensure maximum exposure of the banding on the flat surfaces of the cut rock. We do not know how many individual (*circa* 4-inch thick) slabs were cut, only that four of them were trimmed for eventual fitting together into a single five foot square slab before one face of each slab was polished. Fitted together the individual pieces became the beautiful polished



J A Milligan and sons in the Creetown yard where the pegmatitic gneiss table top of the Special Pedestal was fashioned and polished. Reproduced, courtesy of David Thornton, from his image 58586 posted on-line at www.aditnow.co.uk.

slab of pegmatitic gneiss that is the immediate support of Osman's Magna Carta display case.

In one of Osman's Northamptonshire workshops there was inscribed around the sides of the stone the words 'PRESENTED TO THE CONGRESS OF THE UNITED STATES OF AMERICA BY THE PARLIAMENT OF THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND IN THE BICENTENNIAL YEAR 1976'. The two parts of the pedestal were airlifted to Washington in a military transport plane at the end of May 1976 and assembled in the Rotunda preparatory to the arrival of the display case.

Following it's unveiling on 2 June 1976 the Magna Carta display stood in the Rotunda of the Capitol for more than three decades. In 2010 it was removed for conservation and cleaning and afterwards installed in the so-called Crypt of the Capitol Building. Few of the multitude who annually pass through those hallowed halls will have any understanding of the story, both ancient and modern, attached to the beautiful Hebridean rock which once lay on the opposite shores of an opening Atlantic. For Osman the venture ended in disaster. The casket and its pedestal left him bankrupt.

It was financially unfortunate too in Uist and West Yorkshire. None of the firms behind the making of the Special Pedestal were paid for their contribution to Osman's masterpiece, aka the British government's permanent bicentennial gift to the USA.

Acknowledgements
It is my pleasure to thank the already named individuals who made this article possible as well as thanking for their assistance the following: Eleni Bide (Goldsmiths' Company Library), Jennifer Blancato (Office of the Curator, Architect of the Capitol), Simon Lowe

The pegmatitic top of the special pedestal exposed during the installation of the Magna Carta display in the Crypt of the Capitol Building in 2010. Courtesy of the Architect of the Capitol.

(Aditnow), Gordon Herries Davies, Alistair MacCaulay, Jane Osborne, David Schorstein and Laura Smith.

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The EGS long excursion to Cornwall

By Beverly P Bergman, David Blythe, Douglas Holliday, Stephen Livera, Richard A Smith, Christine L Thompson and Alison Tymon

The EGS Long Excursion 2018 took place in Cornwall from 19–26 May and was led by Professor Peter Scott of Camborne School of Mines and Exeter University, and Dr Mike Styles of the British Geological Survey. The group was based in Falmouth and the aim of the excursion was to study the geology of the Lizard Peninsula and neighbouring localities. Broadly the geology of Southern Cornwall comprises predominantly Devonian mudstones deformed and overthrust from the south during the Variscan orogeny by the spectacular ophiolites exposed on the Lizard; subsequently the central Cornubian granite batholith intruded the mudstones and produced an extensive metamorphic aureole characterised by widespread mineralisation (Figure 1).

At the start of the first day, Peter Scott took us to the elevated viewpoint, Carn Brea, overlooking Camborne, numerous mines and much of the Cornish coast, where he introduced us to Cornish geology. The granite on which we stood formed typical tors; less typical were the scalloped and basin-shaped hollows formed by prolonged exposure to the elements (other than the last glaciation which this area escaped) (Figure 2). Peter pointed out the surrounding hills

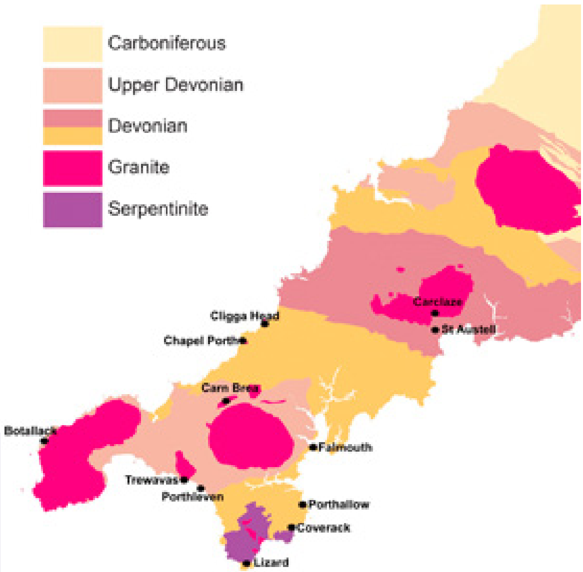

***Figure 1** Simplified geological map of Cornwall after BGS 1:625 000 Scale, Bedrock Geology UK South.*

which were underlain by granites, and the numerous chimneys and engine houses of the tin mines in the adjacent valleys, which mainly worked lodes away from the granite. We paused to imagine how the area might have looked today if modern mining had proceeded to form one vast open-cast pit.

Figure 2 Sculpted granite tor, Carn Brea ©Beverly Bergman.

We then drove west past South Crofty mine, the last to produce tin in the area, onto Cape Cornwall to observe the contact of the Land's End Granite with Upper Devonian mudstones, locally known as 'killas', which have been metamorphosed in the granite aureole. The metamudstones were invaded by numerous early quartz veins and folded in zig-zag folds on several scales. Farther north, at Botallack, picturesque mines and engine houses are sited near the cliffs, inspiring the popular Poldark stories (Figure 3). In former adits we saw skarn mineralisation, composed of tourmaline, garnet and magnetite, that had replaced metabasalts close to the granite. Cross-cutting mineral veins had been exploited along the coast and we searched the old mine dumps for samples of cassiterite, wolframite, chalcopyrite, arsenopyrite and molybdenite as well as secondary minerals. Warm, sunny weather also led us to sample the excellent Cornish ice cream!

The second day began at Chapel Porth west of St. Agnes, looking at Middle to Upper Devonian slates

Figure 3 Crowns Engine House, Botallack Mine ©Alison Kerr.

of the Porthowan Formation of the Gramscathco Basin. These sediments contain sandstones with a distinctly discordant deformation style compared to the softer metapelites. A worked vein in the hanging wall of a normal 'relaxation' fault mineralised by the St. Agnes granite showed copper sulphides (chalcopyrite).

A pleasant walk across the beach in warm sunshine led to the workings below Wheal Coates. The mineralisation was extensive and formed against a rhyolitic elvan[1] located along a fault where the ore fluids were trapped (Figure 4). The mine was initially down to sea level and then a pumping house was built for drainage to enable deeper excavation.

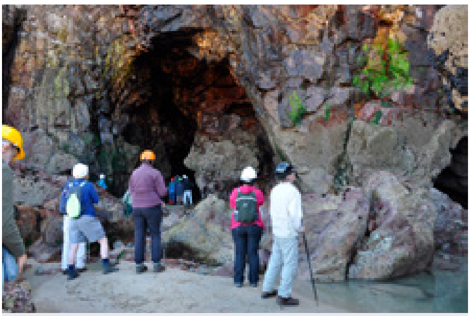

Figure 4 Mineralisation at Chapel Porth, below the Wheal Coates Engine House ©Beverly Bergman.

[1] An elvan is the Cornish mining term for a vein of feldspathic or porphyritic rock crossing a metalliferous vein

The next stop was Cligga Head where the small, eponymous granite intrusion has been completely mineralised and is famous for its greisen and tin-tungsten mineralisation (Figure 5). High temperature late-stage fluids turned the feldspars into micas and deposited an array of minerals, including wolframite, cassiterite and an arsenopyrite variety, lollingite, which breaks down to a distinctive secondary, green iron arsenite, scorodite. At Roche Rock an outlier of resistant granite stands above the surrounding countryside and has been used as a place of worship over the generations. The intrusion is a quartz-tourmaline rock (with no feldspar) intruded into Lower Devonian clastic sedimentary rocks ('killas'). Is such an unusual rock a result of hydrothermal alteration by boron-rich fluids or could it have crystallised from a magma? Current theories favour crystallisation following the late separation of an immiscible boron- and fluorine-rich liquid phase from a granitic magma and there was much discussion, without resolution, about the nature and temperature of such a residual melt from which tourmaline forms instead of feldspar. The final stop of the day was at Carclase, a disused china clay pit in the St. Austell granite, where those who had seen the china clay pits in their heyday

Figure 5 Black quartz-tourmaline veins and extensive wall-rock greisening of granite are both controlled by steeply inclined, closely spaced joints in the quarry on Cligga Head. Kaolinised phenocrysts of feldspar are aligned subparallel to the joints. The notebook is about 15 cm long. ©Steve Livera.

were disappointed to see how these unique features of the Cornish landscape had deteriorated.

Day 3, led by Mike Styles, promised an excursion with a difference: a descent into the former mantle, returning via the Moho and lower crust. This entailed going to Coverack, a fishing village on the Lizard peninsula. The rocks of the Lizard represent an ophiolite—an upthrust sliver of oceanic lithosphere with a characteristic sequence of rocks. The ophiolite rode up and onto the northern margin of a closing ocean basin during the Upper Palaeozoic Variscan orogeny. Our first stop was at the lifeboat station at the south end of Coverack beach. Here we stood on an exposure of ancient mantle in the form of peridotite, an ultramafic igneous rock consisting mainly of olivine and pyroxene. Running through the peridotite were sub-parallel veins of another ultramafic rock, dunite, composed almost entirely of olivine. Mike told us that the veins served as pathways for magma rising-up through the peridotite and feeding magma chambers at the base of the crust.

Working our way northwards, we saw evidence of those magma chambers in outcrops of troctolite (named for its resemblance to the skin of a trout), a rare type of gabbro that collected as a crystal mush at the base of a magma chamber while gabbro crystallised higher up. We were now in a transitional zone between upper mantle and lower crust, probably corresponding to the palaeo-Moho, and gabbro became the more dominant rock the further north we walked. We then moved on to Porthoustock quarry, about 5 kilometres north of Coverack, and marvelled at a sheeted dyke complex very similar to a mid-oceanic dyke swarm. And so, in one day, we had progressed from bottom to almost the top of a typical ophiolite sequence, the only rocks missing being the pillow lavas and deep-sea sediments that would normally cap the sequence.

Peter Scott was again our leader on Day 4, in the Portleven-Polurrian area, where the Frasnian Porthscatho Formation was thrust (Carrick Thrust) over the Famennian Mylor Slate Formation, intruded by the Godolphin-Tregonning Granite, during the Variscan Orogeny, together with associated mineralisation. The Portscatho Formation at Church Cove, south-west of Gunwalloe, comprises strongly deformed grey turbiditic sandstones, siltstones and mudstones (slates), locally isoclinally folded, and exhibiting cleavage. Sole structures occur on the bases of several sandstone beds. These rocks are overlain by Quaternary wind-blown sand with a thin basal deposit containing numerous fragments of Devonian strata. At Porthleven Sands, the Mylor Slate Formation is sheared and heavily deformed. Here, N-S trending quartz veins cross-cut earlier quartz veining. Nearby, beautifully restored historic mine workings, Wheal Rose and Wheal Penrose, had exploited low temperature (100–200°C) lead-zinc mineralisation in N-S trending veins.

After lunch in Porthleven, our examination of Rinsey Cove was curtailed by a rising tide. The wave-cut platform here comprises a roof pendant of the Mylor Slate Formation, locally with andalusite and cordierite, surrounded and metamorphosed by the c. 284 Ma Tregonning-Godolphin Granite. Several xenoliths of country rocks occur within the granite which is pegmatitic in places. The easternmost, low angle junction with the granite contrasts with the vertical western boundary. Above the cove we briefly examined the remains of the Wheal Proper Engine House before proceeding towards Trewavas Head, noting the highly sculptured granite outcrops below (Figure 6). Beyond, more mine buildings were reached, and search of the waste rocks suggested that the copper mineralisation hereabouts was largely confined to the granite itself. With the aid of a Geiger counter, our leader was able to demonstrate increased levels of background radiation in the mine dumps as evidence of uranium ore. From this locality, there were fine distant views to the SE of cliffs (Megiliggar Rocks) showing horizontal sill-like granitic intrusions.

Day 5 began with a brief stop at St. Keverne, after which we inspected exposures of Landewednack (hornblende) schist, with a distinct north-westerly foliation, in the old coastal quarry workings at Porthkerris. The schists were also found to be variously folded and deformed, in some cases with detached fold limbs; the degree of deformation increased towards the north. Metagabbro was encountered on the north side of the cove. This has been subjected to granulite temperature and pressure levels before being retrogressively metamorphosed under amphibolite conditions. It was observed to be highly deformed with a strongly flasered fabric and significant colour variation. Some of the material was distinctly pale and feldspathic while darker, more mafic types approached pyroxenite composition. The metagabbro is thought to be derived from a layered igneous intrusion which is referred to as the 'Traboe Cumulate Deposit'.

Figure 6 Sculptured granite outcrops, Trewavas Head ©Doug Holliday.

At Porthallow, a northerly traverse was again made along the coastal exposures, first examining the metagabbro on the south side of the cove. Outcrops of serpentinised dunite with prominent relict crystals of spinel were also encountered. The location of the Lizard Boundary Fault to the north was identified by a gully in the cliff, a number of sheared fragments of mica schist of possible Cambrian age and a zone of sheared and deformed rock extending over a total distance of about 100 m. Beyond this zone, there was a complete contrast in the geology with an outcrop of altered rhyolite thought to represent a large clast in an olistostrome. This, together with an adjacent exposure of metamorphosed basaltic rock and a succession of clastic sediments, is collectively referred to as the 'Meneage mélange' and is now generally considered to be of Devonian age.

For our final day, Mike Styles guided us around the Lizard looking for evidence of the obduction of the Rheic Ocean ophiolite complex during the Variscan collision. Below the Lizard lighthouse, cliffs of black foliated amphibolite (hornblende schists), originally basalt lava flows on the ocean floor, form the dramatic coastline. Near Lizard Point, where the cafés and RSPB centre do a brisk trade, a headland to the west exposed 500 Ma pale, sillimanite-cordierite schists of the Old Lizard Head Series. The isoclinally folded schists also form the cliffs at Polpeor Cove at the old lifeboat station.

Pebbles of white and black banded Man of War gneiss (the oldest rocks in Cornwall), which forms the offshore islands at Lizard Point, could be found on the beach, evidence of Gondwanan crust.

After lunch at Lizard village, with enough time to peruse the carved serpentinite souvenirs in the tourist shops, we visited Landewednack Church where red and green serpentinite has been used to great effect in the pulpit and font. Finally, at Kennack Sands, the group tackled the origin of the so-called Kennack Gneiss, a coarsely-banded felsic and mafic rock with a complex history of intrusion and deformation. Using field observation, we concluded that granitic and mafic magmas had been intruded into peridotite, judging from the xenoliths and the talc alteration of the peridotite.

As the group headed for home, we reflected that in the space of a week, we had examined mineralisation, mine workings, ophiolite sequences and much else, and had come to appreciate both the complexity and the economic importance of Cornish geology. Most of all though, our appreciation is extended to our leaders, Peter Scott and Mike Styles and, as ever, our organiser Anne Burgess for making it all happen. The advice of David Stephenson helped in the preparation of this article.

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How things change—a UK Geoenergy Observatory in Glasgow

By Alison Monaghan

When I started work as a geologist at BGS over 20 years ago my job was to make maps and 3D digital models of the subsurface in western central Scotland. By integrating fieldwork, coal mine plans and boreholes I mapped and modelled the lithology, stratigraphy and structure of Carboniferous rocks and basins of the Midland Valley. The results were a ‘static’ representation of what’s beneath our feet.

Fast forward to today and the way a geologist works has changed significantly—towards understanding competing resources, impact and change in the subsurface e.g. for waste disposal, for energy resources and energy storage. However, impartial, freely available data to constrain a ‘dynamic’ understanding of subsurface change can be hard to come by. The UK Geoenergy Observatories project is an ambitious £31 million investment that will see BGS set up and operate two subsurface research laboratories on behalf of the Natural Environment Research Council and the UK Government department for Business, Energy and Industrial Strategy, to gain a better understanding of subsurface change beneath our feet.

One Geoenergy Observatory in the Thornton area of Cheshire will focus on a range of subsurface energy technologies to over a kilometre below the ground. The other Geoenergy Observatory will focus on low-temperature geothermal energy from the flooded mine workings below the east end of Glasgow to a depth of a few hundred metres. Here, scientists will be able to move from knowledge of say, their underpinning static geological models of Carboniferous Coal Measures rocks, to answer key research questions on low carbon, renewable, heat resources within those rocks—and enable more widespread use of the subsurface in a sustainable way.

First of all, I’ll describe the concepts behind mine water geothermal energy and then summarise what is planned for the Geoenergy Observatory in Glasgow, the Glasgow Geothermal Energy Research Field Site.

What is mine water geothermal energy?

Many parts of the UK are underlain by abandoned coal mines. Upon closure, the mines became naturally flooded with water which becomes warmed due to the naturally increasing geothermal gradient with depth. For the relatively shallow mine workings in eastern Glasgow the water is thought to be around 12°C, with a stack of seven worked coal seams. These man-made workings have greatly increased permeability for groundwater and the mine working galleries, shafts, roadways and collapse-related fractures have been termed an 'anthropogenically-enhanced aquifer'. By taking advantage of this anthropogenic aquifer, warm water can be abstracted through a borehole and passed through a heat pump to provide a heat source for homes and businesses, before being returned within a sealed loop to a different part of the mine system (Figure 1).

A number of mine water geothermal schemes have been run successfully for tens of years. For example, a scheme in Shettleston in Glasgow provides for a small number of homes, and a much larger scheme

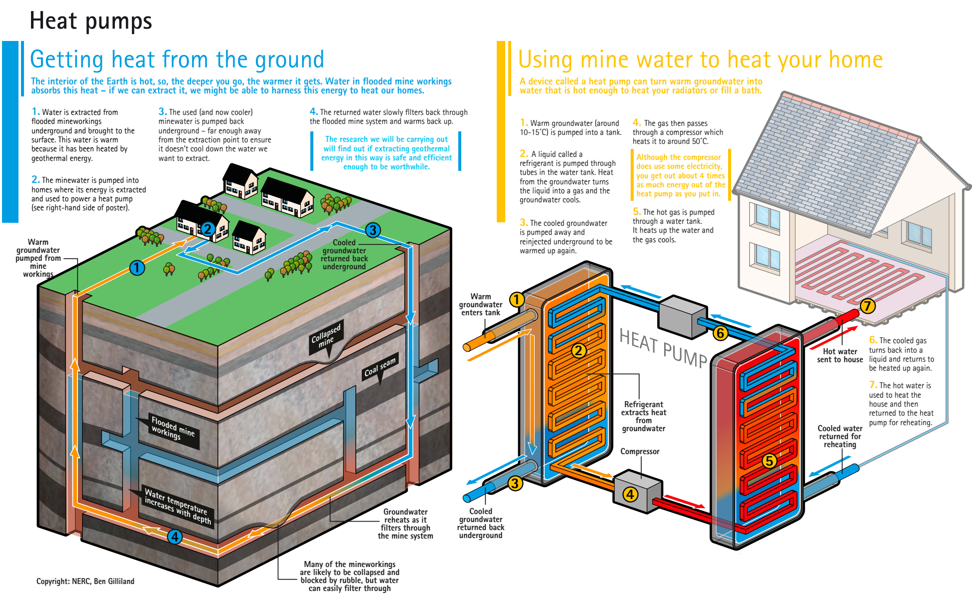

Figure 1 Infographic of mine water geothermal and how a heat pump works. British Geological Survey © UKRI 2019. All Rights Reserved

that also includes heat storage is running in Heerlen in the Netherlands. Several schemes e.g. at Markham in Derbyshire, have targeted mineshafts or roadways. However, few schemes target the much more extensive mine workings — either stoop and room, or 'waste' from total extraction — that it is planned to test at the Glasgow site. Also, most existing schemes have limited subsurface and environmental monitoring to record what happens to the subsurface environment when the warm mine water is abstracted, and the cooler mine water returned.

Mine water geothermal energy is a potentially significant source of low-cost, continuous low-carbon heat that is sustainable long-term. However, its contribution to the UK's energy mix, and to decarbonisation of its energy, is, as yet, largely unrealised. The Glasgow site was chosen as it has much in common with other parts of the UK with a mining history, relatively complex Carboniferous geology and a legacy of former industrial land use. Mine water geothermal, on its own or in combination with other heat sources, could provide community scale heat via district heating networks in former coalfield areas which commonly suffer from fuel poverty. Yet to achieve this there are a number of economic, regulatory and geoscientific challenges. Some geoscientific examples include:

- how quickly warm water is replenished — resource value and sustainability
- what minerals are in the water and how to minimise clogging of pipes etc. — hydrogeochemistry
- costs and risks of borehole drilling — does it matter what type and depth of mine working is targeted?
- subsurface connections between near surface land contamination and mine waters — environmental protection

This is where the UK Geoenergy Observatory in Glasgow comes in.

What's going to be at the Glasgow Geothermal Energy Research Field Site?

The subsurface Observatory will feature a number of boreholes of various depths, which will enable research into the area's geology, underground water systems and the potential for mine water geothermal heat. Measurements will be taken from the boreholes, such as temperature, water movement, water chemistry and of microorganisms (geomicrobiology). Environmental baseline monitoring of near-surface chemistry, gases and waters will also be measured, to provide a record of 'what is normal' before any geothermal research takes place.

Planning approval and permitting for the current characterisation and monitoring phase have been granted with the majority of the boreholes located at the Cuningar Loop, Rutherglen (Figure 2). Planned drill lengths are between around 10 to 90 metres. Six boreholes are targeted to characterise and monitor water in the Glasgow Upper and Glasgow Main coal workings (Figures 2, 3). Five boreholes will be used to record the environmental baseline near the top of the bedrock and superficial deposits. The boreholes are planned to have range of sensors such as resistivity and temperature cables, water data monitors will be installed, and regular water samples will be

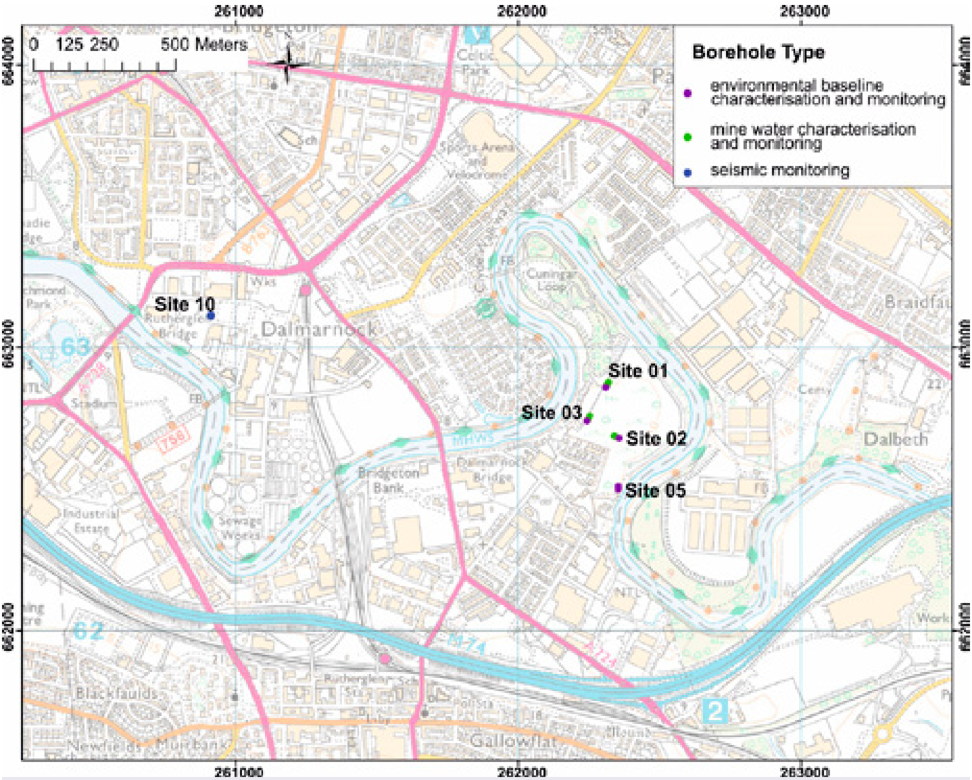

Figure 2 Map of the borehole locations. BGS©UKRI. Contains Ordnance Survey Data © Crown Copyright and database rights 2018. Ordnance Survey Licence no. 100021290.

taken. In addition, there is one seismic monitoring borehole of around 200 m drill length at Dalmarnock (Figure 2), which is planned to provide a borehole core. A new core scanning facility at BGS Keyworth will be used to give a geophysical, mineralogical, and geochemical and optical/X-ray downcore record.

Subsequent to the current phase and permissions for the installation of the pipes and heat pumps that will allow geothermal research, the observatory will be open to the whole of the UK science community to undertake research. Continuous data from state-of-the-art sensors from the boreholes will be open, free and accessible to the public, government, regulators, academia, and industry via an online portal.

Timescale

Planning permission and various permits are in place, with borehole drilling work started on site in November 2018. The aim is for all boreholes and monitoring equipment to be ready for research use from 2020 for a 15-year lifespan.

Geology of the research site

The Glasgow Geothermal Energy Research Field Site is located on the western side of the Central Coalfield of the Midland Valley of Scotland. It is located within glacial and post-glacial Quaternary superficial deposits, overlain by a variable thickness of artificial (made) ground. These deposits rest on approximately 300 m of Scottish Coal Measures Group bedrock. Underlying this are older Carboniferous strata of the hundreds of metres thick Clackmannan and Strathclyde groups.

The Quaternary deposits are of variable thickness, up to 30 m. The upper surface of bedrock was incised, with thicker accumulations of superficial deposits infilling a broadly NW-SE trending channel following the modern-day River Clyde. There is widespread made, filled and landscaped ground relating to a variety of prior industrial land use, in some places this is 10–15 m thick.

Bedrock strata of the Scottish Upper, Middle and Lower Coal Measures formations of the Westphalian Scottish Coal Measures Group are cyclical sedimentary rocks of sandstone, siltstone, mudstone and coal. Recorded coal mine workings in the area were active from 1810–1934 with total extraction and stoop and room workings shown. It is expected that total extraction areas collapsed within a few years of mining to form a waste, and that the mines will be flooded. Figure 3 illustrates a cross-section of the geology and two of the planned sets of boreholes in the Cuningar Loop area—our static model of the geology before we start

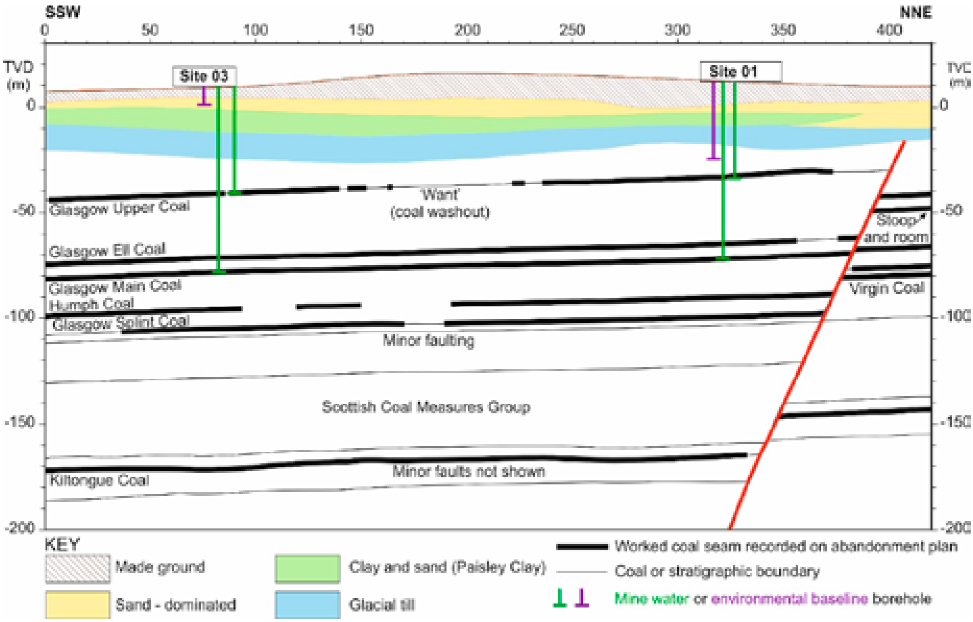

***Figure 3** Cross-section of the geology in the Cuningar Loop area with the planned borehole target depths shown. Note that the thick black lines represent areas recorded on abandonment plans as mine workings. British Geological Survey © UKRI 2019. All Rights Reserved.*

drilling, monitoring and sensing the subsurface.

To conclude
In a few years' time I hope this project will have enabled us to reflect not only on 'how things change' for a BGS geologist's work, or our significantly improved knowledge of 'how things change' in the subsurface environment above and in old coal mines, but because with the results of this national-good science we'll be on the way to changing old coalfield communities with locally sourced, decarbonised heat/heat storage, reinvigorated with local engineering and science expertise.

Further information and references can be found on the BGS website http://www.bgs.ac.uk/research/energy/esios/glasgow/home.html

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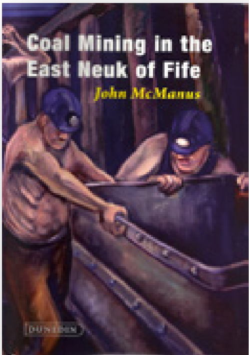
Book reviews

Coal Mining in the East Neuk of Fife by John McManus. Dunedin Academic Press, Edinburgh. 2017. Hardback, 200 pp. Price £24.99. ISBN: 978-1-78046-072-7.



We have an ambivalent attitude to coal these days, so it's always salutary to see recorded the contribution that mining has made to Scotland's economic development and cultural heritage. However, when recalling the heyday of the Scottish coalfields, perhaps the East Neuk of Fife does not immediately spring to mind. All the more welcome therefore is Professor John McManus's impressively researched account of the geological basis of mining in that region, well-illustrated throughout, skilfully integrated with the complementary social history, and rounded-off by a good glossary and index.

In his introduction, Professor McManus claims that it is the underlying geological controls that are the principal focus of his account, and whilst this rather underplays his fascinating social commentary, geology is very much to the fore at the beginning of the book. We start with the big picture. The first of four short chapters takes the reader from the origin of the Earth to plate tectonics and sea floor spreading. This is followed by a summary of Scotland's geology from the Proterozoic Lewisian to the Early Permian amalgamation of Pangaea, then by the story of life emerging from the sea and the evolution of terrestrial vegetation. That leads naturally to a discussion of coal formation, with Carboniferous cyclothems in Fife originating in response to the effect on sea-level of distant glacial fluctuations.

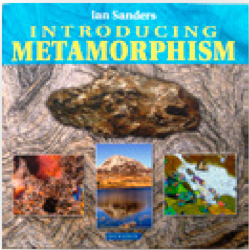
From the broad geological perspective, McManus moves to the history of mining in the East Neuk. The 18th and 19th centuries saw the peak of activity, but few mines survived past the 1920s and only one was still working at nationalisation in 1947. The developments in Fife are integrated into the broader picture of coal mining across Britain and improvements in transport, most notably the expansion of the railway network. A wealth of detail emphasises the hardship and deprivation of life in the mining communities. That theme also permeates the description of the ways in which coal has been won, from stoop and room and bell pits to modern longwall mining. Illustrations include a series of seven evocative pictures of underground work based on original paintings by Derek Salter, himself a former miner and now an art teacher. The paintings have a muscular, almost heroic feel, but in no way glamorise the claustrophobic conditions.

The first nine chapters occupy only 60 pages, but thereafter, in the real heart of the book, the next four chapters take up just over 100 pages. Although given separate status they are intricately interconnected and contain a plethora of detail, facts and figures. The range and intensity of Professor McManus's research is manifest, but the result is not easy reading; this is not a lightweight book. Nor is an understanding of 'The geology of the coal-bearing succession' (Chapter 9) made easier by the omission of a detailed correlation chart for the Carboniferous stratigraphy. Table 1, early in the book, is inadequate and to keep up with the author I found it necessary to have at hand Figure 9.3 from the Read *et al*. (2002) chapter in *The Geology of Scotland*; I recommend a similar tactic. Otherwise the descriptions are well illustrated, and indeed in part the detailed account of "The coal seams and mines of the East Neuk" (Chapter 10) reads like a field guide (complete with a couple of illustrations from MacGregor's classic of 1968). Further detail is then added from two major 20th century coalfield reviews (Chapter 11) before the most important sector of the coalfield, around Largoward, is given individual attention (Chapter 12) although it had featured prominently in the earlier chapters. The overall result is challenging, but persevere, and there is much reward in this exhaustive account which delivers equally on its disparate themes.

A final brief chapter provides some 'closing thoughts'. These extend to fracking but avoid the issues around anthropogenic climate change in which coal is now cast as the principal villain. That's a sad, if inevitable epitaph. John McManus has done a great service to both geologist and socio-economic historian by bringing together a different side of the story from the East Neuk of Fife.

Phil Stone

Introducing Metamorphism by Ian Sanders. Dunedin Academic Press, Edinburgh. 2018. Paperback, 148 pp. Price £14.99. ISBN 978-1-78046-064-2.



This is a fascinating book: although entitled 'Introducing Metamorphism' it is much more than a simple guide to the subject as it covers in considerable detail the causes, geological settings and development of the wide range of metamorphic phenomena.

The book is structured in three parts, a comprehensive glossary, three appendices and the main text in five chapters.

In the preface the author acknowledges that some readers may have a limited background in geological processes and lack familiarity with some of the methods used to study metamorphic rocks. The appendices are designed to provide this information with a synopsis of earth processes, the chemistry of common metamorphic minerals, the main techniques for studying metamorphic rocks including microscopy, the scanning electron microscope, and isotopic age dating. The main text is an excellent description of the different styles and settings of metamorphism both with progressive and retrogressive developments. Technical terms are introduced and clearly defined.

The first chapter starts with the fundamentals. The six main parent lithologies (protoliths) are defined. The main types of metamorphism and their settings are described, including burial, contact, shock, dynamic and hydrothermal.

The second chapter deals in considerable detail with the petrography of metamorphic rocks. This examines the mineralogical changes, in the main rock types, as a result of increasing PT conditions with variable crystal growth rates. The concept of particular index minerals reflecting specific pressure/temperature conditions is introduced, for example biotite zone, garnet zone etc. Also, changes in the structure of the rock under directed stress with the consequent development of cleavages, folds and lineations, and how these may be overgrown by new mineral growth is discussed. The variable mineralogy and textural changes in the various lithological types when subjected to differing metamorphic styles is well illustrated. Different fields on a PT grid for metabasic rocks are defined and the concept of metamorphic facies is introduced.

The third chapter examines, *inter alia*, the critical role of water in promoting and controlling grain growth and its role in retrogression. The production of rock melts can also be determined by the presence or absence of water. The nature of grain growth is also covered.

The fourth chapter considers contact metamorphism and develops the facies concept. Metamorphic belts, reflecting differing styles of metamorphism (e.g. Barrovian and Buchan) are discussed as well as their relationship, in part, to different tectonic regimes. For example, the development of paired metamorphic belts at subduction zones as well as other tectonic regimes. It concludes with a discussion of shock metamorphism basically related to meteorite impact.

The fifth chapter examines the use of geothermometers and geobarometers. The resultant data, related to textural evidence (for example the growth or retrogression of component mineral species), allows the history and character of metamorphic complexes to be determined.

In summary, the author has succeeding in producing a text that provides a comprehensive description of metamorphism ranging from the simple fundamental definitions to complex metamorphic processes. It is superbly illustrated with, in particular, excellent photographs and microphotographs illustrating mineral textures, the relationship of minerals to structures and the relative development of minerals. In addition, there are many very clear and useful diagrams covering mineral types, their stability fields and their development under evolving metamorphic conditions, simplified facies maps, the relationship of minerals within triangular chemical diagrams, etc.

This is a well-produced book and a comprehensive modern account of metamorphism.

Each chapter contains a wealth of detail. It covers items of interest to the novice and those with experience in metamorphic rocks. Because of the depth of information, the relative novice might find a straight read rather overwhelming and might find it better to skim the essence of each section and then go back and study the detail as desired. Either way, all users will enjoy and gain from this book.

Doug Fettes

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