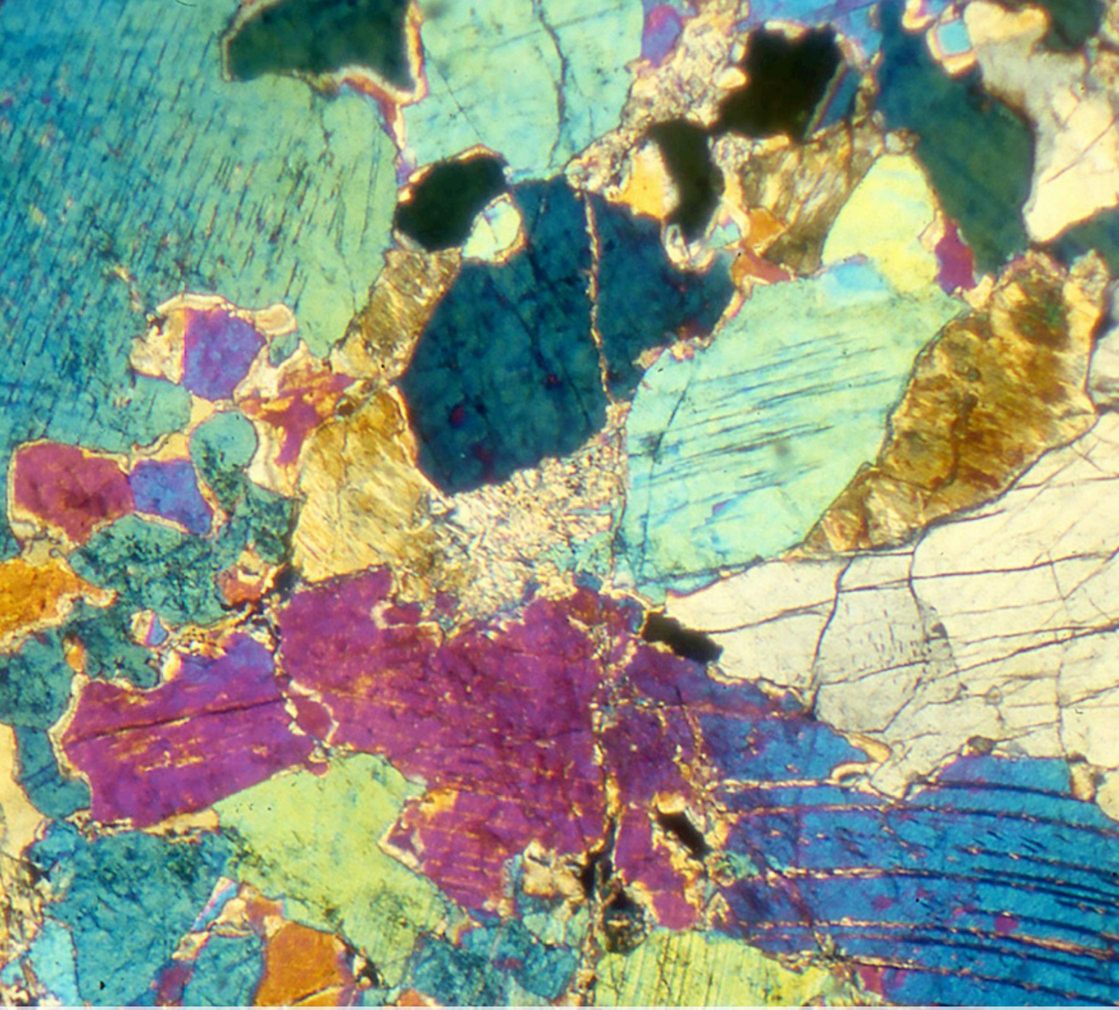

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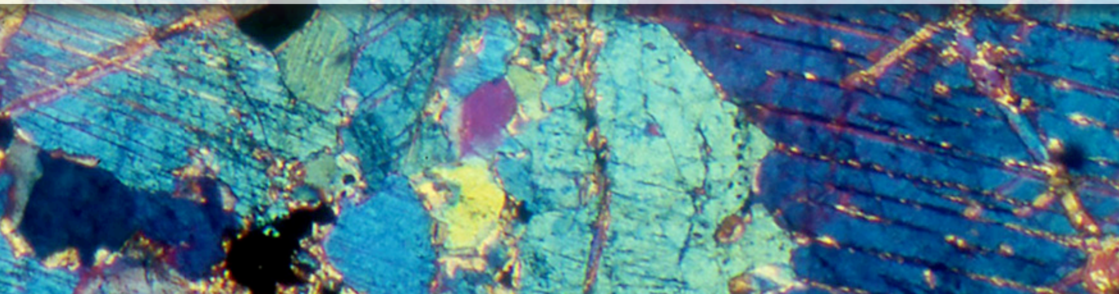

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Cover Illustration

An ultramafic pyroxenite from the Ballantrae Complex, SW Scotland, a relic of oceanic mantle seen here in thin section with crossed polarisers; the field of view measures about 2 mm by 3 mm. For more on the plate tectonic setting of the Ballantrae Complex see the article by Doug Fettes on page 14.

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The Edinburgh Geological Society was founded in 1834 with the twin aims of stimulating public interest in geology and advancing geological knowledge. We organise a programme of lectures and excursions and also publish leaflets and excursion guides. For more information about the Society and membership, please visit www.edinburghgeolsoc.org.

Ice, plates and tombstones

An editorial ramble by Phil Stone

Those of you who have been paying attention to *Scottish Journal of Geology* will know that I have been taking an interest in the activities of the 1902–1904 Scottish National Antarctic Expedition. You might also remember that the last issue of *The Edinburgh Geologist* anticipated some celebration of 'fifty years of plate tectonics', following the Geological Society of London's selection of last autumn to celebrate that anniversary. So, when Ian Dalziel offered an article for *EG* that contrived to combine both of those themes, how could I resist? Ian's account kicks off this issue of *EG*. It might contain bad news for the Scottish expedition's geographical legacy, but it ably demonstrates the way in which plate tectonics has liberated the geological imagination and encouraged contemplation of tectonic linkages—backed-up by extraordinary technical advances—that would undoubtedly have bemused our predecessors.

The selection of the anniversary year might seem a bit arbitrary given the way that the plate tectonics debate played-out in the late 1960s, but a rationale was provided in *Geoscientist*, **27**/11. To quote: "In December 1967, Dan McKenzie and Bob Parker published a paper in Nature—'The North Pacific: an example of tectonics on a sphere'. This paper, building on work by many other scientists in preceding years, was arguably the crucial final step in establishing the paradigm of plate tectonics, providing a unifying context for Earth science." So, there you have it, although I confess I've always hated the use of 'paradigm'!

It wasn't long before the new ideas were being applied to Scottish geology, and I'm pleased to see that a couple of John Dewey's seminal papers are given prominence by Doug Fettes in our second article, which continues the plate tectonics theme. Doug takes on the unenviable task of reviewing the impact of the new paradigm (ouch!) on the perceived relationships developed between the geological terranes of Scotland during the Grampian Orogeny. And if you thought that Scottish geology was all done and dusted post-plate tectonics, read on; the Highland Border Complex seems particularly reluctant to give up its secrets. On the other hand, it was an appreciation of long-established geological features that made the application of plate tectonic models possible in the first place. Whilst celebrating a 50th anniversary, let's not forget all that went before and made the whole thing work. Here's to basic data and the unsung pioneers who collected it all over the World.

Then what of those 'bemused predecessors'? What would the likes of James Hutton have made of it all? These days, in the cosmic microwave background we see a vestige of a big-bang-beginning, whilst the prospect of an end for planet Earth, eventually, is well established. But given the propensity of Hutton and his Enlightenment colleagues to 'follow the evidence', I like to think that they would have been right up there, at the forefront of the new developments. Either way, it's certainly hard to keep Hutton out of the pages of *EG*, although it's his great friend, the chemist Joseph Black—or at least Black's tombstone in Greyfriars—that features in Nina Morgan's article, our third, wherein we discover why Archibald Geikie spent so much time hanging around in graveyards. Picking-up on that thread of ideas, Andrew McMillan then chides those responsible for the neglect of Hutton's grave, close to Black's in the 'Covenanters' Prison'.

Two book reviews complete this issue of *EG*. No 'creative writing' is on offer this time, but all would-be authors out there should bear in mind the closing date for this year's 'Hugh Miller writing competion':15 April 2018. Alternatively, if you are fired-up by the ill-named paradigm's 50th anniversary, you might consider having a go at the

James Hutton (left) and Joseph Black—'Philosophers' by John Kay (1787). Reproduced by permission of Sheila Szatkowski from her book* Enlightenment Edinburgh—a guide *(Berlinn, 2017).

Geological Society of London's 'Plate Tectonic Stories' competition: see www.geolsoc.org.uk/tectonicstories, closing date is 30 April 2018. And something short and original for a future issue of *EG* might also be a good idea.

Thinking of Hugh Miller, a fine statue of him, about two-thirds life-size, stands in the sculpture balcony, high above the Grand Gallery in the National Museum of Scotland. He stands gazing at a freshly-split specimen of the armoured Devonian placoderm fish *Pterichthyodes milleri*, held in his left hand with the counterpart lying at his feet; his right hand grips a small geological hammer. So far, so good, but go around the back and, sad to say, the hammer has no handle. There's just an empty socket where one was once attached. Now, no field geologist, even when shrunk and set in stone, should be deprived of a functioning hammer, so I appeal to the museum management to put things to rights. A nice piece of hickory would not look amiss. Incidentally, a little further along the balcony is a bust of Charles Maclaren (1782–1866), a past-president of the Edinburgh Geological Society but perhaps better known as one of the founders of *The Scotsman* newspaper.

Finally, from a past-president to our new president, and welcome to Bob Gatliff who has taken over the Society reins from Stuart Monro. Bob has a background in marine and petroleum geology and geophysics with the British Geological Survey, but so far as I know has not established a media empire.

The statue of Hugh Miller by Amelia Paton Hill (c.1860s) in the National Museum of Scotland's sculpture collection. It stands about 1.15 m tall.

Did the Scottish National Antarctic Expedition discover a fragment of North America?

By Ian Dalziel

On the 2nd of November 1902 the members of the Scottish National Antarctic Expedition set sail from the Firth of Clyde on board their Steam Yacht *Scotia* bound, according to Expedition Leader Dr W S Bruce, for: "one of the least known parts of the South Polar Regions" …"While 'Science' was the talisman of the Expedition, 'Scotland' was emblazoned on its flag" (Bruce 1906, p. vii–viii; Fig.1). Almost due south, but over 14 000 km distant, *Scotia* was to reach the edge of the Antarctic continent on the eastern side of the Weddell Sea and make the first sighting of land there.

The Scottish National Antarctic Expedition conducted the bathymetric studies that linked the southernmost Andes to the Antarctic Peninsula through the arcuate Scotia Ridge enclosing the Scotia Sea (Bruce 1905; Fig. 2). Its members also undertook extensive geological and glaciological work on the South Orkney Islands and the Falkland Islands as well as

Fig. 1** SY* **Scotia** ***and expedition members, March 1904 while the vessel was beset in heavy pack ice at the most southerly point reached (74°1′S, 22°0′W). Glasgow Digital Library based at the University of Strathclyde.

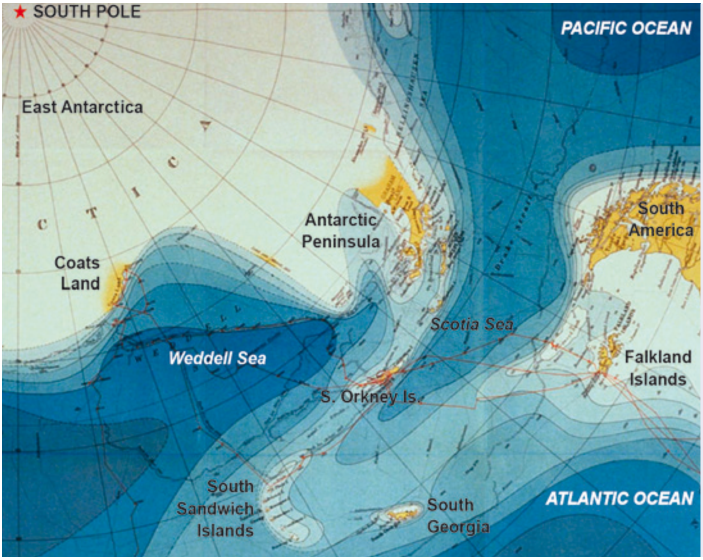

Fig. 2 "Bathymetric Survey of the South Atlantic Ocean and Weddell Sea" (Bruce, 1905), with place names superimposed by the author.

marine biological studies (see Stone 2017, and references therein). This contribution is concerned with the identification and potential significance of the ice-covered land that the Expedition discovered at the southeastern corner of the Weddell Sea. What exactly did they find?

After completing their early oceanographic work and a detailed geological survey of Laurie Island in the South Orkney Islands, *Scotia* headed into the Weddell Sea. Expedition geologist and surgeon Dr J H Harvey Pirie wrote: "We were once again southward bound – following the traditional policy of the inhabitants of Scotland…." (Pirie 1906, p. 231). As the expedition turned south into the Weddell Sea, however, it faced a challenge unknown to Scots bound only for England—ice. At 72 degrees 18 minutes South, 17 degrees 59 minutes West "we were brought up short", wrote Pirie. They had reached what is now known as the Riiser-Larsen Ice Shelf (Fig. 3), "a lofty ice-barrier similar to that discovered by Ross on the other side of the Pole: it stretched in a north-easterly and south-westerly direction" (Pirie 1906, p. 234–235). According to Pirie, Bruce believed that the coast line of Antarctica must run more or less continuously from there to Enderby Land (50–60 degrees East longitude) to account for the ice limits reached by Cook, Bellingshausen and others in their earlier explorations. We now know this to be correct.

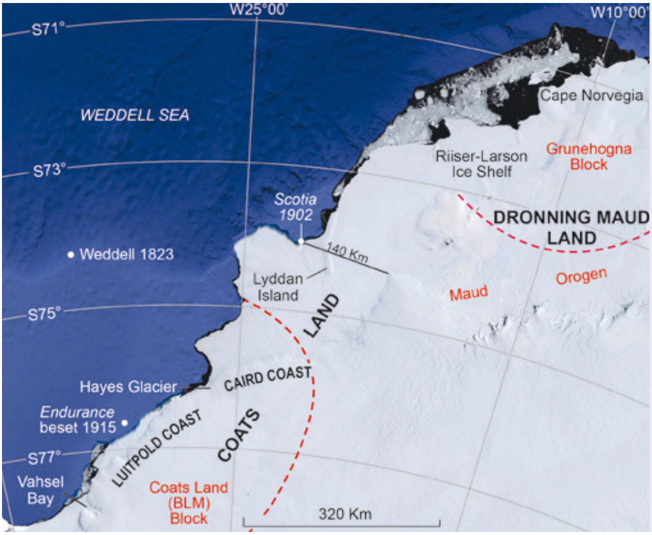

***Fig. 3** Eastern margin of the Weddell Sea showing* Scotia's *farthest south position in relation to Lyddan Island and the East Antarctic mainland. (Google Earth Pro). Tectonic boundaries and provinces mentioned in the text are shown in red.*

A few days later, *Scotia* was able to follow the shelf edge, 'the Barrier', about 150 miles south-west where the "Inland Ice … seemed to rise up very gradually in undulating slopes ...in one place there appeared to be the outline of distant hills." No 'naked rock' was visible, but a sounding of only 159 fathoms, 2.5 miles from the barrier, convinced the party that: "we were really off a new Antarctic land" (Fig. 3). Most critically the nature of ice-rafted boulders dredged in the vicinity seemed convincing evidence that any ice-covered land nearby was of 'continental character'. The dredge hauls included 'granites, schist, gneiss, quartzite, sandstone, slate and limestone' (see discussion in Stone 2017). The party was also impressed by the numerous birds and penguins in the area and hence of the likelihood of beaches and cliffs suitable for nesting in the proximity, noting that Anglo-Scottish explorer James Weddell had observed similar bird populations in 1823 near his then record 'southing' of 74°15´in the sea now bearing his name (Fig. 3).

They named their discovery 'Coats' Land', now simply Coats Land, in honour of their chief financial supporters, Mr James Coats Jr and Major Andrew Coats of the Paisley sewing cotton manufacturing family 'J and P Coats'. They left it for future explorers to determine whether they had discovered a large island, or part of the Antarctic mainland, and regarded the latter as more likely. However, plotting *Scotia's* southernmost position of 74° 01´

S, 22°00´W on a modern satellite map (Fig. 3) indicates that the land they saw was snow covered Lyddan Island, later named for topographic engineer W R Lyddan of the United States Geological Survey who plotted it from the air in 1967 (United States Board of Geographic Names 1995). The closest part of the East Antarctic mainland is over 140 km to the east across the island and the intervening ice shelf.

The weather took a turn for the worse with a north-east blizzard pressing pack ice against, and indeed beneath *Scotia's* hull. Pirie describes his night watches as 'dreich and eerie', an ambience perfectly captured by expedition artist William A Cuthbertson in his painting of the Coats Land margin from the vessel (Fig. 4). For several days the expedition had to contemplate and plan for the unwelcome possibility that the vessel might be trapped for the winter at its farthest south point, but at last the ice parted enough for *Scotia* to free herself, and she headed north for Gough Island, and eventually Cape Town, *en route* home to the Clyde.

Fig. 4 Portion of painting of the Coats Land margin of the Weddell Sea by expedition artist William A Cuthbertson. (National Museums Scotland).

It was German explorer Wilhelm Filchner who was to discover the only 'naked rock' in the region. This was in 1912 at his farthest south of ~77°55´S, 34°30´W at modern-day Vahsel Bay (see below) during the Second Deutsche Südpolar-Expedition aboard *Deutschland* (Filchner 1922; Fig. 3). Filchner named this most southerly land area along the eastern margin of the Weddell Sea the Prinz Regent Luitpold Land. Today the name Coats Land is generally applied to the land region extending from 20° to 36°W (United States Board of Geographic Names 1995), its southern coastal area being known as the Luitpold Coast with the Caird Coast to the north (Fig.3). The latter was named by Ernest Shackleton, after one of his sponsors, Dundee jute manufacturer

Sir James Caird, during his 1914-1915 voyage into the Weddell Sea prior to *Endurance* becoming beset and subsequently sunk by heavy pack ice. The exposed rock along the Luitpold Coast consists of three groups of small nunataks distributed near and around Vahsel Bay (Fig. 5), named for *Deutschland's* captain who died during the expedition. Moltke and Bertrab nunataks were named by Filchner after Prussian officials, the third group was left unnamed until it was visited by a United States helicopter-supported expedition in the late 1950's when it was named Littlewood Nunataks after a United States oceanographer. The three Bertrab Nunataks, four Littlewood Nunataks (Fig. 6) and two Moltke Nunataks, were referred to as the 'BLM' by Kleinschmidt and Boger (2009), who note that modern usage incorporates them into Coats Land despite some historical ambiguity. The Bertrab Nunataks form the foundation of the active Argentinian base 'Belgrano II'.

Fig. 6 The author orientating cores for palaeomagnetic study at Littlewood Nunataks. Note very gentle tilt of lava (~11°).

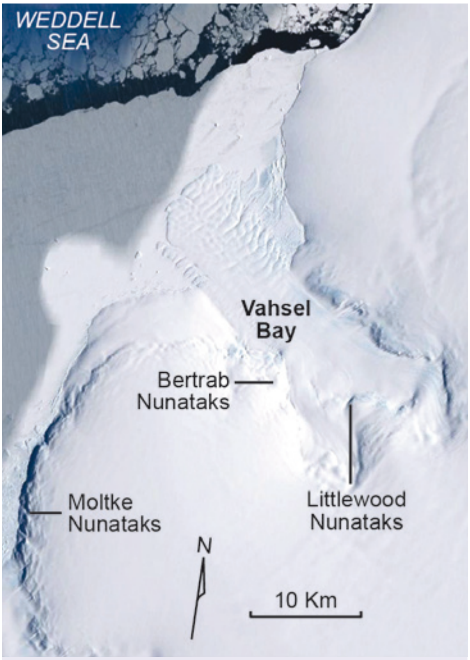

Fig. 5 Image of Vahsel Bay, Prinzregent-Luitpold Land (Coats Land) showing location of nunataks. (Google Earth Pro).

The Bertrab and Littlewood nunataks comprise fractured and gently tilted, but otherwise undeformed and unmetamorphosed, silicic igneous rocks; granophyre (Bertrab) and rhyolite (Littlewood; Fig. 6). Their chemistry indicates a likely 'postcollisional' or 'within-plate' origin (Kleinschmidt 2002; Kleinschmidt & Boger 2009).The Moltke Nunataks, only accessible beneath an ice fall at considerable risk, are described by Raina *et al*. (1995) as 'low-grade metamorphic limestone' and 'lithic arkose'. Aerial observations reveal open to tight folding and cleavage and suggest low grade metamorphism (Kleinschmidt & Boger 2009). Given the physiography of the Vahsel Bay area and the absence of deformation of the rocks forming the Littlewood and Bertrab nunataks, it seems likely that the low-grade metamorphic rocks exposed at the Moltke Nunataks form the basement to the silicic volcanic rocks. The latter have yielded U-Pb zircon ages of 1113+18/-4 Ma for rocks at Bertrab Nunataks and 1112±4 Ma for samples from Littlewood Nunataks, while a U-Pb titanite age of 1106 ±3 Ma was obtained from a rock at Bertrab (*Gose et al.* 1997).

In the past twenty-five years, many papers have been published on pre-Pangaea palaeogeography and the possible configuration of the Rodinia supercontinent that is widely believed to have amalgamated with the global-scale ca. 1.0 Ga Grenvillian orogeny. Although the proportion of Earth's continental crust involved is not clear, Rodinia would have existed until the opening of the Pacific Ocean basin at ca. 750 Ma led to the amalgamation of the cratons of East and West Gondwanaland at the end of the Precambrian along a Pan-African suture or sutures extending down the eastern side of Africa to the Transantarctic margin of East Antarctica (see for example Goodge *et al*. 2017; Jacobs *et al*. 2008). If Gondwanaland was attached to Laurentia at the time of its amalgamation in the latest Precambrian, another supercontinental configuration

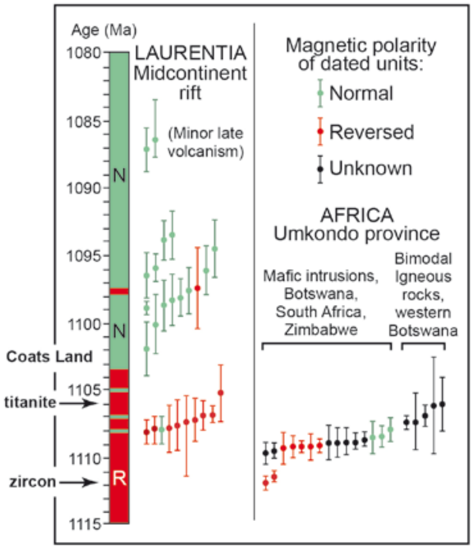

Fig. 7 Ages of Coats Land rocks and minerals with respect to those of Laurentian mid-continent rift (Keweenawan) and African Kalahari (Umkondo) large igneous provinces. (Vertical lines are error bars). Modified from Hanson et al. (2004).

may have briefly existed prior to the separation of Laurentia. This configuration has been referred to as Pannotia, the 'all southern' supercontinent (Powell *et al*. 1995; Dalziel 1997, 2013). Gose *et al*. (1997) and Loewy *et al*. (2011) have demonstrated that the silicic volcanic rocks exposed in the Littlewood and Bertrab nunataks are not only the same age, 1112–1106 Ma, as the older part of the Keweenawan large igneous province along the mid-continent rift system of Laurentia (Fig. 7) but also have the same Pb isotope composition. Moreover, the lead isotope composition of the Coats Land rocks differs markedly from that of the only other large igneous province of ca. 1.1 Ga, the Umkondo province of southern Africa.

The limestone exposed in the Moltke Nunataks is interpreted as having been deposited 'in a shallow-water environment, probably in the low energy area of the shallow shelf seas' (Raina *et al*. 1995). In the Franklin Mountains of west Texas, the Castner Marble dated at ca. 1260 Ma underlies the ca. 1.1 Ga volcanics associated with the mid-continent rift system and is cut by the associated Red Bluff Granite Suite (Pittenger *et al*. 1994). The marble is interpreted as having been deposited 'during a transgressive event on a low-energy carbonate ramp'. Limestones elsewhere along the present southern margin of Laurentian craton both to the east in Texas and to the west in Arizona are correlated with the Castner Marble and interpreted to have been deposited in a rift system formed ca. 1.4 Ga (Marsaglia 2002). Thus, while no dates are yet available for the limestones of Coats Land, their field relationship to the silicic volcanic rocks seems directly comparable to that of the southwestern United States Mesoproterozoic limestones and the magmatic rocks of the Keweenawan province.

A high quality, well dated palaeomagnetic pole for the Coats Land rocks (Gose *et al*. 1997) permits their having been close to the present day southern Laurentia (New Mexico and trans-Pecos Texas) at 1.1 Ga (Loewy *et al*. 2011). The exposed Coats Land rocks are part of an isolated geophysically defined crustal block separated from the Archaean-Palaeoproterozoic Grunehogna block of Dronning Maud Land, East Antarctica, part of the Archaean core of the Kalahari craton of Africa before Mesozoic opening of the southwest Indian Ocean, by the ca. 1.0 Ga 'Grenvillian' Maud orogen (Fig. 3). Thus, a former extension of present-day southern Laurentia (west Texas and New Mexico) seems to have been sutured to the

Fig. 8 Reconstruction for the early Cambrian by the author (Dalziel, 2014). Blue crescent schematically represents the seaway I suggest to have opened at that time between the already open palaeo-Pacific and opening Iapetus ocean basins, perhaps leading to the global Cambrian marine transgression. Gray overlay represents Laurentian Grenville and Antarctic Maud ~1.0 Ga orogens. Red colour shows positive gravity signature of Laurentian mid-continent rift system and 1.1 Ga Keweenawan large igneous province; the red star shows the position of the associated Red Bluff Granite Suite in the Franklin Mountains of western Texas. Laura Martin of the Jackson School of Geosciences designed the illustration.

Kalahari craton of Africa ca. 1.0 Ga and a reconstruction such as that of Figure 8 can be envisaged with the Grenvillian orogen of Laurentia continuing into the Maud orogen of Antarctica (Loewy *et al*. 2011; Dalziel 2014).

In conclusion, leaving aside the possibility that the Scottish expedition sighted Lyddan Island rather than the mainland of the East Antarctic craton, it is nonetheless possible that they did in fact discover land comprising a continuation of the type ~1.0 Ga Grenvillian orogen of present day eastern North America. It is the rocks cropping out to the southwest at Vahsel Bay discovered by *Deutschland's* party led by Wilhelm Filchner that hold the main clues to a possible Laurentian connection. The undeformed Mesoproterozoic volcanic rocks there are part of the Coats Land, or BLM, crustal block that may have been a fragment of the pre-Grenvillian Laurentian cratonic core.

This hypothesis obviously requires further study. Nonetheless the Scots' discovery of a continental land mass on the eastern side of the Weddell Sea has proved to be of considerable palaeogeographic significance, conceivably with a bearing on Earth history at a critical time for the development of life on the planet. The Cambrian 'explosion' of metazoan life is closely linked to a marine transgression. This may have been driven by the opening of an oceanic gateway between Laurentia and Gondwanaland that isolated the olenellid trilobite fauna of Laurentia from the redichliids of Gondwanaland (Dalziel 2014). Regardless of the validity of that additional hypothesis, it would indeed be fitting if a scientific party from Scotland, itself a tiny fragment of North America until separation a mere 55 million years ago (Fig. 8), discovered a far southern land that was a much earlier offspring of the same parent continent.

Acknowledgements
My work in the Antarctic over nearly five decades has been entirely supported by the United States Antarctic Program of the National Science Foundation, but my lifelong interest in palaeogeography was inspired by reading Arthur Holmes' classic book 'Principles of Physical Geology' as an undergraduate in The University of Edinburgh and by evening discussions following his retirement. My friend and former colleague Robert H Dott Jr, Emeritus Professor at The University of Wisconsin, Madison, was instrumental in my becoming involved in Antarctic geology, and I dedicate this short contribution to him. His ancestors were Scots.

This contribution benefited greatly from Phil Stone's editorial advice. The new illustrations were prepared by Jeffrey Horowitz.

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Plate Tectonics and the Grampian Orogeny

By Doug Fettes

Last year the geological world marked the 50th anniversary of the general acceptance of a viable mechanism for plate tectonics. Since that point plate tectonic models have become increasingly sophisticated and fundamental to our understanding of global-scale geological mechanisms. In parallel with these advances our understanding of the detailed sedimentological, structural and chronological history of the various component parts of the British and Irish Caledonides has grown dramatically. It is fascinating therefore to consider how these major developments have not only allowed us to stitch together the various regions of the 'British Caledonides' but have allowed credible correlations throughout the Caledonides chain from Scandinavia to the Appalachians. Although these broad correlations are now largely accepted the models for the development of the Scottish Caledonides have become ever more sophisticated and although a broad consensus now exists, there are still areas of uncertainty.

For the purposes of this short article the following definitions are used. The Caledonides refers to the orogenic zone generated between the Cambrian and Devonian periods at the junction of the Laurentian, Baltic and Avalonian continental plates following the opening and closure of the Iapetus Ocean. The term Grampian Orogeny (or Event) refers to the tectonic cycle in Scotland and Ireland during the Ordovician (Chew & Strachan 2014, Tanner 2014).

Early models

One of the first orogenic models was proposed by Dewey (1969, 1971). It argued that as Avalonia and Laurentia closed on each other, consuming the Iapetus Ocean, oceanic crust was subducted northward below the Midland Valley block producing a volcanic arc. Some of the oceanic crust escaped subduction and was instead obducted onto the Midland Valley block to form elements of the Ballantrae Complex. To the south, subduction of Iapetus oceanic crust below the margin of Avalonia produced the Borrowdale volcanic assemblage in the English Lake District. These early models regarded the Highlands and Midland Valley as an integrated block and assumed orthogonal movements. Phillips *et al*.

(1976) then produced a more extensive model that linked developments across the British Isles from the Ordovician to the Devonian and emphasised the role of oblique collisions in generating sinistral strike faults.

Subsequently, McKerrow *et al*. (1977, *inter alia*) produced a model to explain the Southern Uplands 'enigma', namely the series of steeply inclined fault-bounded tracts, that comprise the area and individually young to the north, but which become successively younger to the south. This phenomenon they explained in terms of an accretionary prism. That is, a thrust complex formed above a subduction zone that developed as slices of oceanic sediment (which younged upwards) were sequentially sheared off, thrust under earlier slices, and rotated towards the vertical (see also, Chew & Strachan, fig. 15).

During the following decades, although the broad elements of these

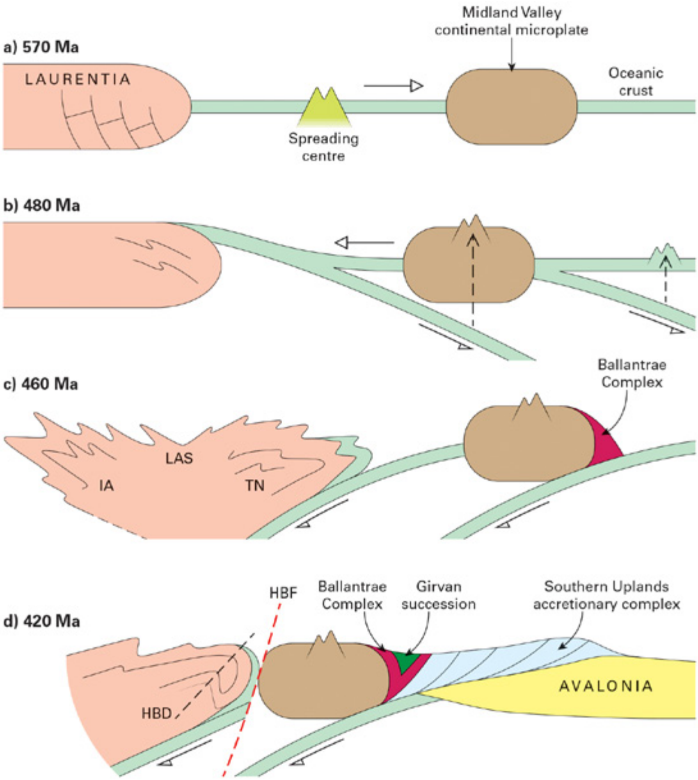

***Figure 1** A series of cartoons illustrating the possible development of the Grampian Orogeny (not to scale) based on Strachan (2000), Stone (2014), Chew & Strachan (2014) and Tanner (2014). HBD, Highland Border Downbend, HBF Highland Boundary Fault, IA, Islay Anticline, LAS, Loch Awe Syncline, TN Tay Nappe.*

early models remained, increasingly more sophisticated variations were proposed. These developments were driven by a vast amount of new geochronological, sedimentological and structural data as well as comparisons with analogues in Ireland and North America. It is beyond the scope of this short article to consider all of this work, but we can jump to our present understanding. However, before describing the current interpretation (illustrated by the series of sketches in Fig. 1) it is worth considering three areas that are critical to the tectonic models, namely, the major structures of the Grampian Highlands, the Highland Border Complex and the Ballantrae Complex.

The structure of the Grampian Highlands

As shown in Fig 1c, the present N-S structural profile of the area (that is between the Great Glen and Highland Border faults) is a fan shaped series of major nappes. The Tay Nappe and associated folds face south whereas the Islay Anticline and associated folds face north, the zone of divergence forming the Loch Awe Syncline. The nose of the Tay Nappe is bent down and overturned along the Highland Border. Another significant feature is the along-strike change in metamorphic character, from the Barrovian-style zone (intermediate pressure metamorphism) in the centre and southwest to the Buchan-style zone (low pressure and relatively high temperature metamorphism) in the northeast. Also, the relatively high heat flow in Buchan is associated with the intrusion of significant gabbroic and granitic suites.

The Highland Border Complex

The Highland Border Complex (HBC) is exposed as a series of outcrops along the Highland Boundary Fault. It comprises a variety of metasediments (arenites, siltstones, limestones) and ophiolitic lenses (metamorphosed oceanic crust), all now steeply inclined in the Highland Boundary Downbend (Fig.1d). The status of the complex has been the subject of considerable research and debate. Central to this debate was the relative age of the metasediments to the Dalradian succession and its structural sequence. There have been proposals (e.g. Bluck 2010) that the metasediments postdate, and have a distinctive history from, the Dalradian succession. However, there is strong evidence that the metasediments are in structural continuity with the Dalradian and, in the absence of confirmed palaeontological evidence to the contrary, there is probably a consensus that the metasediments constitute the highest unit of the Dalradian succession (designated the Trossachs Group by Tanner & Sutherland 2007) and as such share the same structural history. The ophiolitic rocks are believed to have been obducted on to the metasediments, possibly producing thermal effects (Henderson & Robertson, 1982, Tanner & Sutherland 2007)

The Ballantrae Complex

The Ballantrae Complex lies on the Ayrshire coast south of Girvan. It is bounded to the south by the Southern Upland Fault. The complex consists of a wide variety of ophiolitic rock types but also includes basalts derived from oceanic arcs and within-plate volcanic centres as well as gabbro and granitic units. At the simplest level the complex is presumed to be composed of a sequence of rocks derived from a range of oceanic settings and obducted onto or compressed against the Midland Valley block in the mid-Ordovician as the Iapetus Ocean closed (Fig. 1c). Stone (2014) suggested that the complex now occupies a fault zone on the north side of the Southern Upland Fault and that some of the rock units have been brought together within the fault zone through both substantial vertical and horizontal movements

The plate tectonic model

The Caledonides were initiated as the supercontinent of Rodinia broke up in the Neoproterozoic and specifically when the continents of Laurentia, Baltica and Amazonia drifted apart creating the Iapetus Ocean. Present-day Scotland lay at the margin of Laurentia and as the area (probably composed of Moine and Lewisian rocks) was stretched it developed as a series of fault-controlled rifts (Fig. 1a). The sedimentary infilling of these rifts formed the Dalradian succession. Variations in the rate of subsidence are reflected in the sedimentary facies with possible major rifting near the centre of the basin allowing eruption of the Tayvallich and related lavas. It is important to emphasise that the continental split would not have been a clean break but was most probably marked by a ragged edge with small microcontinental masses breaking free.

One such block now forms the basement of the present Midland Valley. As this block drifted off, an oceanic basin opened between it and the main Laurentian edge (Fig 1a). This situation persisted until the early Ordovician when the relative movements of the continents had changed and Avalonia moved towards Laurentia, effectively consuming the Iapetus Ocean. As a result, the Midland Valley block reversed direction effectively closing the Highland Border basin (Fig 1b). Oceanic sediments and crust were obducted onto the top of the Laurentian continent, compressing the Dalradian sequence and initiating the development of the nappe structures. At this stage it is possible there was also subduction of oceanic crust southwards below the Midland Valley block (Tanner 2014) leading to the development of a volcanic arc there (Fig. 1b). South from the Midland Valley intra-ocean subduction led to the development of a series of volcanic arcs (see Stone 2014, fig 3) which ultimately provided constituents of the Ballantrae Complex.

Subsequently at about 460 Ma, there was a probable double subduction flip as northwards subduction developed below both Laurentia and the Midland Valley block (Fig. 1c). It was this northward subduction and compression of the Dalradian sequence which led to the development of the major nappe complex, with underthrusting effectively causing the Tay Nappe to overturn and flatten towards the south. At the same time, the pressure of the northwards underthrusting pushed the more northerly nappes upwards and outwards to form the present fanned profile (Fig. 1c, Tanner 2014, figs 18,19).

Dewey *et al.* (2015) and Tanner (2014) suggested that a spreading centre in the Highland Border basin was subducted below the Buchan region effectively providing a heat source for the distinctive features of that region. However, this explanation does not explain the lower degrees of deformation in Buchan and it is possible the variations relate to a degree of oblique collision or subduction (Fettes 2013). To the south, the final closure of the Highland Border basin resulted in a collision between the Midland Valley block and Laurentia (Fig. 1d). This deformed the nose of the Tay nappe downwards to produce the Highland Border Downbend (HBD) and brought the youngest Dalradian down to form the HBC (Tanner 2014).

Meanwhile at about 430 Ma the Baltica continental plate had closed on Laurentia (Chew & Strachan, 2014, fig. 1) resulting in the Scandian deformation in northern and western Scotland which included the obduction of the Shetland ophiolite. The marked absence of Scandian effects in the Grampian Highlands led Dewey *et al*. (2015) to propose a displacement of 500 km on the Great Glen Fault, effectively distancing the areas of Scandian influence from the Grampian region

However, when considering the events and processes outlined above, it is important to remember that ocean closure and plate collision were not simple affairs. On a regional scale, the Laurentian margin would have been ragged and convergence of the microplates, volcanic arcs, etc would have been complex and locally oblique. In this scenario it is easy to conceive of major strike faults in association with the Highland Border and Ballantrae complexes, as well as the development of major sinistral faults in the Highlands.

Further, it has not been possible in this short article to discuss properly the immense amount of work and data that underpins the models described above, nor is it possible to discuss all the alternative proposals. However, the models cited are hopefully close to a consensus. Hopefully also they give an indication of the huge steps which have been taken in understanding the plate tectonic evolution of the Grampian Orogeny as we reflect on the 50th anniversary.

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Cemetery Science: Archibald Geikie's scientific sideline

By Nina Morgan

Archibald Geikie [1835–1924] cut his geological teeth with studies in Edinburgh and the Hebrides, and in the 1860s worked with Roderick Murchison [1792–1871] to untangle the complex geology of the Northwest Highlands. Geikie led the Geological Survey in Scotland from 1867 to 1882, and although the Murchison-Geikie interpretation was debunked in the 1880s, he moved to London in 1882 as the Survey's overall Director-General, a post he held until his retirement in 1901. In 1913, he moved to Haslemere, Surrey where he served as Chairman of the Haslemere Educational Museum from 1914 until his death in 1924.

Sir Archibald Geikie, 1835–1924. BGS image P255071.

Geikie also had many other strings to his bow. He was a gifted writer and published a number of textbooks. But to the public at large he was perhaps best known for his readable and popular books about geology. A review of the second edition of his *Scenery of Scotland*, which appeared in *The Spectator* magazine in 1888, praised his writing skills above his scientific talent:

"Dr Geikie is perhaps the most agreeable writer on geology now left to us. When his *Scenery of Scotland* originally appeared, in 1865, it had a distinct success, less perhaps in virtue of the scientific theory it expressed and exemplified, than of its picturesque descriptions, in which the ring of the geologist's hammer had the accent of poetry, somewhat perhaps as the drone of the bagpipe is positively musical when heard a sufficient number of miles off."

But along with the landscape in *Scenery of Scotland* Geikie also described a simple methodology for monitoring and studying weathering in building stones. In Chapter 2 he noted:

"Nowhere can the nature of weathering be more conveniently and instructively studied than upon ancient masonry, and notably among the gravestones of a churchyard. Originally as they left the hands of the mason, the stones of a wall or slabs and pillars of a monument were smoothly dressed, or even polished. We can, therefore, compare their present with their original condition, and mark the nature and amount of the disintegration they have suffered. Moreover, when the dates of their erection are preserved, we obtain from them a measure of the rate of waste."

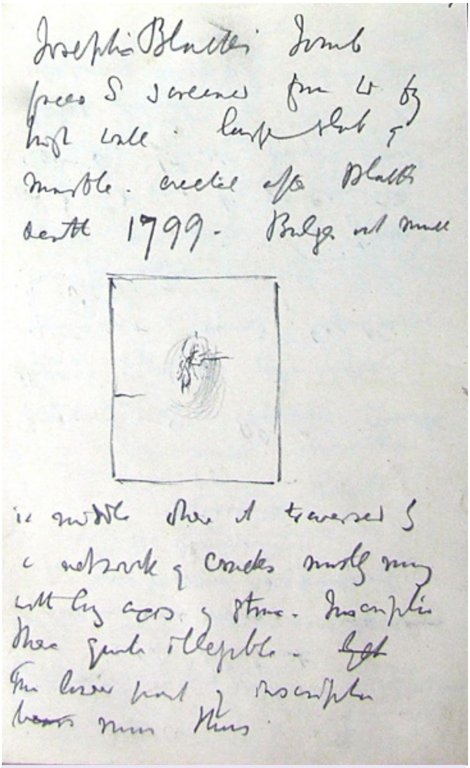
It was a simple idea, but a very powerful one—and it fit in very well with his professional field work. As he recalled in his autobiography, *A Long Life's Work*:

"In the course of my journeys all over Scotland there was always an interest in examining the tombstones in graveyards, first for the light which they so often thrown upon the families that have lived for generations in a district... and next for the valuable and unexpected information which they frequently afford as to the manner and rate of decay which various kinds of stone, employed for monumental purposes, suffer from the disintegration effects of the atmosphere."

Geikie's geological fascination with graveyards was inspired after reading about experiments conducted in the 1870s by the German geologist and professor of mineralogy at the University of Erlangen, Germany, Friedrich Pfaff, and designed to precisely measure the effects of weathering on a range of rock types. Geikie first published the results of his gravestone studies in 1880 in a communication entitled *Rock-weathering, as illustrated in Edinburgh churchyards (Proceedings of the Royal Society of Edinburgh*, **10**, 518–532 and Plate XVI). He also summarised his gravestone work in his more popular publications. For example, in his popular book *Geological Sketches at Home and Abroad* (1892), Geikie devoted a whole chapter to a description of his gravestone work.

His observations on weathering in gravestones soon led him to conclude that acid rain—essentially carbonic acid (H_2CO_3) formed when carbon dioxide (CO_2) emitted from the burning of coal was dissolved in rain water—was a major culprit. The effects, he noted, were especially obvious on marble, a stone often chosen for high status graves. As an illustration, he cites the degradation of the gravestone in Greyfriars churchyard in Edinburgh honouring the chemist Joseph Black, who died in 1799.

"This sumptuous tombstone," Geikie noted in *A Long Life's Work* (1924), "consisted of a solid framework of



A page from Geikie's field notebook with his observations about Joseph Black's grave (Courtesy of Haslemere Educational Museum).

hard siliceous sandstone into which a large upright slab of white marble had been firmly fastened, recording in Latin, with pious reverence, the genius and achievements of the discoverer of Carbonic Acid, and Latent Heat, and adding that his friends wished to mark his resting place by the marble while it should last."

No doubt those well-meaning, but perhaps chemically illiterate, friends imagined the marble would last a lot longer than it did. When Geikie visited Black's grave in 1879, less than 80 years after it had been erected, he noted that the inscription on the marble was becoming illegible, and worse:

"...The slab, still firmly held in place by the metal fastenings all round its margin, had bulged out considerably in the centre, forming a large blister-like expansion, which had been rent by numerous cracks."

By 1894 the marble had crumbled so badly that the Town Council of Edinburgh was forced to replace it with a slab of what Geikie described as a "far more durable sandstone on which the original epitaph had been carefully copied."

But perhaps because his observations of badly weathered sandstone gravestones demonstrated that many types of sandstone were also very vulnerable to the effects of weathering, Geikie decided to risk using granite—then a relatively novel material for tombstones—for his own family's gravestones. This in spite of his observation in his 1880 paper that 'granite has been employed for too short a time as a monumental stone in our cemeteries to afford any ready means of measuring even approximately its rate of weathering'.

Joseph Black's tombstone as it appears today in Greyfriars cemetery.

The gravestone commemorating his wife, Alice Gabrielle Pignatel, (died 1916) and his son, Roderick Geikie (died 1910), which is located in Brookwood Cemetery in Surrey is made of smoothed but unpolished granite, possibly from Scotland. The inscription in white lettering, is still clearly visible more than 100 years later. Although it is not known whether he chose the stone for it himself, Geikie's own gravestone in the Derby Road Cemetery in Haslemere, is also made of granite with a smooth, but unpolished surface. The slightly pink or orange tinge to the stone suggests that the feldspar in this granite may be a potassium-rich variety, and may have come from the granite quarry at Peterhead in Aberdeenshire.

Measurements of the effects of weathering in gravestones continues to play an important role in studies of rock weathering and stone conservation. The results of these studies are now being applied by conservation organisations including Historic Scotland.

Thanks to modern methods of transport, a wide range of stone types is readily available for a wide range of uses, including in cemeteries. As a result, gravestones—which could be considered as easily accessible giant hand specimens—are also now playing an important role in the teaching of geology and in science outreach aimed at the general public. Given Geikie's great interest in science communication and talent for popular writing about geology, surely he would be pleased with this outcome.

Nina Morgan is a geologist and science writer based near Oxford and co-author, with Philip Powell, of *The Geology of Oxford* Gravestones (copies available from www.gravestonegeology.uk). The pair often lead gravestone geology walks based on the book, and so far have opened the eyes of more than 300 people to the wonders of gravestone geology.

The state of Hutton's memorial in Greyfriars Kirkyard

By Andrew McMillan

Nina Morgan relates Archibald Geikie's discussion of the fate of the original marble tombstone commemorating James Hutton's great friend Joseph Black (1728–1799). This stood almost opposite the Balfour lair, Hutton's own final resting place, in the Covenanters' Prison, Greyfriars Kirkyard. Hutton died in his house at St John's Hill on 26th March 1797. At the approach of the 150th anniversary of his death in 1947, his grave was unmarked although recent research by Beverly Bergman has established that a record of monumental inscriptions at Greyfriars published in 1867 (Brown, J. *The Epitaphs and Monumental Inscriptions in Greyfriars Churchyard, Edinburgh*. Edinburgh 1867) contains details of an earlier memorial to him. A committee established by the Royal Society of Edinburgh in conjunction with the Royal Physical Society, the Edinburgh Geological Society, the Geological Society of Glasgow and H.M. Geological Survey (Scotland) established a fund to organise an appropriate commemoration of the sesquicentenary of Hutton's death. As part of these events, the then Lord Provost, Sir John Falconer, unveiled a small polished grey granite panel commemorating Hutton as the Founder of Modern Geology.

Recently, I accompanied Beverly Bergman and Christine Thompson on a visit to examine the physical state of the memorial to James Hutton. Our attention had been drawn by one of the Kirkyard guides to the fact that his memorial was in a poor state.

At the time of our visit, the lead lettering on the panel was discoloured (probably owing to the development of lead carbonate) although the letters themselves were intact and in good condition. The panel displayed a small amount of algal growth. In contrast the adjacent sandstone memorial to the Balfour family, related to James Hutton through his mother, Sarah, is in a parlous state. The left-hand sandstone tablet has come loose from the wall and probably presents a safety hazard to anyone going up to Hutton's memorial. The carved stonework above it is extremely loose. The centre sandstone tablet shows signs of water penetration and efflorescence. There is a spout which projects through the wall immediately above the Balfour monument, which is undoubtedly leading to water running down the monument in wet weather. It comes through the wall from the vicinity of the old TA Drill Hall. There is extensive vegetation around the lair, including *Buddleia* which is forcing the stones of the walls apart.

Attempts are currently being made to discover who would be responsible for carrying out remedial work on the memorial stones and re-positioning the water spout to take drainage water away from the lair. As always, maintenance of monuments and buildings is crucial. But as the dear late Norman Butcher was once heard to comment on a geological excursion about some crumbling building: '…… another example of Man's puny attempts to compete with nature."

In that respect, and further to Nina Morgan's article, it is worth recalling Geikie's eloquent comment in the 3rd (and best) edition of his volume *The Scenery of Scotland* (1901): "As I examined the marble of [Black's] tomb and its Latin inscription that records the genius of the discoverer of carbonic acid, I could not but reflect on the curious irony of Nature, that has furnished in the corrosion of this monument her own testimony to the truth of his discovery." At least the replacement sandstone tomb (1894) for Joseph Black, although needing some attention, is in reasonable condition.

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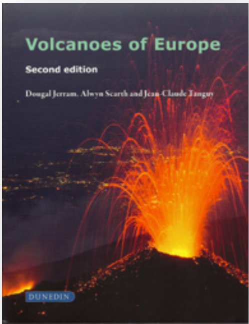
The Balfour Lair in the 'Covenanters' Prison', Greyfriars Kirkyard. Hutton's memorial plaque is set on the wall to the left.

Book reviews

Volcanoes of Europe (2nd edition) by Dougal Jerram, Alwyn Scarth and Jean-Claude Tanguy. Dunedin Academic Press, Edinburgh. 2017. 278 pp. Hardback, Price £60, ISBN 978-1-78046-054-3. Paperback, Price £29.99, ISBN 978-1-78046-042-0.



This highly attractive, superbly illustrated book provides a comprehensive review of 'European' volcanoes that have been active in the past 10000 years. It includes all active and dormant volcanoes and some that can probably be regarded as extinct. 'Europe' is meant in a political rather than a geographical sense and hence includes oceanic islands of the North Atlantic and the Mid-Atlantic Ridge. Tectonically, most occurrences do lie on the Eurasian Plate, though the Canary Islands are on the African Plate and half of Iceland and the two most westerly Azores are on the North American Plate.

The first edition, by Scarth and Tanguy in 2001, has been expanded, revised and updated by Dougal Jerram to incorporate modern research and the latest eruptions, with many new colour illustrations throughout. The target readership is student, amateur and professional Earth scientists and I think it fulfils that admirably. The descriptions concentrate upon physical volcanology and environmental aspects in the context of the history of civilization and man's interaction with and recording of eruptions. Technical jargon is kept to a minimum and, although the products of each eruption are described comprehensively in modern petrographical terms, complex petrological discussions are avoided. The result is a very clear, enjoyable text that is a joy to read.

The introductory chapter has sections on rock types, magma generation, types of volcano, types of eruption, large igneous provinces, plumbing systems and the overall tectonic setting of the 'European' volcanoes. The explanations and discussion in the text are very clear and generally hit the right level, though I feel that the section on rock nomenclature could have done with a little expansion. Some accompanying figures (figs. 1.3A and the melting diagrams in

1.4), adapted from other sources, lack explanation and hence confuse rather than enhance. But overall the chapter does set the scene very effectively and whets the appetite for what is to come and that can only be described as exemplary.

The main chapters work systematically through Italy (Etna and Stromboli are almost continuously active), Greece (last onshore eruption 1950), Spain (i.e. Canary Islands, last onshore eruption 1971), Portugal (i.e. Azores, last onshore eruption 1958), Iceland (last eruption 2015), France (Massif Central, last eruption 7600 years ago) and Germany (Eifel, last eruption 10 000 years ago, fumeroles continuing). By virtue of Jan Mayen Island (last eruption 1985) and Loki's Castle, a recently discovered submarine vent field, both in Norwegian waters on the North Atlantic Ridge, Norway also qualifies for inclusion. Offshore eruptions are also described, with latest examples in the Straits of Sicily (2000), the southern Aegean Sea (1650), The Canary Islands (2012), the Azores (1999) and the Vestmann Islands (1963).

An attractive and highly effective feature is the use of boxes with background colour to highlight details of notable historical eruptions and, in a novel digression, interviews with present-day volcanologists, the latter under the heading 'Meet the Scientist'.

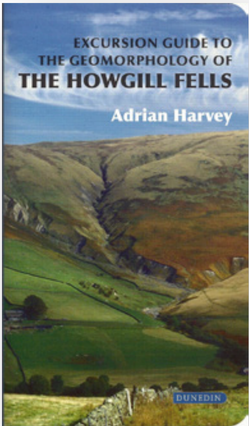
Although, appropriately, there are no references in the text, there is a very comprehensive Bibliography. There is also a Glossary, which is generally very good, especially on volcanological terminology, but which could maybe have utilised more-systematic petrographical definitions of rock names, which tend to rely more upon geochemistry. There is a 'Vocabulary' of non-English volcanological terms used in the text and, in a most-useful reference facility, a chronological list of 'Eruptions in Europe in historical times'.

The overall design and layout is excellent, with text, illustrations and boxes all tightly integrated. Editing and production errors are few, my only serious gripe being the small size of the maps of Etna and the Chaine des Puys, which are almost unreadable. Such attractive and important documents well merit larger reproduction.

Ironically, I received the invitation to review this book whilst on a Geologists' Association tour of Italian volcanoes, but I did not see it until after I had returned home. It summarises and illustrates beautifully all that we saw on that trip but how I wish that I had had it earlier and I know that this is a volume that I will dip into again and again.

David Stephenson

Excursion Guide to the Geomorphology of the Howgill Fells
by Adrian Harvey. Dunedin Academic Press, Edinburgh. 2017. Paperback, 118pp. Price £14.99. ISBN 978-1-78046-070-3



This recently published book forms the latest in an irregular series of field guides to classical areas of European geology and geomorphology. In northern England, the location of the Howgill Fells has led to this area being overlooked, squeezed as it is between the more popular Lake District and the Yorkshire Dales. This neglect of the Howgill Fells is unfortunate as the landscape is distinctly different from these two other areas. Whilst the Howgill Fells are related to the Lake District with respect to bedrock geology, they show a much gentler topography which reflects a different geomorphological evolution that is related to the glacial history of northern England.

The book is divided into two parts; the three chapters of the first part give a general overview of background geology and geomorphology and attempt to place the Howgill Fells into a regional context. These should be important chapters, as the present landscape can only be interpreted by understanding the nature of the underlying bedrock and response to changing external climate forcing mechanisms at a number of temporal scales. As such, present upland British landscapes usually show clear evidence of the operation of glacial events. In contrast, the Howgills owe their distinctive topography to minimal glacial activity and show a notable non-glacial topography which may reflect location under a passive ice divide and the operation of cold climate periglacial processes during deglaciation. To this geomorphic evidence must be added the overall understanding of former environmental conditions from palaeoclimatic proxy records. As the author readily admits (p. 112) long timescale research is not his main interest and these chapters (1&2) are somewhat general and poorly structured in comparison to the detailed informative background chapter on present day geomorphology (3).

With this final chapter of Part 1, the guide changes level dramatically reflecting the high quality geomorphic research that has been undertaken by the author over a long career. This provides an excellent review of the main topic—the nature of slope-channel coupling to understanding the present geomorphic system operating within the Howgill Fells. The chapter clearly explains Late Holocene landscape dynamics, demonstrating the importance of specific rainfall events to trigger high magnitude geomorphic landscape change, particularly over the last forty years.

The second part of the excursion guide begins with an overall chapter (4) that takes the reader on a circular reconnaissance road trip to a number of viewpoints that show off the Howgills landscape to good effect. Sensible instructions about fieldwork in this remote area of few roads are provided with caution being stressed regarding high river flows. The next three chapters (3–7) get you out of the car and on with your boots and take you to different parts of the Howgills and up a number of the deeply incised stream valleys to examine specific geomorphic situations—in each of these valleys the main landforms and sediment sections are described in exceptional detail allowing appreciation of the landscapes. Here, the text is enhanced by high quality images and superb maps illustrating the geomorphic changes that have occurred over the monitoring period. The final chapter (8) is brief but provides an interesting reflection on a long research career in this area, directing questions to topics about the Howgill Fells with respect to other British uplands and showing that much work still needs to be done on this topic.

Overall this excursion guide deals with the important but specific geomorphic aspects of gully development and channel response to specific externally triggered meteorological events. This is done to a high research standard which is only spoilt by a poor synthesis of published background palaeo-environment research on northern England. That aside, if you want to understand the Howgills landscape, this is an excellent guide to help your appreciation.

Wishart Mitchell

Both books reviewed above are published by Dunedin Academic Press, and we have another of their recent books still available for review: *Coal Mining in the East Neuk of Fife* by John McManus. Any volunteers?

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