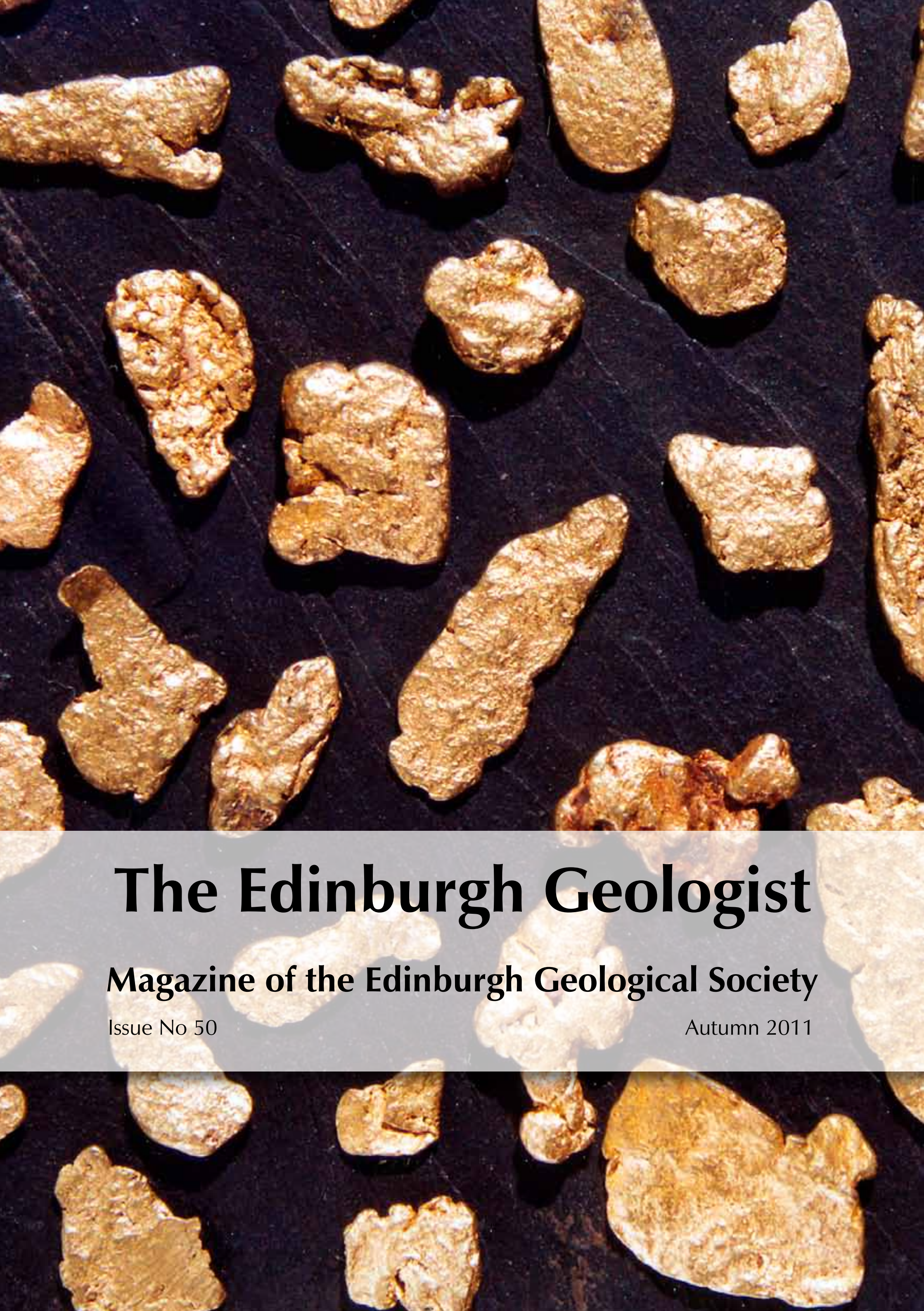

The Edinburgh Geologist

Magazine of the Edinburgh Geological Society

Issue No 50 Autumn 2011

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Cover Illustration

Since this is the 50th issue of *The Edinburgh Geologist*, it seemed appropriate to have some gold on the front cover. These grains (the largest only a few mm across) were panned from the Kildonan Burn, a tributary of the Helmsdale River in Sutherland (BGS image P243790). For more on the story see Graham Smith's article — *Does Scotland have a golden future*?

Acknowledgements

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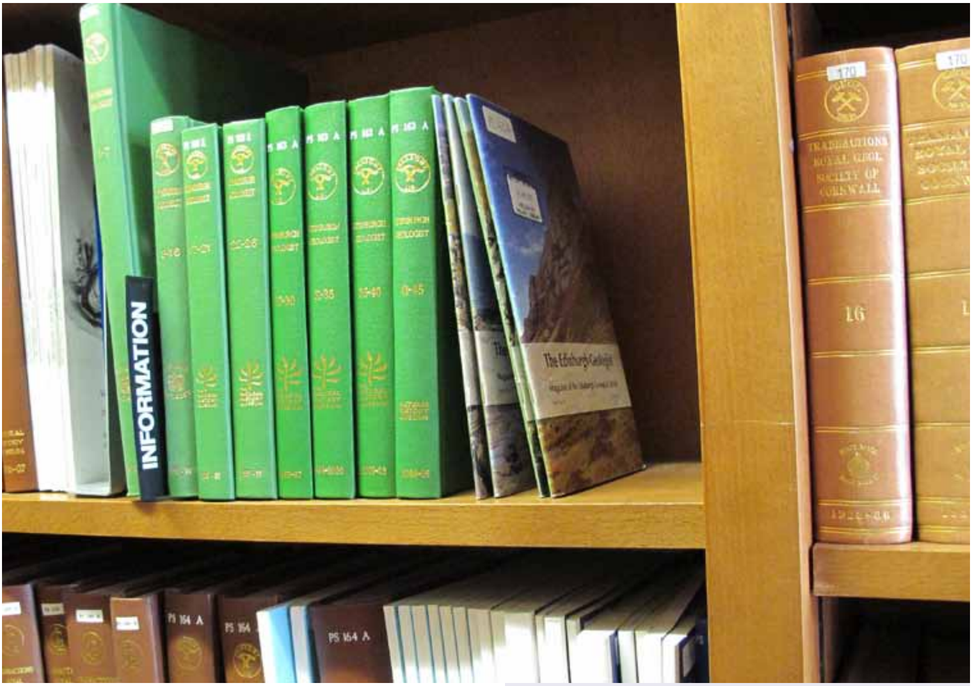
A 50th birthday, our debt to the Torridonian, a new National Museum and some very fancy steps.

An editorial ramble by Phil Stone

This issue of *The Edinburgh Geologist* is number 50. I wonder how many people still have a complete run? It goes out to all members of the Edinburgh Geological Society (that's about 500) and though most of you are local to the city there are plenty spread across the rest of Scotland, quite a few in other parts of the UK and a fair number based in far-flung parts of the world, where *EG* seems particularly appreciated. Example: at *Our Dynamic Earth* I recently met Professor Ian Dalziel (Clough Medallist 2003–04) of the University of Texas at Austin. Ian was in town for a symposium on Antarctic geology but assured me that when *EG* arrives he takes it to his favourite bar and enjoys it with a margarita. The *EG* is also sent to places where its survival is pretty-much guaranteed, such as the British Library and the National Library of Scotland. Its fate in some of the Scottish University Libraries is a bit more hit and miss, and I discovered that even the set held by the British Geological Survey in the Murchison House library (now rebranded as a Research Knowledge Services centre) is not complete. Perhaps something should be done about that. Elsewhere *EG* appears more cherished, and I was much cheered to note the beautifully bound copies preserved in the London library of The Natural History Museum, sharing shelf-space with the adjacent *Scottish Journal of Geology* and *Transactions of the Royal Society of Edinburgh*. Overall, the implication is clear: if you seek literary prestige write for *The Edinburgh Geologist*. Not convinced? Remember in the last issue we featured an article on early life in Scotland by Martin Litherland — it was picked-up and the story re-run by *The Oban Times* no less.

Progress to number 50 has not been entirely smooth and painless, as is evident from the irregular publication timetable and the missing years. Nevertheless, we have arrived, thanks to the joint efforts of a succession of editors and scores of contributors, and reaching our 50th anniversary is obviously worthy of some celebration. Looking back



Bound copies of **The Edinburgh Geologist** *in The Natural History Museum's library, London. Note that there is still plenty of space for future issues. Thanks to Adrian Rushton for the photograph.*

to issue number one, put together by the founding editors, Helena Mansbridge assisted by Andrew McMillan, we find contributions on the Dalradian, the Southern Uplands, and a newly discovered mineral deposit in Shetland. What could be more appropriate than a scientific retrospective? The original authors — Doug Fettes, Euan Clarkson and Graham Smith — all agreed to the proposal and their reappraisals of the same topics, together with editorial reflections from Helena and Andrew, make up the bulk of this, issue 50 of *The Edinburgh Geologist*. Particularly felicitous for our 50th anniversary is Graham's focus on gold in Scotland.

So what of the future? Can we look forward to *The Edinburgh Geologist* number 100? Should it appear, it will undoubtedly be in a very different format, and probably medium, to number 50. Despite the style changes experienced by *EG* so far, it has remained a printed document, with hard copy posted to recipients. That mode of operation seems unlikely to last. Whilst relative printing costs have diminished, postal rates have risen to near-punitive levels and there has been a general flight of scientific publication from words and pictures on paper to digital files on the web. It seems to me inevitable that sooner or later *EG* will follow the same route. I, for one, shall regret the passing of the printed page and the consequential metamorphosis of libraries into research knowledge centres housing nothing but computer screens. But of course there will be compensations. *EG* 100 may be part of an interactive geo-social network as yet unimagined. Even so, for my part, in the highly unlikely event that I am still around, I'd hope to have my feet up and be enjoying a good book.

More early life in Scotland
In the previous issue of *The Edinburgh Geologist*, number 49, we featured evidence for the first signs of life in Scotland. One report from November, 2010, claimed a chemical signature of bacterial activity from 1.2 billion year-old Torridonian strata, reinforcing previous interpretations of sedimentary structures from the Diabaig Formation as indicative of microbial mats. Then, in April 2011, came even more remarkable evidence, not just for bacterial activity but for multicellular life (Paul Strother and others, *Nature*, doi: 10.1038/nature09943). What's more, this multicellular life had made it out of the ocean into the lacustrine, Torridonian environment, to become the Earth's earliest non-marine eukaryotes. Organic-walled microfossils had first been described from the Torridonian in 1907, in the Geological Survey's 'North-west Highlands' memoir, but the recent resampling and modern investigation takes the interpretation a lot farther. I doubt whether these early Scottish colonisers were much to look at, but just possibly we are all descended from that Torridonian slime.

Edinburgh rock
The summer saw the opening in Edinburgh of two splendid new geological attractions; one designed as such, one conceived as something very different.

At the end of July we celebrated the long-awaited opening of the National Museum of Scotland after the mammoth redevelopment of what had been the Royal Museum. I've only had the opportunity of a quick look around so far but am much impressed by what I've seen—and relieved that real rocks and fossils still form the core of the geological exhibits, even if some specimens seem a bit short on explanation. In this issue of *Edinburgh Geologist* we have an excellent 'insiders' viewpoint from Yves Candela and Peter Davidson describing the philosophy behind the new displays and providing an introduction to what can be seen. I'm sure that many of you reading this will have visited already, or be intending to, so let's hear your opinions for inclusion in the next issue of *EG*. For some reason, I was particularly pleased to spot a coelacanth. What item caught your eye?

In complete contrast to the carefully planned museum displays was the fortuitous geological extravaganza provided in June by the opening of the refurbished Scotsman Steps. This landmark spiral stairway runs down from Edinburgh's North Bridge adjacent to The Scotsman Hotel (formerly the HQ of *The Scotsman* newspaper) to Market Street, and is contained within an octagonal tower constructed of Prudham Sandstone from the north of England. The Steps had fallen into disrepair and had been closed off for a number of years, but have now been colourfully restored as an artwork commissioned by Market Street's Fruitmarket Gallery with the support of various other public and private benefactors. Accordingly, the Steps are now Martin Creed's 'Work No. 1059, 2011'. The geological connection comes from this piece of public sculpture having involved Creed in resurfacing each of the steps (originally Carmyllie Flagstones from Angus) with a different ornamental marble—which means that sizeable slabs of 105 of such rocks are now laid out for inspection in close juxtaposition. The ornamental stones, provided by an Italian supplier but cut to size and shape in Leith, are sourced from all over the world, from as far afield as Afghanistan and Bolivia, but I can't help but be disappointed that not a single Scottish rock was included, nor indeed any from the rest of Britain. But of course that wasn't the point. To quote from the Fruitmarket Gallery's informative brochure (which lists the trade names of all of the stone varieties used—I particularly like the sound of *Fior di Pesco Fantastico*):

"Creed himself has described the work as a microcosm of the whole world – stepping on the different marble steps is like walking through the world.

Work No. 1059 . . . is an exercise in adding and subtracting by degrees. To make it, Creed started from nothing, and added something. The process of addition, though immensely complicated, involving architects,

A selection of the renovated Scotsman Steps.

planners, engineers, stone cutters, builders etc, results in an intervention whose deceptive simplicity seems almost to take the addition away (though extravagantly marble and chromatically beautiful, the steps are still only steps, after all)."

I guess that geologists, if involved at all, are lumped above into 'etc'. But geological interest is certainly there in abundance, with textural, petrographic and even palaeontological features all laid out for inspection. So what we urgently need is a 'Geological Guide to the Scotsman Steps'. Any volunteers? Quite apart from Martin Creed's intention that his work should emulate walking through the world, the geological perspective would add to that experience journeys through time, through long-lost environments, and through the depths of the Earth's crust. Of course, Creed has also set up a technical experiment into the relative durability of the different lithologies. The different types were selected and positioned on aesthetic considerations within an artistic concept and some, I suspect, are not generally used for paving. How they stand up to the assault of myriad feet, aggressive cleaning and winter salt remains to be seen but first impressions of a few steps are not encouraging. My advice is to take a good look as soon as possible before any deterioration sets in — and don't forget to send your impressions to *The Edinburgh Geologist*.

Another image perhaps?

A few words from our founding editors

Helena Mansbridge (Butler) writes:

When I graduated with a geology degree in 1974 I joined the Edinburgh Geological Society, as many of us did. I looked forward to receiving the Scottish Journal of Geology and read it enthusiastically but was aware that many of the amateur members of the society would find it very academic and of limited interest. In 1976 over 'high tea' in Crief, after a very enjoyable EGS fieldtrip to Glen Lednock, I suggested that there might be a place for a more general-interest publication of the Society in which current research in geology would be discussed with an amateur audience in mind. There was considerable interest in the idea and after a period of due deliberation, the Edinburgh Geologist was born. I edited the first 17 issues with invaluable assistance from Andrew McMillan—and many others who contributed a wide range of enlightening articles during my time as editor.

I am delighted that the Edinburgh Geologist is still going strong after 34 years and has reached its 'Golden Edition'. It is clear from the content of recent issues that the original aim of telling the story of geological research and endeavour in an accessible manner has remained an essential feature. Keep up the good work!

Andrew McMillan writes:

This is a piece of sheer indulgence. Back at the beginning of the eighties when I was Membership Secretary, someone (may be it was Colin Will) gave me a Peanuts cartoon which I unearthed recently. Snoopy is seen drafting the minutes of the Cactus Club. It went as follows: "The Secretary will read the minutes of the last meeting." "A suggestion was made that we purchase a computer to keep track of our membership." "After the laughter died down, we had refreshments".

That's just one perspective on what life was like in the formative years of The Edinburgh Geologist, first published in 1977. Before the days of mass usage of PCs, word processing was only just emerging as the ultimate solution to document and magazine production. For the early editions we used to provide typed up clean copy to printers at the University of Edinburgh, and they would run off the required number of A4 stapled copies – sufficient for members who were resident in and around Edinburgh. I had been delighted when the concept of the magazine for members became a reality in 1977 with Helena Butler as editor. Thank you to Euan Clarkson, Norman Butcher and the late Wally Mykura for their support for this new enterprise. The Scottish Journal was not everyone's cup of tea and it was good, particularly for non-professional geologists, to have an informal magazine in which short articles, local geological news, book reviews and even crosswords (I had great fun drafting some) were welcome. I joined Helena in a co-editorial role in 1979, and used the position to cajole colleagues to produce interesting material. There was no house style for diagrams and the editors were sole referees. A more professional looking format was introduced in 1980 when my sister-in-law Val suggested she could produce the camera ready copy on her new word processor and the university printed issues in a neat A5 format. Over the years we were blessed with some regular contributors. Bill Baird springs to mind with his 'Strange Earth' series which ran and ran. And then there were excursion reports, the sort that didn't suit more formal Proceedings. These accounts could be very amusing although the poetry was usually worse than William MacGonagall.

I'm really pleased that Phil Stone and Bob McIntosh have picked up the baton of editorship thus reviving the fortunes of this excellent magazine which went into hibernation for a year or so. They have succeeded in matching their predecessor Alan Fyfe's editions which really did put The Edinburgh Geologist up there as an attractive and professional compilation. Of course, today's technology allows them to do formatting things that we could only dream of, but the standard of articles makes for a very readable magazine. Congratulations on reaching the half century! Here's to all of the editors who have had a hand in steering the magazine. I hope it goes from strength to strength even if, as the pace of change accelerates, it becomes necessary to transmit our contributions electronically!

New geology exhibits in the redeveloped National Museum of Scotland

by Yves Candela and Peter Davidson

More than six years after the start of the project and three years after the closure of the Royal Museum, the redeveloped National Museum re-opened to the public on the 29th of July. The outside of this familiar Victorian building has largely retained its unique character, but a major new feature is apparent: two street-level entrances have been opened into the bowels of the museum, the basement area where collections used to be stored.

Sixteen new galleries have emerged from the redevelopment project and nine of these now feature a mixture of geological and palaeontological specimens (Figure 1). Geology is most prominent in 'Restless Earth' and 'Earth in Space' which focus on the geology of the Earth, and its place in the solar system and the

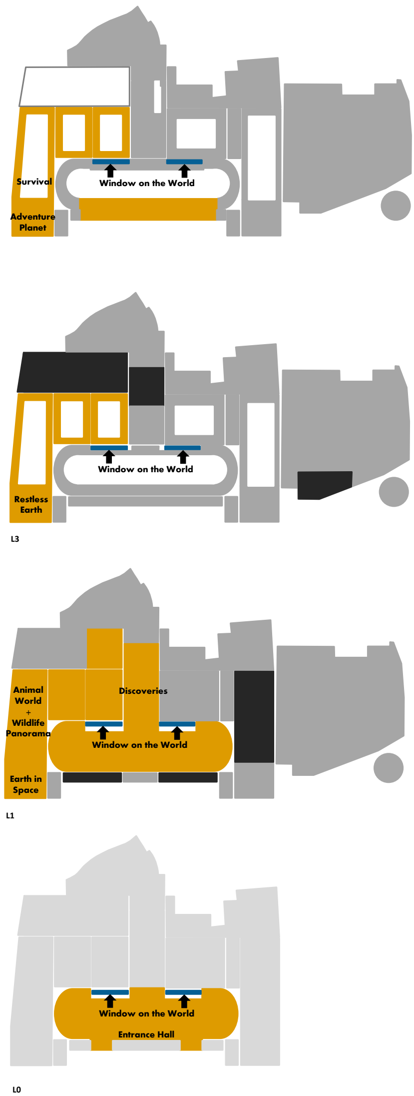


***Figure 1** **Maps of the redeveloped museum.** © National Museums Scotland. EiS—Earth in space, Wild Pano—Wildlife Panorama, Discov—Discoveries, Rest Earth—Restless Earth, Adv Planet—Adventure Planet.*

universe, respectively. 'Restless Earth' is entirely dedicated to displaying geological specimens and showcasing the geological processes that have shaped, and continue to shape, the Earth.

Displaying the specimens

The newly refurbished galleries present exhibits in a more multidisciplinary manner than previously. The systematic display of fossils by species within a phylum is often seen by the public as too didactic or patronising. In developing these new galleries, we have taken the best ideas of the creators of 19th Century museums, who wanted to establish a special dialogue with the visitor. Our galleries retain their emphasis on the specimens but merge them with the most recent developments in exhibition technology and design to form an exciting mix of interactive exhibits featuring some outstanding items from the collections of the National Museums Scotland. We seek to demonstrate that a modern museum can combine real objects with modern technology and up-to-date design concepts to create truly exhilarating experiences for the visitor that will inspire them and excite their curiosity to learn more.

Of course, many members of the public don't visit museums to be educated. They may be there to drink in the sheer beauty of objects and their environment. For that reason, we have designed the museum's displays to be aesthetical as well as educational, and this approach is fully applied to the geological specimens. Our objects are used in three different ways: 1) to interpret the main themes of the exhibition; 2) to showcase the collections, by displaying adjacently specimens with no apparent relationship to each other — a similar philosophy to a traditional 'cabinet of curiosities'; and 3) as aesthetic or fascinating objects, with interesting stories related to them.

We will now give a quick overview of some of the geological specimens you will encounter on entering the museum, then talk about 'Earth in space' and 'Restless Earth' in more details. First of all, a cut and polished monolith of fossiliferous limestone with *Gryphaea arcuata* (a.k.a. 'the Devil's Toenail') stands in the 'Entrance Hall' to welcome the visitors. The interpretation of the specimen includes a mixture of scientific fact and popular myth. This specimen was chosen as an 'attractor' and fits into the third category mentioned above. It is a new acquisition, collected by museum staff from a Site of Special Scientific Interest on the Isle of Skye, with the kind consent of Scottish Natural Heritage. Access to the original Main Hall, now renamed 'Grand Gallery' is possible either by a new staircase or via glass panelled lifts. Here an 18-metre high wall displaying over 800 specimens from across the full breadth of the collections confronts the visitor. Inspired by an ancient 'cabinet of curiosities', it contains specimens that illustrate the wide range of the NMS collections. A similar feature, though more modest in scale, can be seen at *'Die neue Sammlung—The International Design Museum',* part of the *Pinakothek der Moderne'* in Munich, Germany. Prominent in our 'wall of wonders' is a one-metre high, 19th century carved vase of Derbyshire 'Blue John' fluorite from the NMS mineralogy collection. The banded blue and yellow (*bleu et jaune* in French—hence Blue John) fluorite was once extensively mined for its ornamental value but today only a few hundred kilograms are mined each year. From the Grand Gallery, visitors may enter the new galleries. Let's look first at 'Earth in Space' (my personal recommendation—Yves).

Earth in Space

This gallery uses a mixture of specimens, graphics, text and audiovisual presentations and interactive displays to tell the story of the Earth and its place in the Universe. Most specimens in this gallery are exhibited in showcases and are organised in three main areas: 'Matter', 'Space' and 'Origin of Life', with the geological content concentrated in the first and last sections. These feature fossils, minerals and rocks. In 'Matter', visitors see that the 'stuff' we are made of is found throughout the Universe and that elements or combinations of elements can give rise to a wonderful diversity of minerals—gold from Australia (Figure 2), platinum from Russia, sulphur from Italy, calcite from Scotland. Meteorites are featured in this section and play an important role in connecting matter from space with matter on Earth. The public is able to get close to and even touch a 150kg fragment of a meteorite collected in Sweden. Other open display specimens include a large hematite mass from the North of England and smoky quartz from Brazil.

In 'Origin of Life', the audience 'meets' ancient life-forms found in Scotland and elsewhere through actual fossils and life-size (or larger) models and reconstructions; they include Ediacaran and Burgess Shale fossils. The visitor is also able to travel back in time even farther, to within a few hundreds of million of years of the formation of the Earth: the oldest rock on Earth, the Acasta Gneiss from

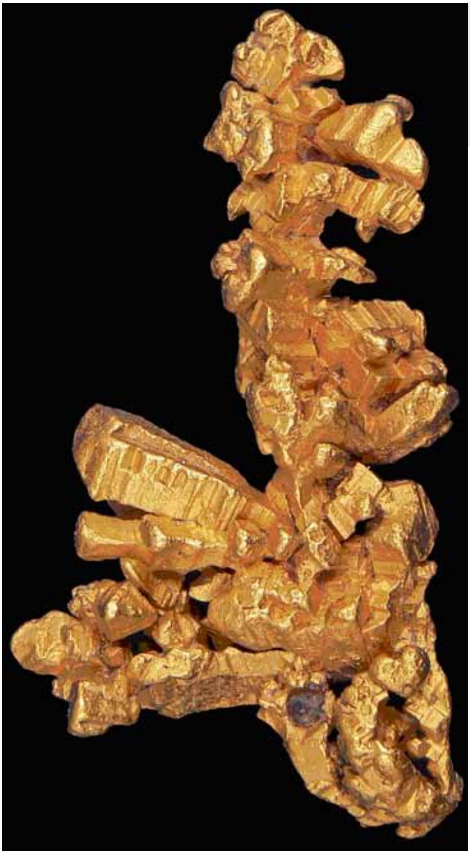


***Figure 2** **Gold from Ballarat, Australia (longest dimension = 80 mm).** © National Museums Scotland*

Northern Canada at about 4000 million years old, and the oldest rock in Scotland, the Lewisian Gneiss dating to almost 3000 million years ago, are astonishing examples from the NMS collection.

Visitors with an interest in local geology will strongly engage with the displays in this gallery as some choice specimens with a strong Scottish connection are featured. Among these are a group of minerals named after Scots (for example Jamesonite, named after Robert Jameson, professor of Natural History at Edinburgh and founder of the museum) or Scottish places (for example Strontianite, named after the village of Strontian, Argyll, which also gave its name to the element Strontium). The largest known Scottish meteorite that fell through the roof of a house in Strathmore, and a saltire flag which went up in the space shuttle and was signed by astronaut Nick Patrick are also examples of the Scottish connection showcased in the gallery.

Restless Earth: the gallery of geology

The visitor to this gallery is led on a journey of discovery and understanding of how the Earth works. A succession of exhibits mingling specimens, graphics and text together with exciting audiovisual and interactive displays across the gallery floor brings this whole topic to life. In 'Journey to the Centre of the Earth' for example, the showcase dealing with the internal structure of the Earth, both sides of the case are cleverly utilised: one side displays an interpretative illustration with peepholes through which specimens are seen in their context of origin, while the other side thematically displays specimens from the collection. In addition to this, an interactive audiovisual brings to life the concepts highlighted in the display.

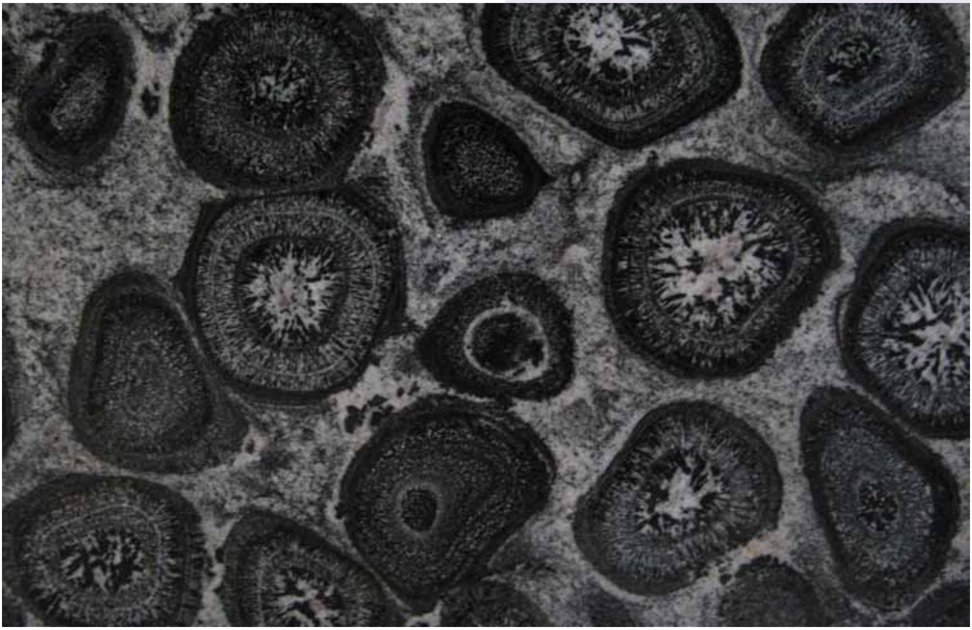
'Earth Events' presents a series of four showcases that give the visitors an overview of the geological events that are shaping the planet, from plate tectonics to volcanism to earthquakes and finally to erosion. Once again, both sides of the showcases are used: the graphic side of each case is the base for a large illustration with cut-out windows (peepholes) that allow the visitor to see some specimens from two different angles. These specimens are displayed in the context of their formation so, for example, in the showcase dealing

***Figure 3** (Top) Sapphire from Loch Roag, Lewis, Scotland (width of crystal in matrix = 120 mm, width of cut crystal = 12.5 mm); (Middle) Opals from San Juan Del Rio, Mexico (height of the opal set in matrix = 190 mm); (Bottom) Malachite from Siberia, Russia (width = 175 mm).*
All © National Museums Scotland.

with volcanism and volcanic rocks, the peepholes are positioned in such a way to allow the visitor to see the rocks located in their zone of formation within a vertical section of an idealised volcano. Double-sided panels with text and images assist in the interpretation. On the other side of the showcase, a range of rocks and minerals are displayed which relate to the topic, selected both for educational and aesthetic purposes. Highlights from this four-case section include a slab with two preserved skeletons of *Mesosaurus*, a sample of fine and fragile Pele's hair and a large sample of snowflake obsidian. By design, this section of the gallery has strong links with the Scottish schools' curriculum. It also engages the public with geology through events that are widely covered in the media, such as earthquakes, tsunamis and volcanic eruptions.

'Story of Rocks' looks at the three fundamental types — igneous, sedimentary and metamorphic — using many fine examples. An entire showcase is devoted to a display of minerals,

***Figure 4 Orbicular granodiorite from Mount Magnet, Australia (orbicules are about 120 mm in diameter).* © National Museums Scotland.**



which includes a unique Scottish sapphire, some exquisite Mexican opal and a beautiful polished specimen of Russian malachite (Figure 3). But the public will not only be able to see specimens inside cases. Some large specimens are exhibited on open display. These include not only specimens that had been on display in the former galleries, but a large number of new acquisitions brought to NMS either by purchase or through fieldwork by NMS' geology section staff. The public can enjoy the physical contact and accessibility of these specimens from all sides, leading to a greater sense of engagement. Some of the recently acquired specimens include a polished monolith of orbicular granodiorite from Australia (Figure 4), a part and counterpart of a large amethyst geode (each half weighs about 1000 kg), a boulder of peridotite xenoliths in basalt, with a cut and polished section, from Arizona and a large example of ropey lava (also known as pahoehoe) from the 1783 eruptions of the Laki fissure in Iceland, an event that caused much hardship in Europe at the end of the 19th century.

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Reflections on the Lower Palaeozoic of south and central Scotland—where do we stand now?

By Euan Clarkson

There are certain regions in European geology, which may be taken as a coherent whole, yet which display remarkable diversity within a confined area. For the Palaeozoic one thinks, for example, of the Ardennes-Eifel massif, the Armorican peninsula (Brittany and adjacent regions), the Barrandian syncline of the western Czech Republic. And surely the Lower Palaeozoic of southern Scotland belongs here too.

The monumental Geological Survey memoir by Ben Peach and John Horne on the Lower Palaeozoic rocks of Southern Scotland, published in 1899, was so comprehensive that it seemed to act as a damper on further research for many years, and only a few papers were published, apart from some monographs on fossils, until after WW2. The area covered in this massive work included the Ordovician and Silurian mountain country in the south (chiefly cherts, shales and above all greywackes) but also the Ordovician and Silurian of the Girvan area and the Midland Valley Inliers. Peach and Horne built upon the splendid research of Charles Lapworth, who was the first to use the graptolites commonly found in the oceanic black shales in the south, and to correlate those rocks stratigraphically with the shallow marine sediments to the north. This short article reviews some of the changes that have taken place in our understanding since 1899, considers our current perspective, and wonders where we go from here.

Let's look at the kinds of rocks that are present, their depositional environments and their interpretation. Strata across the vast area to the south of the Southern Upland Fault were deposited in deep water, as Lapworth recognised in the 1870s. But for a time there were alternative models, and until greywackes were recognised as turbidity current deposits in the 1950s, at least some geologists believed that deposition had taken place in a great expanse of shallow water mud and sand flats. It is now clear that radiolarian cherts were formed in deep water, lying on top of ocean floor basalts, and that these were succeeded by graptolitic

A selection of graptolites from the Birkhill Shales Formation at Dob's Linn, Moffatdale: a) *Rastrites* ***sp., b)*** *Campograptus communis*, ***c) a climacograptid.*** ***BGS image P772042.***

shales; the graptolites are eminently suitable for biostratigraphy and their excellent stratigraphical control has enabled a valuable elucidation of events. Subsequently, turbidity currents swept in to cover the graptolitic shale with thick successions of greywacke. Southwards, the greywacke was deposited on progressively younger and younger shale, for reasons that we now interpret in terms of plate tectonics — progressively younger oceanic crust being carried north by sea floor spreading towards a trench and subduction zone, where the greywacke was deposited. Occasional tsunamis brought down shallow water fossils into deep water, including the coral Kilbuchophyllia, previously unknown, which occupies a critical position in the evolutionary history of corals. The greywackes

The coral Kilbuchophyllia recovered from a debris flow deposit in the late Ordovician Kirkcolm Formation at Wallace's Cast, beside the Wandel Burn to the north-east of Abington. BGS image P521144.

themselves, once thought to be boring and monotonous are now known, through petrography and geochemistry, to be differentiable into several groups, of different origins. These greywacke bands can be mapped out in detail; compare the common purple tint of the older maps with the elegant coloured stripes of the maps of today.

The inliers to the north, lying in the southern Midland Valley, are of surpassing interest for palaeontologists, since they are replete with splendidly preserved, undistorted fossils. Only in the Girvan area is the Ordovician represented, by several sedimentary cycles each beginning with conglomerate and ending with shale, the result of successive intervals of unroofing and uplift. Alwyn Williams, in the early 1960s, was able to show that Ordovician sedimentation in Girvan was controlled by contemporaneous faulting, with conglomerates cascading over the edges of the submarine fault scarps. As is now known, and even more arresting, is that the fault-bounded blocks were moving laterally as well as vertically, sliding into their present position only later. The other inliers, Knockgardner, Lesmahagow, the Hagshaw Hills, Carmichael and the Pentland Hills are all Silurian. Now in all cases the succession in these inliers begins with marine sediments, eventually passing upwards into redbeds of continental origin as the sea receded. Whereas each of these inliers represents a former part of the Laurentian continental shelf, the faunas in each are different. The central Hagshaw and Lesmahagow inliers are dominated by fish and arthropod faunas; these may have been deposited in brackish-water conditions. The Knockgardner

The late Ordovician trilobite* Stenopareia shallochensis *recovered from the Drummuck Subgroup at Lady Burn, near Girvan.* *BGS image P521133.

and Pentland Hills inliers are not dissimilar faunally, but whereas the former represents an open shoreface environment, the fossiliferous sediments of the Pentland Hills were deposited in a broad, quiet-water lagoon, separated from the open ocean by an offshore barrier system. The changes in faunas, as related to this system have been meticulously documented, and this work is still continuing.

The original structural model adopted by Peach & Horne for the Southern Uplands was that of an isoclinally folded complex; it was based directly on the interpretation of Lapworth and held sway until the 1960s, when ENE-WSW strike faults rather than folds were recognised as truly the dominant structural control. Paradoxically, one of these great strike faults passed almost directly below Birkhill Cottage, in Moffatdale, where Lapworth stayed during his field work. And when the plate tectonic revolution began in earnest in the 1960s it became clear that the Southern Upland region was originally an ocean basin (the Iapetus Ocean), underlain by a subduction zone dipping to the north. As subduction continued, northward, the shales and greywackes covering the oceanic plate were stripped off along great thrust planes, now seen as the great ENE-WSW strike faults. This process built up a huge accretionary complex at the margin of the Laurentian continent, before its oblique collision with the Avalonia continent advancing from the south. This overall concept is not in doubt, but can we say more about it? There are persistent problems, and there have been two related but separate interpretational models. The first is that the Southern Uplands did indeed form as an accretionary prism, the top of which rose above sea level to form a chain of eroding islands, known as Cockburnland. To the north lay an ‘upper slope basin’, an elongated part of the Laurentian continental shelf in which accumulated the successions now seen in the Midland Valley Inliers. Although this seems to fit very well with the evidence, there are some additional complexities, for to the south was an andesitic island arc complex, known from southerly derived turbidites rich in andesite and quite different from the quartz-rich turbidites derived from the north. Might the area of the Southern Uplands have been a back-arc basin, rather than an accretionary prism? It is certainly possible, but since we do not really know the palaeogeography of the basin before continental collision there the matter rests, though most recent research has favoured the accretionary prism model. It has also become clear that lateral as well as vertical movements have taken place through time, and these require much further investigation

In terms of modern tectonic theory we now have a pretty good idea of the geological history of this area, but much more remains to be done. Firstly, refinements in biostratigraphy are much required, and nowadays organic-walled microfossils such as chitinozoans, acritarchs and radiolarians are proving increasingly useful. Next, we need more basic mapping—not a fashionable pursuit these days. The Geological Survey's excellent programme of mapping, extending from the south west has reached as far as St Mary's Loch. But with extra pressures on the Survey, and with key staff retiring or being reassigned, it has stalled. Then there is the effect of global sea-level change, which has hardly been applied yet, though it is undoubtedly very important in interpreting the successions. In the Girvan area, for example, chitinozoans have recently been used effectively for biostratigraphy but the sedimentology and palaeoenvironments of Ordovician and Silurian successions still need to be considered in terms not only of tectonic effects but of sea-level change also. Recent preliminary studies in these fields are excellent and serve to show what else might be done in the Silurian Midland Valley Inliers. And then there are the graptolites, which remain available for meticulous stratigraphical and ecological studies. I can only hope that future generations will delight in the geology of this marvellous area as much as people of my generation have been able to do. And it is scenically beautiful too . . .

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Progress on understanding the Dalradian

by Doug Fettes

The Dalradian Supergroup is one of the great icons of Scottish geology. It comprises a varied sequence of metamorphic rocks of Neoproterozoic to Early Ordovician age, which stretches from the west coast of Ireland to Shetland, some 700 km. In Scotland it forms most of the ground between the Highland Boundary and Great Glen faults, ranging from the craggy indented coastline of Argyll to the lowlands of Buchan. To the geologist the fascination of the Dalradian is its key role in the evolution of Scottish Geology. The metamorphic sequences established by Barrow and Read underpin modern systematics. The lithostratigraphy and elucidation of the major structures owe much to that great character of Highland geology, Sir Edward Battersby Bailey. And, more recently, it was geologists such as Basil King, Nick Rast and Mike Johnson who were inspirational in establishing the different structural and metamorphic phases of the Grampian Event. These geologists and those who followed have provided a very detailed understanding of the Dalradian succession and its history. However, it would be wrong to think it has surrendered all its secrets and considerable research continues. In recent years the focus has moved to the wider setting of the succession and important aspects of this are the age and nature of the sedimentary basin.

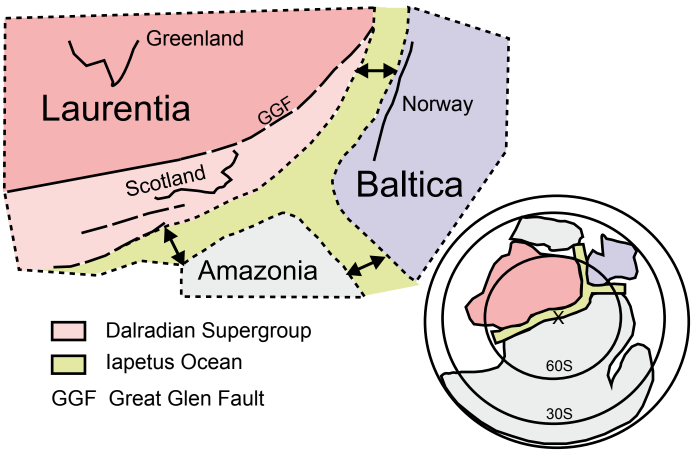

***Figure 1** The breakup of the Rodinia supercontinent and the birth of Iapetus, c. 590 Ma., showing the position of the Dalradian sedimentary basin. Simplified from Leslie et al. 2008.*

How did the Dalradian form?

The Dalradian was formed as the supercontinent of Rodinia broke up, and specifically as the continental masses of Laurentia, Baltica and Amazonia drifted apart opening up the Iapetus Ocean (Figure 1). The Dalradian sedimentary basin developed as the crust thinned and rifted. Then, following continental rupture, deposition continued on the margin of Laurentia as Iapetus opened and closed. The lithostratigraphical groups of the Dalradian reflect stages in the evolution of this process.The basement to the Dalradian is likely to be varied but, where seen, the lowermost beds rest on the Dava-Glen Banchor succession (Figure 2), a Neoproterozoic unit broadly equivalent to the Moine assemblage.

The *Grampian Group* marks the start of sedimentation. Crustal extension led to subsidence, active rifting and the development of a series of linear fault-bounded basins. The sediments are dominated by siliciclastic turbidite fan systems. Towards the top of the group more stable conditions developed marking a transition into the *Appin Group,* which is characterised by shallow shelf sediments. The Appin Group divisions, which are marked by limestones, black mudstones and quartzites, can be traced across the whole strike length of the Dalradian from the west coast of Ireland to Banffshire. This remarkable degree of continuity reflects a lack of rifting with uniform subsidence along the basin. These conditions changed markedly with the onset of the *Argyll Group*. Crustal stretching increased

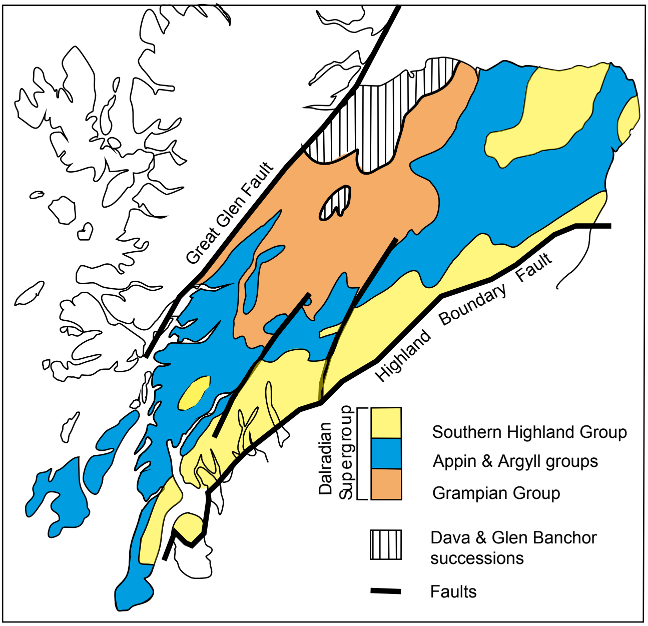

Figure 2 Lithostratigraphical divisions of the Scottish Dalradian succession.

with the development of complex rift basins marked by rapid deepening and sediment deposition. The thinned crust led to decompression and major volcanism along the Dalradian belt, the products of which are well seen on Farragon Hill and Ben Vrackie. Ultramafic bodies, possibly derived from the mantle, the presence of ultramafic detritus in many of the lithostratigraphical units, and the chemistry of the volcanic rocks all suggest there may have been actual local rupture of the crust at this time. Another indicator of these extreme conditions is the presence of stratabound exhalitive orebodies particularly within the Easdale Subgroup; for example, as found in the Foss barytes mine, near Aberfeldy. The top of the Argyll Group is marked by the dominance of coarse clastic turbidite fans, which characterise the succeeding *Southern Highland Group,* wherein individual lithostratigraphical units are difficult to distinguish and latterly discontinuous. It seems probable that the extreme crustal stretching and potential rupture characteristic of the Argyll Group ceased as a result of full scale rupture offshore from the Dalradian basin. Thus the marked change in sedimentation at the top of the Argyll Group represents the start of deposition on the foundering margin of the Laurentian continent, as it broke free. It is important to emphasise that rupture would have been complex in space and time with an almost certain ragged continental margin and the creation of several micro-continental bodies.

Current thinking regards the greater part of the Highland Border Complex as a contiguous part of the Dalradian succession and has ascribed it to a new group, the *Trossachs Group*. This unit consists of metamorphosed sandstones, limestones and black mudstones and represents deposition on the Laurentian margin as the Iapetus Ocean opened and eventually closed, marking the end of Dalradian sedimentation.

How old is the Dalradian

The age of the Dalradian succession is critical in interpreting regional events. The Dalradian has to be younger than its basement, elements of which have been dated at 815 Ma, and older than the Grampian tectontothermal event at *c*. 470 Ma. Direct radiometric and fossil evidence is limited and is summarised on Figure 3.

Recently a considerable effort has gone into establishing global glacial events. These are marked by the development of glacigenic deposits or tillites. These tillites may be correlated globally using, *inter alia*, the distinctive isotopic signature

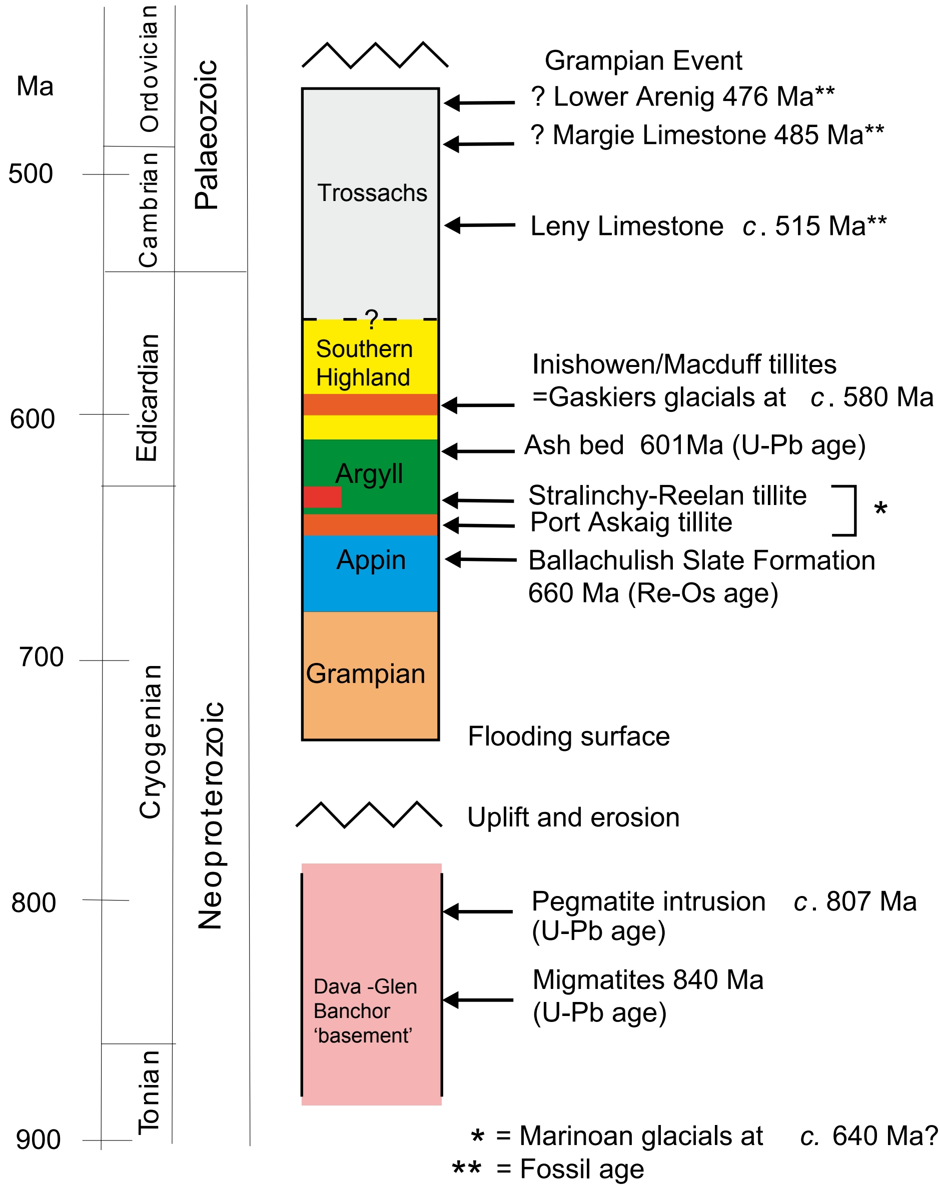

Figure 3 Dalradian stratigraphical section showing dated points.

of associated carbonates. Using radiometric or fossil evidence, these tillite/carbonate horizons may be dated and potentially provide global time planes. However, the necessary database is still incomplete, and so far the defined glacial events appear to comprise several phases and in some cases to extend over millions of years.

There are three tillite horizons in the Daradian succession. The best developed is the Port Askaig Tillite (and its correlatives), which lies at the base of the Argyll Group, above are the Stralinchy-Reelan formations in Donegal, which lie close to the base of the Easdale Subgroup (lower Argyll Goup), and finally the Macduff Boulder Bed (correlated with the Inishowen beds in Donegal), which lies within the Southern Highland Group. The Macduff unit has been correlated with the Gaskier global event at *c*. 580 Ma, consistent with the radiometric dates. The Port Askaig and Donegal units are fairly tightly constrained by the radiometric dates and are also stratigraphically close (Figure 3). As such it seems probable that both represent stages in the Marinoan global event at *c*. 640 Ma.

There is still considerable debate about these correlations and they have to be treated with caution. However, taking all the data together the best estimate is that Dalradian sedimentation lasted from *c*. 730 Ma to *c*. 470 Ma with the main rupture and break away of Laurentia around 630–620 Ma.

Final thoughts

As the global database increases so our understanding of the accretion and disruption of supercontinents and the processes involved develops. Discovering the position of the Dalradian in these bigger pictures maintains the fascination of this intriguing piece of Scottish geology.

Further reading (and references therein)

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Does Scotland have a golden future?

[Not a comment on independence, but a review of the nation's gold resources]

by Graham Smith

The existence of gold in Scottish rocks has been known for over 950 years. Adamson (1980) cites over 180 localities where gold was historically recorded, pre-eminent amongst which were those at Leadhills and in the Helmsdale River. Leadhills produced c. £500 000 worth of gold, including the source material for the present Scottish regalia, in the 16th and 17th centuries. Helmsdale was the site of Scotland's only gold rush in 1868–69 during which time around 400 'miners' produced over 3500 ozs. In both areas the metal was found in river gravels and like all the other historical occurrences had accumulated by alluvial processes. There were two unsubstantiated accounts of gold being traced to bedrock in the Leadhills area, but probably the first authenticated account of primary gold in Scotland was by Thost (1860) who reported up to 6 oz per ton of native gold in gossans in the Lochearnhead area. He also notes gold being discovered during crushing of the lead ore at the Corrie Buie Mines in Perthshire. Thereafter, although no visible gold was recorded, the metal was discovered in late 19th and early 20th century ore assays at a number of lead and copper mines and trials. These included Wood of Cree, Talnotry, Stronchuillin, Inverneil, Kilmartin, Castleton, Clachan Beag, McPhun's Cairn and Loch Duich. In the early 1960s, an assay of a grab sample taken from Halliday's Vein at Tyndrum recorded 122 g/t gold.

Modern gold exploration in Scotland commenced in the early 1980's, initially encouraged by advances in analytical technology, which effectively made detection more rapid and cost effective, thus enabling a greater throughput of material. This in turn, coupled with comparisons with overseas occurrences, led to a better understanding of which rock types might have the potential to contain economic grades of gold. Other early stimuli included the work of the British Geological Survey's (BGS) Mineral Reconnaissance Programme and the funding offered under the Government's

Mineral Exploration and Investment Grant Act. However, probably the greatest incentive came from the BGS's Regional Geochemical Survey Programme (now known as G-Base), which comprised a UK-wide collection and analysis of stream sediments. Although, G-Base does not routinely analyse for gold it does record where gold is noted in panned concentrates of the stream sediments. It also analyses concentrations of the 'pathfinder elements' antimony, arsenic and bismuth, so called because they frequently accompany gold. When incorporated into a GIS system the three plots can be superimposed and if they are assigned a primary colour then a white spot will result if all three are sufficiently concentrated, thereby identifying possible targets for gold exploration.

Establishing the likely bedrock source of alluvial gold grains is now aided by microchemical analysis, whereby the silver content and the geochemistry of inclusions within the grains is utilised. By this method it is possible to show that the Leadhills gold may have several sources. Some exploration targets are indentified by modelling through comparisons with deposits elsewhere in the world. For example, the discovery of the Gairloch and Cononish deposits was based on the initial premise that gold is often found in association with base metal sulphides such as pyrite, chalcopyrite and galena.

The Gairloch deposit is the oldest known gold concentration in Scotland, occurring within 2000–2200 ma Lewisian rocks of the Loch Maree Group in a volcanogenic, massive-sulphide-type deposit; native gold occurs along with pyrite and chalcopyrite in a sequence of metabasalts and metasediments. Gairloch was amongst the first of the deposits to be investigated in the modern era of exploration, the target being identified by comparisons with Precambrian massive sulphide deposits in Canada and Scandinavia and a literature reference to copper mineralisation in that area.

Subsequent investigations involved a wide range of targets in terms of age, rock type and geographical area, undertaken by both academic and commercial organisations and the BGS. These included: Dalradian-hosted deposits in Unst; porphyry-copper style mineralisation in Devonian intrusions, some sub-volcanic, at Lagalochan, Black Stockarton Moor, and Foreburn; igneous contact veinwork at Moorbrock Hill; and the Devonian cherthosted occurrence at Rhynie. The ground south of Loch Tay, has attracted considerable exploration interest mainly because of the unusually large number of small sulphide deposits These include the Calliachar vein suite, south-west of Aberfeldy, which along with the Cononish veins are the only occurrences currently being economically assessed.

The Calliachar suite comprises 14 north-west trending, sub-vertical quartz veins cutting Dalradian metasedimentary rocks. Although generally only a few cm wide, they locally contain significant gold concentrations. For example 1000 grams of gold were obtained from a 10 tonne bulk sample, some of which was used to produce a number of gold-plated replica James V 'bonnet pieces'. The upper few metres of many veins are deeply weathered and hence would be amenable to limited surface mining.

Cononish could be the first ever bedrock gold mine in Scotland. Its discovery was the result of some extremely innovative sleuthing by

The entrance to the exploratory adit at Cononish. ***BGS image P550931.***

***Inside the exploratory adit.** BGS image P001604.*

EGS member Richard Parker. Initially attracted to the Tyndrum area by the abundance of vein-hosted sulphides (although none of the structures other than Halliday's Vein had recorded gold), and aware that there were historical records of alluvial gold in the area, he panned up the Cononish River and discovered a mineralised boulder, which was eventually traced to a vein close to the former Eas Anie lead mine. Subsequent assessment, which included extensive drilling and driving a 0.9 km exploratory adit, concluded that the deposit had mineable reserves of 450 000 tonnes of rock grading 11 g/t gold and 60 g/t silver. A recent application to mine was turned down by Loch Lomond National Park Planning Board and a revised application is in preparation.

Modern exploration has thus demonstrated that Scotland has a number of small, but potentially mineable bedrock gold deposits. With the exception of Calliachar and Cononish most of the modern gold exploration in Scotland was undertaken by major international mining companies by who's standards the Scottish prospects would be regarded as very small beer. This, coupled with the significantly lower gold price of yesteryear might explain why they were never brought to fruition. It is possible then that some of these deposits could now be attractive to 'junior' mining companies, if the high gold price (currently about $1500 per oz) is maintained. However,

A sheared breccia vein in the Cononish mine. Gold occurs with pyrite and galena scattered through the host quartz.
BGS image P244649.

their development would have to contend with objections from the environmental lobby and with ever-burgeoning planning legislation, (especially if more designated areas such as National Parks are created); together, these constitute the greatest barrier to Scotland becoming a gold producing country.

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Book reviews

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