

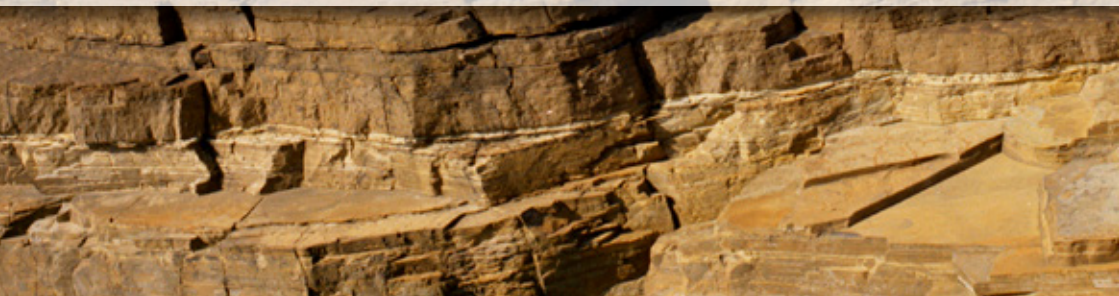


# **The Edinburgh Geologist**

**Magazine of the Edinburgh Geological Society**

Issue No 64

Autumn 2018





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### ***Cover Illustration***

The cliffs at Yesnaby, Mainland Orkney, cut into the Devonian Yesnaby Sandstone Group. BGS image P000624. For some palaeontological curiosities from a different part the Orkney Old Red Sandstone, see David Leather's article on page 20.

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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](http://www.edinburghgeolsoc.org).

# Rewarding geology, Scottish islands, and odd palaeontological furniture

*An editorial ramble by Phil Stone*

Over the past few decades there has been dramatic growth in our knowledge of Scotland's offshore geology as the technical prowess of the hydrocarbon industry has been applied to exploration for oil and gas. This kind of geology is far removed from the experiences of most of us but the Society's current president, Bob Gatliff, has spent many years at the forefront of offshore geological investigations. For our first article for this issue of *The Edinburgh Geologist* Bob has provided some background to his career with the British Geological Survey and provides us with some insight into what goes on, geologically, 'offshore'.

It's a small step from offshore geological exploration to the confirmation of sea-floor spreading and hence to the reality of plate tectonics. An even smaller step from there reaches Arthur Holmes, and as a follow-up to our focus on 'Fifty Years of Plate Tectonics' in EG63 Gilbert Kelling provides, as our second article, some reminiscences of Holmes' teaching at Edinburgh University in the 1950s. Gilbert

notes that one of the prestigious awards bestowed on Holmes was the Vetlesen Prize which, given its status as the earth science's 'Nobel' is not nearly as well known as it deserves.

Georg Unger Vetlesen (1889–1955) was a Norwegian marine engineer involved in ship building in the United States of America. He served as a commander in the U.S. Navy during World War II, assigned to Special Forces headquarters in London to work with the Norwegian resistance; later he became president and chairman of the U.S. company representing the Norwegian-American shipping line, and then the chairman of the board of Scandinavian Airline Systems (SAS).

His Foundation was established in 1955, shortly before Vetlesen's death, with the Vetlesen Prize then inaugurated in 1959. It is awarded biennially for scientific achievement resulting in a clearer understanding of the Earth, its history, or its relations to the universe and is administered by Columbia University's Lamont-Doherty Earth Observatory (City

of New York). The prize consists of a cash award of \$250 000 and a medal. Holmes was honoured in 1964. In a slightly ironic association, his immediate predecessor had been the geophysicist Sir Harold Jeffreys—identified by Gilbert Kelling as one of the principal villains of the continental drift controversy who adamantly opposed the idea on mechanistic grounds. I suspect that Holmes would have found that order of succession rather satisfying, Jeffreys perhaps less so.



### *The Vetlesen Medal.*

For our next two articles we move back onshore—or at least onto Scottish islands. First, Bob Gooday describes the history of geological research on the isle of Arran and brings it up to date with an account

of recent research findings. Arran presents something of a microcosm of Scottish geology (including the original ‘Hutton’s Unconformity’) and many of us will have enjoyed what it has to offer so Bob’s fresh insights—which have been supported by a Clough Award from EGS—are very welcome. Our second foray into Scottish geology is provided by David Leather who takes us to Orkney, to the Devonian Rousay Formation on the island of Westray and into the slightly murky palaeontology of fish coprolites—fossilised faecal pellets. David shows what can be done with a modern assessment, but when thinking of the early days of coprolite research the name that immediately comes to mind is that of the famously eccentric English geologist, William Buckland (1784–1856).

Buckland’s interest had focussed on ichthyosaur coprolites from the Jurassic strata of the Dorset coast at Lyme Regis, and he drew conclusions on the diet of the animals from the presence of crushed bone and bits of belemnite. One outcome of Buckland’s fascination with fossilised excrement was the construction of an extraordinary ornamental table displaying an inlaid panel in which were set about sixty polished coprolitic nodules. The table is now in the collection of the Lyme Regis Museum



and from the museum's website you can download a full account of its history<sup>1</sup> by Richard Bull—to whom, together with museum director David Tucker, I'm indebted for permission to use the pictures.

For many years it was thought that the table's coprolites had been sourced from the Lyme Regis area, but detective-work by Richard Bull, assisted by EGS member Mike Taylor and Edinburgh antique furniture specialist Murdo McLeod, has proved otherwise. Buckland's coprolites actually came from Edinburgh, from the Carboniferous Wardie Shales outcrop on the shore of the Firth of Forth between Granton and Leith. Buckland had been in Edinburgh for the 1834 meeting of the British Association for the Advancement

of Science and later he described collecting coprolites whilst there. The following extract from Buckland's 1836 *Bridgewater Treatise* is taken from Richard Bull's article:

"Mr W C Trevelyan recognised Coprolites in the centre of nodules of clay ironstone, that he found in a low cliff composed of shale, belonging to the coal formation at Newhaven, near Leith. I visited the spot, with this gentleman and Lord Greenock, in September 1834 and found these nodules strewn so thickly upon the shore, that a few minutes allowed me to collect more specimens than I could carry. Many of these contained a fossil fish, or a fragment of a plant, but the greater number had at their nucleus, a Coprolite, exhibiting an internal spiral structure: they were probably

derived from voracious fishes, whose bones are found in the same stratum. These nodules take a beautiful polish and have been applied by the lapidaries of Edinburgh to make tables, letter presses,



***Buckland's coprolite table-top courtesy of Lyme Regis Museum. The inlay panel containing the cut and polished nodules measures 44 cm by 59 cm.***

and ladies ornaments under the name of Beetle stones from their supposed insect origin.”

I wonder if the ladies of Edinburgh realised what they were wearing. The ‘supposed insect origin’ of the ‘[b]eetle stones’ derived from the appearance of the nodules in cross-section. The coprolites are encased in a coating of sideritic mudstone that has been split by septarian cracks that give the impression of legs. Although the Wardie area has been much developed since 1834, and the shale exposure much reduced, it is still possible to collect coprolite nodules at low tide.

Another name from the early history of British geological research, Adam Sedgwick, features in one of the two book reviews that complete this issue of *EG*. One book, by Graham Park, attempts an ambitious geological review of the world’s mountain belts. The second, a facsimile edition of Colin Speakman’s 1982 biography of Sedgwick (1785–1873) is well timed to commemorate the bicentenary of Sedgwick’s appointment as Woodwardian Professor at the University of Cambridge, from which position he became a dominating force in British geology. Speakman’s



***A selection of coprolite nodules collected recently at Wardie by Richard Bull. The largest nodule is about 13 cm long.***

book also provides an unexpected connection with the Edinburgh Geological Society through its dedication to Arthur Raistrick (1896–1991) who, in 1938, became only the second recipient of the Clough Medal. That award would have most probably been made on the basis of Raistrick’s work on coal palynology but his life was difficult; it took some extraordinary and unfortunate turns and eventually he was forced away from geology and into industrial archaeology. The biography by John Marshall in *Geological Society of London Special Publications* **241** (2005) is well worth a look—but only after you have finished reading *Edinburgh Geologist*.

Note 1.

[www.lymeregismuseum.co.uk/related-article/bucklands-coprolite-table/](http://www.lymeregismuseum.co.uk/related-article/bucklands-coprolite-table/)

# An introduction

*By Bob Gatliff, Edinburgh Geological Society President, 2018–2019*

It was in early 1981, five years after I had joined the British Geological Survey (BGS) in the same week that the new office in Keyworth opened, that I was reassigned to the new Hydrocarbons Unit, which was then operating in Grange Terrace, Edinburgh. This was an exciting time, with a young group of enthusiastic geologists working together to provide independent advice for the then Department of Energy on the oil industry activity on the United Kingdom Continental Shelf. I soon joined the Edinburgh Geological Society and am now honoured to be serving a term as the Society's president. Over the past few months I've been able to get to know more of our tremendous membership and look forward to that process continuing.

As an undergraduate, just about my only experience of seismic data was collecting refraction data with a sledge hammer in the Parks in Oxford, and my previous BGS experience had been with the sand and gravel resources of East Anglia and the Carboniferous limestones in Derbyshire. But from 1981 it was

almost entirely seismic interpretation, with coloured pencils and manual matching of the seismic to well logs. One early project with the 'West of Shetlands' team led to publication of the first example of sequence stratigraphy and seismic imaging of the submerged Erlend Igneous Centre (Gatliff *et al*, 1984).

From 1988–1990 I was lucky enough to be posted to Tonga, to promote hydrocarbon exploration in the fore-arc basin. Then, on return to Edinburgh, I worked on the first computer-based seismic interpretation systems and contributed to the regional offshore report series (Gatliff *et al* 1994) and the BGS offshore mapping programme, which was recognised by the Edinburgh Geological Society by the award of the 1993–4 Clough Medal to John Hull on behalf of the Marine Geoscience team. We continued to explore the geology of the deeper waters of Rockall and Hatton and developed a series of collaborative projects with consortia of oil companies. One highlight was taking a drill ship to the Hatton Bank and recovering core from a dipping sequence buried by around

20 m of Holocene sediments on top of the ridge.

In 2003, I was appointed to lead the BGS Marine and Petroleum Programme and we developed a new strategy based on multibeam data to drive the next generation of more detailed mapping. This led to the purchase of a small coastal survey vessel and we now work closely with Marine Scotland, CEFAS (Centre for Environment, Fisheries and Aquaculture Science), JNCC (Joint Nature Conservation Committee), the Crown Estate and others to provide new analyses to underpin the definition and monitoring of marine protected areas and other aspects of marine spatial planning. A key part of the current programme is working with the offshore wind industry and this is leading to a step change in our understanding of the Quaternary of the North Sea.

Since 2004, BGS has led the ECORD (European Consortium for Ocean Research Drilling) Science Operator team and together with partners, we have organised a series of IODP expeditions. These include the first deep scientific Arctic drilling, the use of robotic seafloor drills (on the Atlantis Massif) and a jack-up to core the Chicxulub meteorite impact crater (as featured on BBC *Horizon* and in *Edinburgh Geologist* No. 60).



***The BGS coastal survey vessel White Ribbon passing under the Forth Railway Bridge. BGS image P741057.***

It is now two years since BGS moved out of Murchison House and into its new home at the Lyell Centre, on the Heriot-Watt University campus at Riccarton. In addition to the main office and laboratories, the BGS RD2 robotic drill, which can operate in up to 4000 m water depth, is housed in the adjacent Sir George Bruce Building, which provides better engineering facilities than we have ever enjoyed before. The new facilities will help to keep Edinburgh as a global centre for geoscience and I am delighted to have seen this move through successfully. Now, after more than 40 years at BGS, it seems like a good time to retire and focus on the Edinburgh Geological Society.

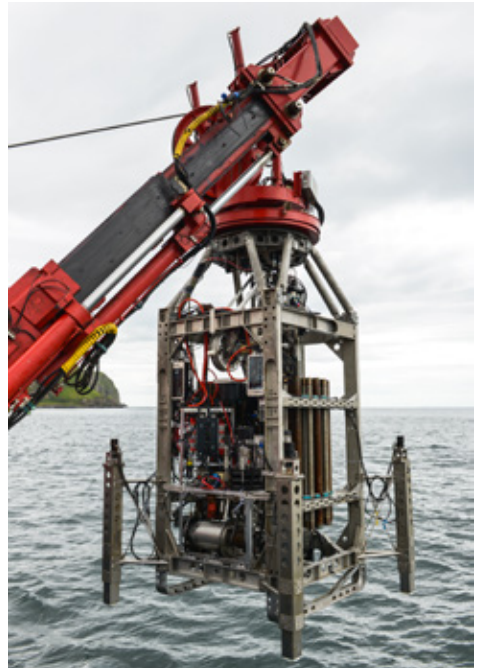
The success of the Society depends on an active membership and an enthusiastic and dynamic Council.



I am lucky to take over with the Society in excellent shape. Each member of the Council is making a valuable contribution, and together we are now well into our 5 year strategy. Having the professional help of Angus Miller and such an active Council is building success and raising the profile of the Society with our members, academia, the public, industry and government bodies.

Perhaps one area where we might do something different is to try to raise the profile of geology at a Scottish level. There are some big issues such as the decline of oil and gas production, potential for carbon capture and storage, new interest in geothermal energy, and impacts of climate change and sea level rise. Perhaps national academic conferences on some of these issues, run in collaboration with our sister geoscience groups would go some way to raising the profile of geoscience. They could lead to special editions of the *Scottish Journal of Geology*. I think it is important to reaffirm the contribution that the Scottish geology community makes in Scotland, the United Kingdom and around the World.

Bob Gatliff,  
[president@edinburghgeolsoc.org](mailto:president@edinburghgeolsoc.org)



***Deploying the RD2 sea-floor robotic drill. Photograph by Mike Wilson, BGS.***

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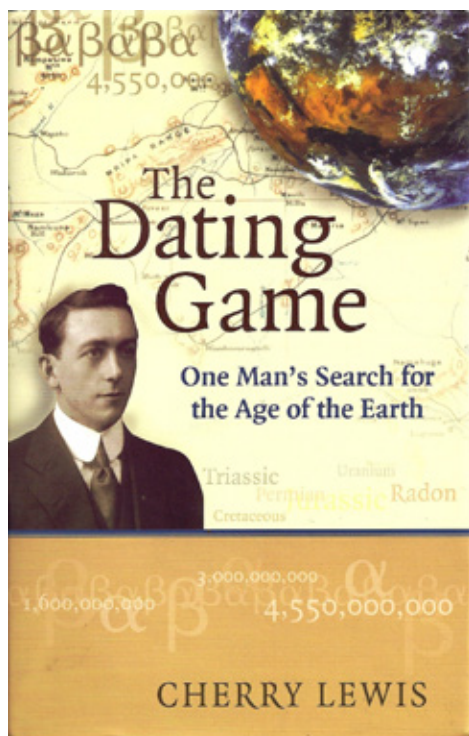
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## Arthur Holmes and Continental Drift: some personal recollections

By Gilbert Kelling

Arthur Holmes' early and perceptive involvement in the continental drift debate has, in my view, still not received the credit that his intervention deserves. His seminal contributions to radiometric dating have been recognised in some measure (including Fellowship of the Royal Society, the Vetlesen Award and other prestigious Medals, and Cherry Lewis' 2000 biography *The Dating Game*), but the pivotal role he played in inculcating a more 'mobilistic' mind-set in the 20<sup>th</sup> century earth-science community has yet to be adequately documented and acknowledged. The monumental 4-volume history of *The Continental Drift Controversy* by Henry Frankel (2012, Cambridge University Press) certainly went some way towards redressing the balance, although I believe it still underplayed the role of Sir Harold Jeffreys and some fellow geophysicists in stifling proper geological evaluation of the hypothesis in the UK for a couple of decades.

I first encountered Arthur Holmes, figuratively speaking, in Fountainbridge Public Library,



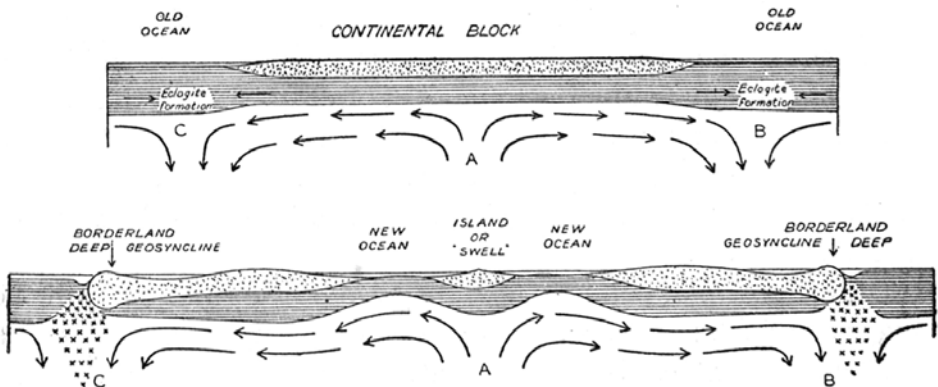
Edinburgh. Still a schoolboy, I was fascinated by 'stones, fossils and things' and a near-neighbour, Col. L Merson Davies (ex Indian Army), an accomplished micropalaeontologist, suggested that I should read Holmes' textbook *Principles of Physical Geology*, published just a few years earlier, in 1944. Like many another,

delving into the *Principles* I found myself captivated by the facts and concepts he revealed in such a readable style. I was particularly struck by Holmes' portrayal of a mobile and ever-changing planet, but one marked by order and organisation at every level, from mineral-forming molecules to the mighty mountain chains traversing continents. Moreover, he was the Professor in EDINBURGH University!

A couple of years later I enrolled at Edinburgh University for a degree course in Geology with Chemistry. In those days we geologists were denied exposure to our chosen subject until we had completed a first-year apprenticeship in cognate sciences (in my case, chemistry, physics,

mathematics and zoology). Thus, it was not until our second year of study that we could experience the great man's exposition, and it was well worth the wait! Holmes' lecturing style was like the man himself—quiet, clear and impeccably ordered—the ideal pattern for the committed note-taker. He used illustrations (lantern-slides) liberally and effectively, while the blackboard was usually replete with tables and diagrams before the start of each lecture.

Holmes taught almost all the First Year Introductory Geology course for science students and my notes indicate that he touched on most of the topics covered in the first edition of his textbook but deviated slightly in the order of treatment. He discussed



**Holmes' original figure illustrating mantle convection as the driving force of continental drift as published in *Transactions of the Geological Society of Glasgow*, 1931 (for 1928-29), volume 18, p. 579. A slightly more sophisticated version of the figure appeared in the *Principles of Physical Geology* (1944, 1965).**

mountain building and the nature and causes of volcanicity relatively early in the course and it ended with a discourse on earthquakes and their causes. More significantly, the only reference to continental drift in my notes is an aside in lecture 3, dealing with the distribution of continents and oceans and the possibility of mantle convection!

In my second year of Geology (1953–54), Holmes offered a 10-lecture course entitled ‘Radioactivity and Geological Time’. This introduced us to the methods and outcomes of the dating methods he had pioneered and included some exciting practical sessions where we undertook age-calculations using analytical data he had obtained, using mineral suites from a wide range of rocks across the globe. To be involved, even at second-hand, with determining the age of the then-oldest known minerals (monazites in Archaean rocks from Southern Rhodesia—2650 my), was a highly stimulating experience! Equally significant, in retrospect, was Holmes’ casual remark concerning the calibration of the Phanerozoic time-scale, which in 1954 he asserted was based on just 5 radiometrically dated fixed points (2 of which were stratigraphically debatable!). I also vividly recall the remark with which ‘the Prof.’ closed a lecture dealing with the age of the Earth, referring to

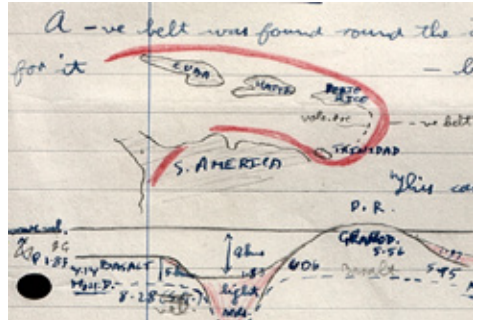
his ongoing debate with Sir Harold Jeffreys on this topic: “The beginning of the world is clearly getting older every year and may continue to age for some time yet.”<sup>1</sup>

In the summer of 1954, prior to entering my Final Year, I was chosen as the Edinburgh University representative on the famous ‘Students’ Geological Tour’ organised by the Geological Society of London and funded by Shell and BP oil-companies. This Tour brought together students from around 25 British universities and we were taken on a 4-week marathon ‘geo-fest’, visiting important geological localities around mainland Britain. Apart from intellectual indigestion, my abiding memory of this trip was the astonishment and dismay I felt on realising that my Department was regarded by most of my fellow-trippers as a hotbed of geological heresy, because of the notions of continental drift advanced by Holmes in *Principles*, coupled with the espousal of wholesale *granitisation* then being championed by his wife, Doris Reynolds. I was baffled by this strident opposition to continental drift, when the geological and palaeontological evidence seemed so powerful to me. However, when I tried to persuade my fellows of this, the invariable retort was to demand of me what mechanism could possibly



accomplish this break-up and re-arrangement of the Earth's crust?

Of course, this was a question that Holmes himself was striving to address at that time, as became clear in his Final Year course devoted to 'The Crust of the Earth'. Here he revealed, modified and amplified many of the concepts and ideas expressed in the last few chapters of his *Principles*. For example, from my notes it seems that by now he had rejected the model of a universal basaltic layer forming much of the crust and was convinced that there were distinct compositional and genetic differences between 'oceanic' and 'continental/plateau' basalts. He also cited the recently discovered Benioff zones of the Pacific rim as evidence for underthrusting of oceanic crust beneath the continents. Moreover, he qualified the definition of continental sial, as presented in *Principles*, emphasizing that the 'granitic layer' recognised by seismologists was dominated by 'basement complexes', representing highly folded and metamorphosed ancient orogenic belts that had been incorporated into the continents over many aeons. In this course Holmes also introduced us to the pioneering geophysical work of several 'continental' workers, such as the Austrian Oscar Rehm and the Dutch group headed by Felix Vening-Meinesz, now recognised as pioneers in marine geophysics and



***A fragment of my notes taken during one of Holmes' lectures in which he discussed the origin of volcanic island arcs, integrating the latest geophysical results.***

seismology—and in the concept of a mobile earth.

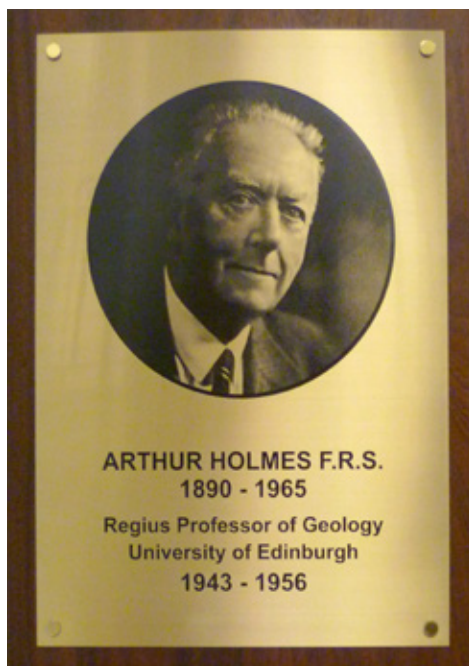
During my final year I became seduced by sediments and decided to attempt research for a PhD based on a study of the Lower Palaeozoic turbidites in the Scottish Southern Uplands, under the supervision of Ken Walton, then a recently appointed lecturer in sedimentology. As a result of Ken's advocacy, Holmes offered me the chance to become an Assistant in the Department. This was then the bottom rung on the academic ladder, with responsibilities mainly concerned with the running of practical classes for First Year students, together with some lectures and field classes for Arts students, who at Edinburgh in that era were required to undertake an elementary science class. I accepted

this offer with alacrity, not least because the stipend was 25% higher than a standard DSIR (governmental) research studentship!

So, for the next year, until he retired in 1956, I was technically required to report to Arthur Holmes about teaching dilemmas that included the vexed question of how much we could reveal to our tyro-charges about Continental Drift, the Earth Contraction Hypothesis, etc. In practice, Holmes (by this time an ill man) delegated these advisory and supervisory roles to his junior staff, and when Fred (later Sir Frederick) Stewart was appointed to succeed Holmes as Regius Professor—thus maintaining the ‘Durham connection’—he was happy for his Assistants to continue to exercise a large degree of autonomy in carrying out these duties.

Despite the significant teaching load, combined with commitment to my PhD research, the three years that I spent as an Assistant in Edinburgh were very enjoyable and rewarding, working in a lively Department with congenial colleagues who were fully committed both to teaching and research. This is testimony to the outstanding legacy bequeathed by Arthur Holmes.

Gilbert Kelling  
Edinburgh University 1951–1958  
Latterly Professor of Geology at Keele University



***The memorial plaque to Professor Arthur Holmes that now graces the main staircase in the Grant Institute of Earth Sciences, University of Edinburgh.***

Note 1 ... A quotation expressing a very similar sentiment appears on the front dust-cover of *The Dating Game* (on the fold-in flap) and is attributed to Holmes (1964). Then, on page 234, it is repeated as having been part of Holmes’ response to the presentation of the Vetlesen Medal:

“Looking back it is a slight consolation for the disabilities of growing old to notice that the Earth has grown older much more rapidly than I have—from about six thousand years when I was ten, to four or five billion years by the time I reached sixty.”

# Arran's volcanic past— classic geology and new ideas

*By Bob Goody*

The Isle of Arran, in the Firth of Clyde on the west coast of Scotland, has been a training ground, laboratory, and site of pilgrimage for many geologists for over two centuries. For such a small area, the island has spectacular and incredibly diverse geology—most of which is beautifully exposed and easily accessible. Many of the concepts upon which modern geological reasoning is based were tested and refined on the island. It is easy to think that with so many brilliant geologists having visited the island in the past, the work is all but done! But with recent advances in understanding, there will always be new ways to look at classic localities and make new deductions about the processes occurring so far back in the geological past.

## **Arran's half-billion-year story**

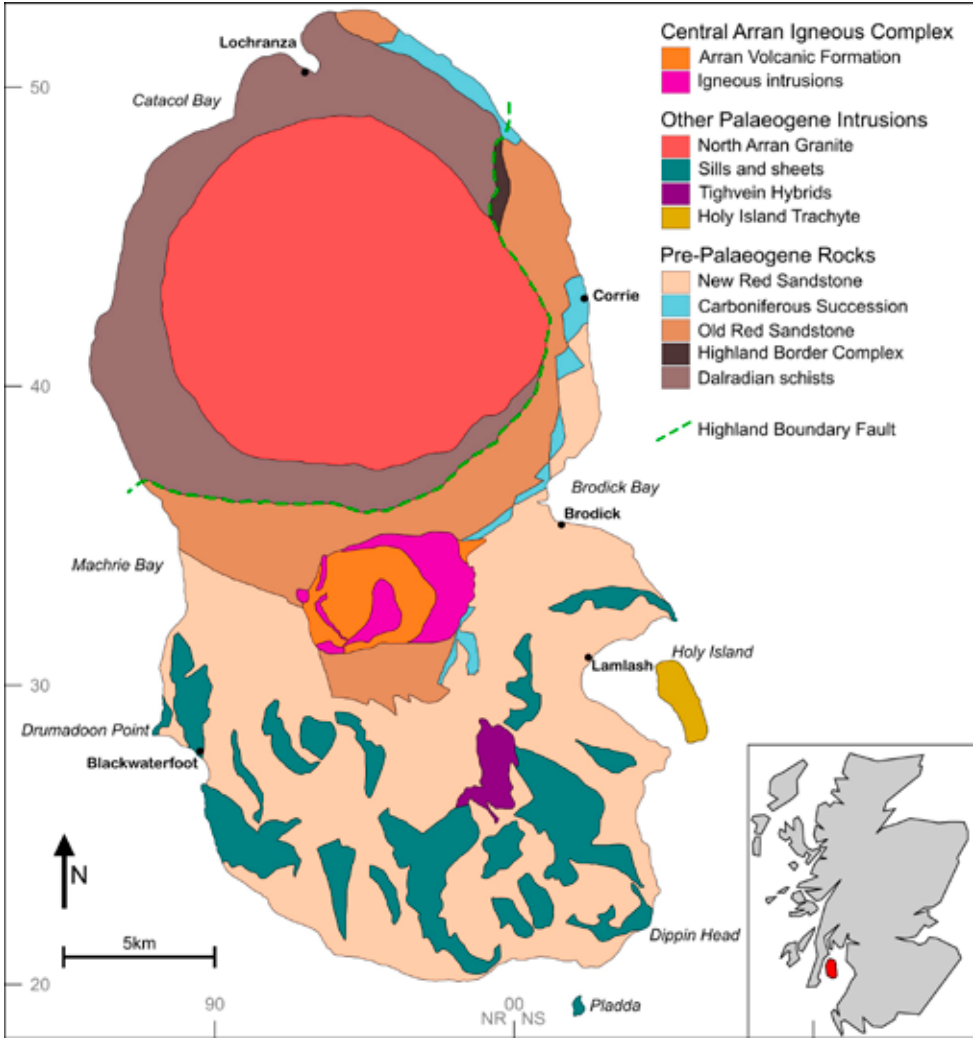
The oldest rocks on Arran are the Dalradian schists (Fig. 1), which were deposited on the seafloor around 540 million years ago (Ma) and subsequently deformed and metamorphosed during the Caledonian Orogeny, towards the end of which the northern and southern parts of the British Isles collided (as parts of, respectively, Laurentia and Avalonia).

During the Upper Palaeozoic (419–252 Ma), Arran moved north across the equator, as shown by the sandwich of desert-environment rocks (the Old and New Red Sandstones) with the intervening tropical sea and coal-swamp sediments of the Carboniferous Succession (Fig. 1).

Around 60 Ma, during the Palaeogene, Europe and North America began to rift apart as the North Atlantic Ocean opened. This thinned the crust, allowing a great amount of magmatism and volcanic activity, the products of which are preserved throughout the western parts of Scotland. The Palaeogene igneous rocks on Arran include the mountainous North Arran Granite in the north, a series of intrusive sills around the south, and the volcanic rocks of the Central Arran Igneous Complex in the centre of the island (Fig. 1). It is this Central Arran Igneous Complex which has been the focus of our recent research.

## **Arran—a cradle of geological understanding**

In 1787, Arran was visited by Edinburgh geologist James Hutton.



**Figure 1** *Geological map of Arran, after BGS 1987.*

He was trying to understand the nature of granite, and igneous rocks in general. The thought at the time was that all rocks had been formed in the sea or, according

to theologians, the Biblical Flood. Hutton was looking for evidence that granite had formed from molten rock within the Earth and had squeezed its way into the surrounding rocks.



He found this evidence in several places on the island but was not quite finished with Arran. At the extreme northern tip of the island, he noted that gently dipping sedimentary rocks lay on a surface of steeply dipping metamorphic rocks (Fig. 2). This unconformity showed Hutton that a huge amount of geological time must have passed between the formation of these two units. He realised that the Earth was incredibly ancient—much older than the 6000 years suggested by religious doctrine—an idea confirmed in 1788 when he discovered the Siccar Point unconformity in Berwickshire.

Around a hundred years after Hutton's visit, the British Geological Survey sent geologists to start the systematic mapping of Arran. A large part of the work was done by Archibald Geike, Ben Peach, and William Gunn, and the 'One-inch Geo-



**Figure 2** *Hutton's Unconformity at Newton Point near Lochranza.*

logical Map of Arran' was published in 1910 (its modern counterpart at 1:50 000 was published in 1987). The detailed petrographic work for the Geological Survey's Arran Memoir was published by George Tyrrell (of Glasgow University) in 1928, with a contribution from Alfred Harker (of Cambridge University). Along with the work done around the same time on Mull and Skye, these publications provided detailed observations and modern theories on how magmatic and volcanic systems behaved, from the chemistry of their magmas, to the physical processes of intrusion and eruption. These ideas laid the foundations for all subsequent study of active and ancient volcanic provinces.

The presence of a volcanic complex in central Arran was first documented by Gunn, who stated that this "*focus of great volcanic activity*" was "*exceptionally gigantic in its proportions*" (Gunn *et al.*, 1901); we would today call a volcanic system of this size a 'caldera'. He recognised that the complex was made up partly of fragmented explosive material and partly of intrusive granitic rocks. It was Tyrrell who classified the system as "*a ring complex of the Mull type*", by which he meant that the volcanic system was almost totally encircled by a granitic 'ring dyke', much like the Loch Bà ring intrusion that the previously mentioned geologists, along

with Sir Edward Bailey, had described from Mull (Bailey *et al.*, 1924).

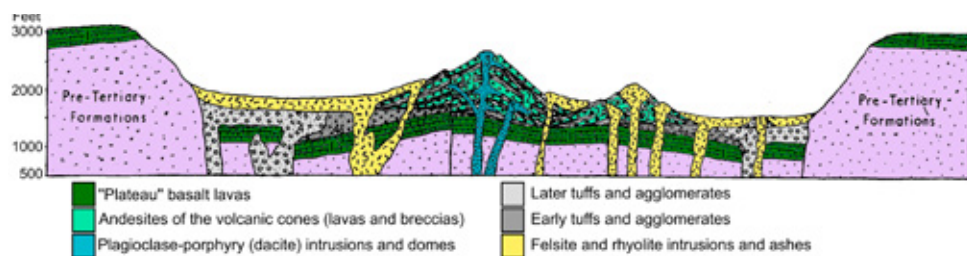
It was Basil King (at the time also based at Glasgow University) who described the volcanic, intrusive, and sedimentary rocks of the 'ring complex' in great detail (King, 1954). He proposed a model in which a great phase of explosive activity formed a deposit of 'tuffs and agglomerates' within the caldera, which were then intruded by felsite and rhyolite magmas (Fig. 3). This was followed by a phase of 'resurgent volcanism', in which small volcanic cones, comprising andesite and dacite magmas, were built in several places on the caldera floor (Fig. 3). The whole complex was then intruded by a series of granites, including the near-continuous ring dyke.

King's map of the Central Arran Igneous Complex was incredibly detailed, and his model of formation highly convincing. It is to his credit

that on such a heavily visited and studied island, no-one saw any reason to challenge his ideas. However, over sixty years have passed since then, and in that time a huge amount of progress has been made by the volcanological community, in a large part thanks to the wealth of observations made by specialist instruments at erupting volcanoes. It is with the benefit of this research that we have headed back to central Arran to see what modern ideas can be applied to the rocks there.

### Arran—an ongoing project

A team of geologists from Cardiff University (Gooday and Kerr), the University of Glasgow (Brown), and the British Geological Survey (Goodenough) have spent the last few years doing fieldwork on the Central Arran Igneous Complex. This has involved making a new map of the complex and interpreting the volcanic rocks of the caldera in terms of the processes occurring at the volcano as they were being formed.

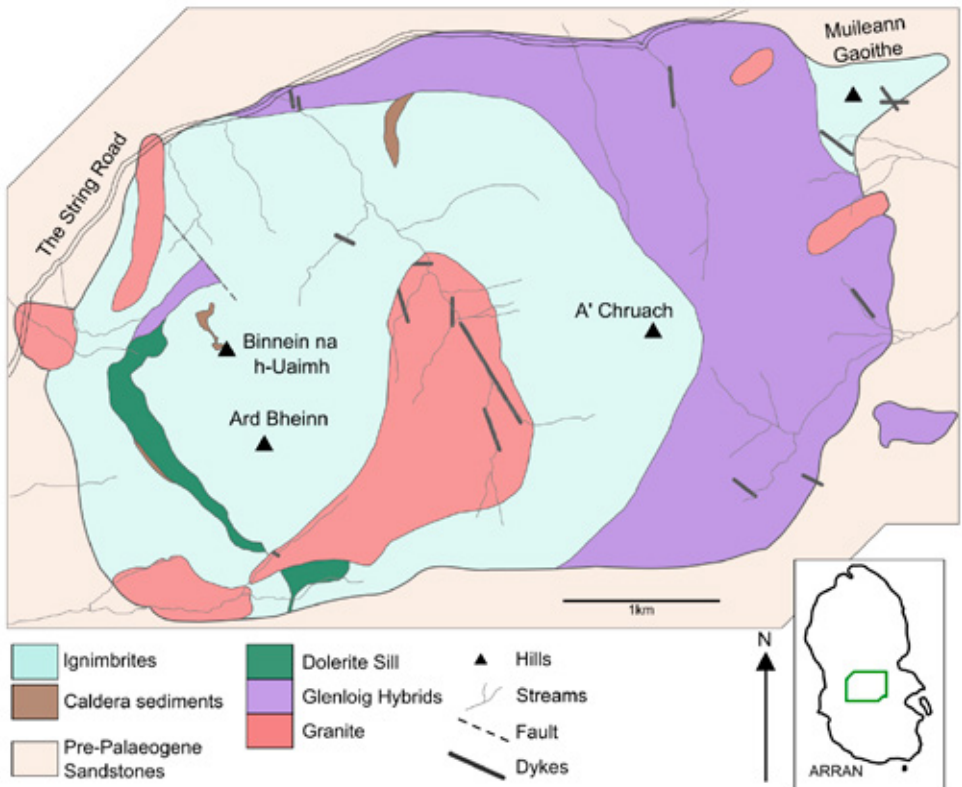


**Figure 3** Basil King's proposed cross section of the Central Arran Igneous Complex (King, 1954).

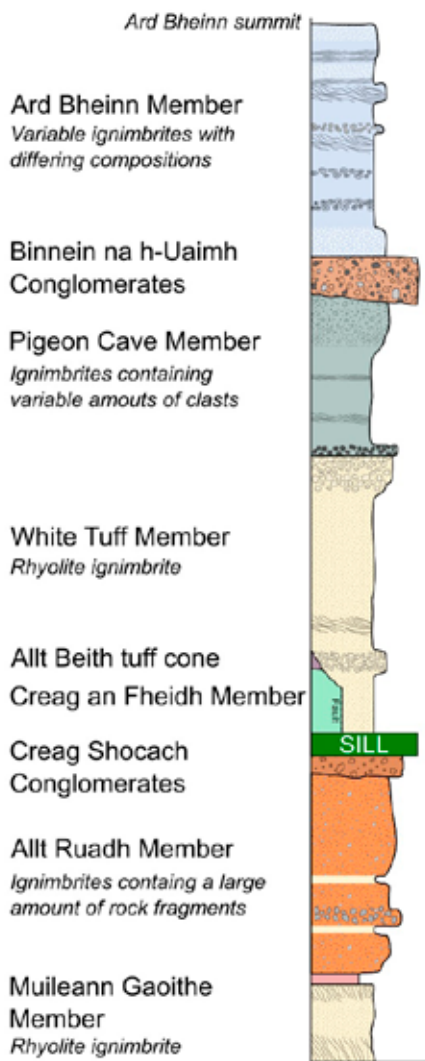
A major difference between the new geological map of the Central Arran Igneous Complex (Fig. 4) and those of Tyrrell and King is that there is no granitic 'ring dyke' surrounding the complex. There are certainly granite intrusions around the margins of the complex, but these are isolated from one another. The north and east parts of the complex are made of intrusive rocks which are highly variable and were clearly formed from the

interaction of two or more types of magma (named the Glenloig Hybrids on Fig. 4). It is now possible to study the nature of these magmas, and how they relate to other magmatic rocks on Arran, using precise geochemical analyses which were not available to previous generations of geologists.

The main advance, in terms of volcanological processes, is the conclusion that all of the rocks within the



**Figure 4** Geological map of the Central Arran Igneous Complex. From Gooday et al. (2018).



**Figure 5** *Stratigraphic log through the units deposited inside the caldera.*

caldera formed from a series of discrete volcanic and sedimentary events. The rocks deposited in the caldera are

mostly ignimbrites—the deposits of pyroclastic density currents formed during explosive eruptions—with minor sedimentary horizons. Together, these units have been called the ‘Arran Volcanic Formation’. This Formation can be divided into separate ‘Members’, which are single units formed during a particular phase of activity. The main features of these units, and their relationship to one another, are shown in Fig. 5.

The crucial result of interpreting these deposits as a series of individual and identifiable units is that the caldera system can now be discussed in terms of volcanic *processes* changing through *time*. The ignimbrites were formed by a series of explosive eruptions which involved magmas of differing compositions, and which had variable physical characteristics, such as power of explosions and temperature of ash deposits. Between these violent volcanic episodes, there must have been long periods of time where surface erosion and sediment deposition could take place. A caldera is a low point in the landscape, and erosion of the steep walls into the caldera during these volcanically quieter times is shown by the presence of conglomerates at certain levels within the stratigraphy.

The results of this study provide a useful comparison for currently



active calderas, which can be hard to study due to being filled with recent volcanic or sedimentary rocks, or water.

### Arran—finally all figured out?

Such is the nature of field geology in places where forests, heather, and peat cover the landscape, that any interpretation of a geological system is exactly that—an interpretation. The observations made by the latest team are of the same rocks as those studied by geologists over a century before. The only difference is the process of explaining those observations in the context of the current geological paradigm. Any geologist mapping the area now or in the future will certainly come up with a different model—and we look forward to seeing it! It is possible (if not almost certain) that sometime in the next century volcanological concepts will have evolved yet further, and this decade's work will start to look out-dated or even implausible. Don't worry, we aren't going to run out of geology to do any time soon.

### Acknowledgements

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Kerr, Davie Brown, and Kathryn Goodenough for their help, wisdom, and patience.

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## A Devonian coprolite from Orkney and its possible fish producer

*By David Leather*

In the 1820s, Mary Anning collected stones of fossilized reptile dung from the Jurassic shore near Lyme Regis. By 1829 William Buckland had given them the name coprolite, Greek for 'dung stone'. About the same time, others were discovering fossil fish at the other end of the UK in Devonian flagstones from the Moray Firth to the Orkney Isles, and among the fish, less well-documented coprolites.

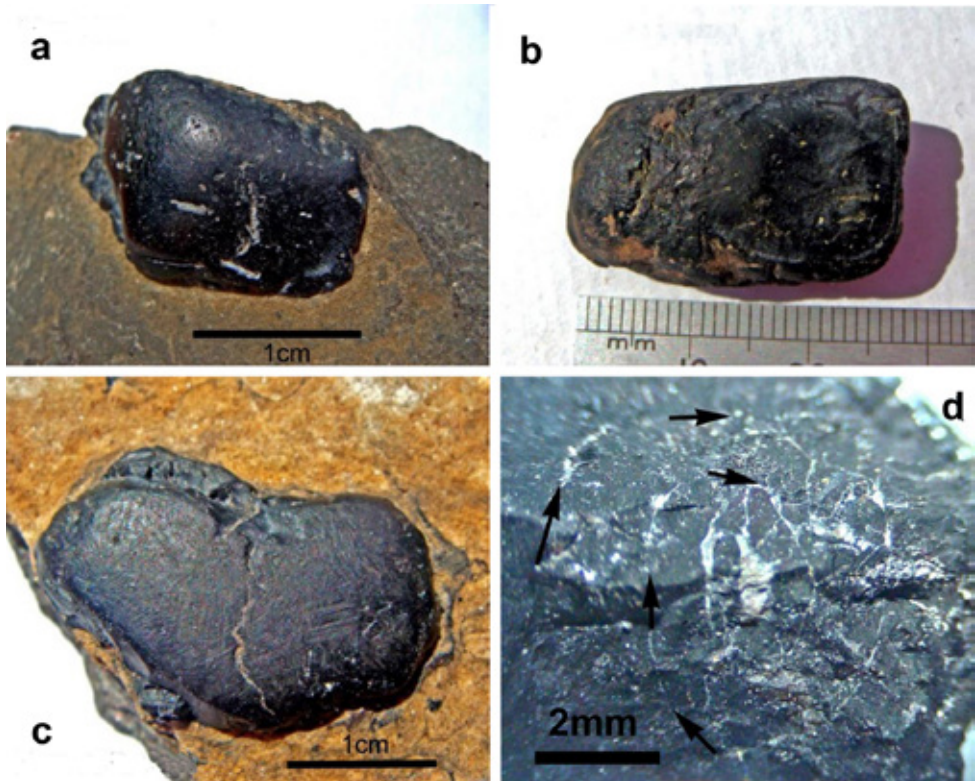
In 1878 Archibald Geikie named the freshwater lake within the Orcadian Basin, Lake Orcadie. When the lake was high enough to overflow to the Rheic Ocean, fish were able to swim up rivers and colonise the desert waters. Fish were by far the main inhabitants and mostly predators. There was such competition, which appeared to be global, that most of the fish developed armour plating that enshrouded the head and shoulders, protecting the most vulnerable parts. Species included an array of armoured fish, lobefins, lungfish and spiny fish, with sizes from a few centimetres to a metre and a half in length.

Recently, on the island of Westray, Orkney, I collected or photographed well over 100 coprolites from lake sediments across the island, mostly from two or three notable fish beds. The coprolites vary considerably in shape and size as you would expect where 14 fish species have been recorded. They are on average 3 or 4 cm long and generally rounded in cross-section, varying in length from a few millimetres to 9.4 cm. The biggest had a diameter of 18 mm. Many have a drawn out spiral structure, well seen on a weathered specimen, which may reflect the internal intestinal morphology, like modern sharks. Most fish faeces presumably contained crushed, half-digested bones, spines, scales, teeth and fragments of armour plate, but among those I found, there is no clue as to what they had eaten, apart from a rough texture on the weathered surface, or occasional sand grains. When freshly broken, they have a black, smooth and chert-like appearance. They come from sediments that have many shallow-water indicators, unlike those from the Achanarras deep lake sediments where both fish and coprolites sank to the anoxic muddy depths. In the case

of these Westray samples, things were different.

The palaeoclimate of Lake Orcadie was a monsoon type with a strong seasonal oscillation. As the lake waxed and waned with the seasons, the shoreline may have migrated several kilometres across the salty mudflats. It is suggested (personal view) that newly deposited fish

droppings, containing phosphates and carbonates, were preserved by salts from the rapidly evaporating lake waters and once stranded, may have been baked like brick clay or cement to become hard and solid in the hot sun. They were not compressed by later overburden, unlike the surrounding muds and, on becoming rigid they may have rolled around unscathed, fallen into a mudcrack, or

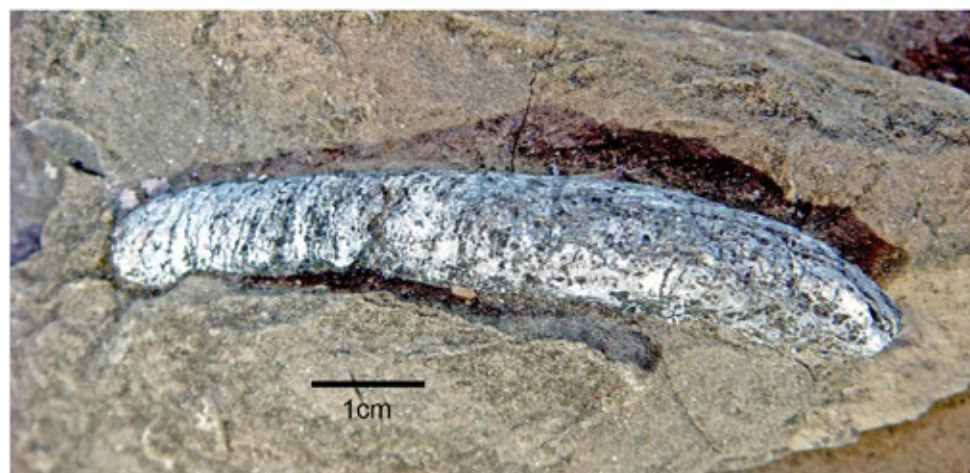


**Figure 1** Examples a, b and c are of the short fat round coprolites from the first cycle of the Rousay flagstone in Westray, Orkney; (d) shows part of the scroll in a cross section (arrowed) under a 20x binocular microscope.

been carried along by flash floods or turbidity currents without breaking up. Today, coprolites are commonly seen in relief on weathered flagstone, where they may occur along with mudcracks or salt pseudomorphs. Interestingly they are often far from fossil fish remains. On extraction they break up easily and only rarely weather out in one piece. In the

Rousay flagstone cycles there's a close correlation between fish beds which contain coprolites and the presence of sub-aerial mudcracks, showing that shallow parts of the lake dried out from time to time.

To match a coprolite with its producer is an almost impossible task, but there's one conspicuous coprolite



**Figure 2** Three typical coprolites from the Rousay flagstone in Westray, including a spiral form and a larger sample 47 mm long.



that is rather short, plump and round. The texture is very smooth, almost shiny and it's made up of hard siliceous, flinty material with small amounts of calcite and pyrite.

These short, fat round coprolites appear to be most frequent in fish beds where the lungfish, *Dipterus*, is common. This is especially true of the first cycle of the Rousay flagstone, which crops out in five localities across Westray. In this fish bed, *Dipterus*, which was about 30 or 40 cm long, appears with two smaller, and rarer osteolepids. *Dipterus* had teeth of a sort, tooth-plates on which the teeth were little more than

rounded protuberances. Like many modern fish, *Dipterus* was likely to have been a grazer that here fed on 'algae', strictly cyanobacteria, in the form of sessile microbial mats or stromatolites that grew on the shallow lake bed where sunlight could penetrate. *Dipterus* may have also taken small crustaceans, millipedes, worms and clam shrimps. That both the plump coprolite and disarticulated remains of the lungfish *Dipterus* occur in the same fish bed is some indication but not a conclusive match between the two.

However, on closer examination of one of the broken coprolite



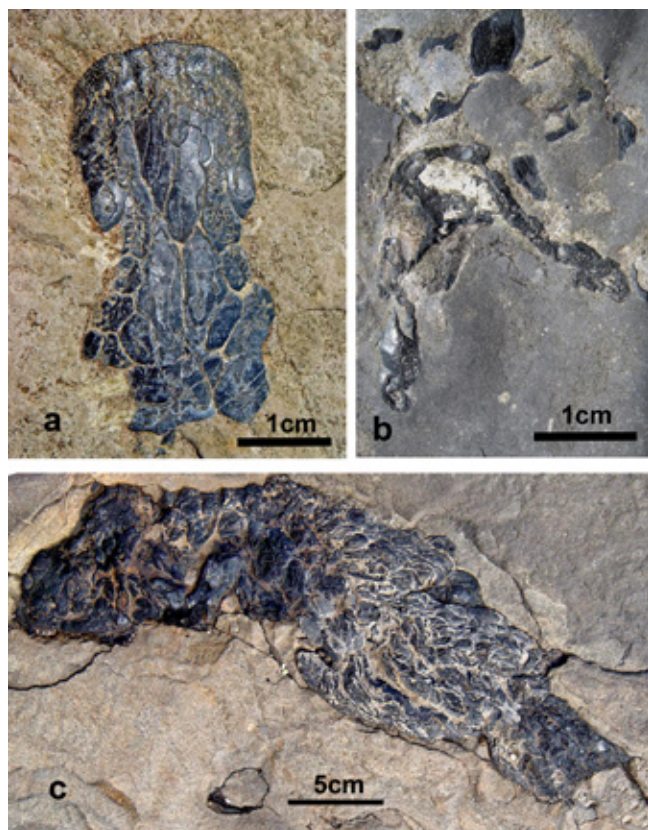
**Figure 3** Gently dipping Rousay flagstones on the 'Westside' of Westray Orkney allow a huge area of bedding plane surfaces to be investigated. In the distance is the island of Rousay.



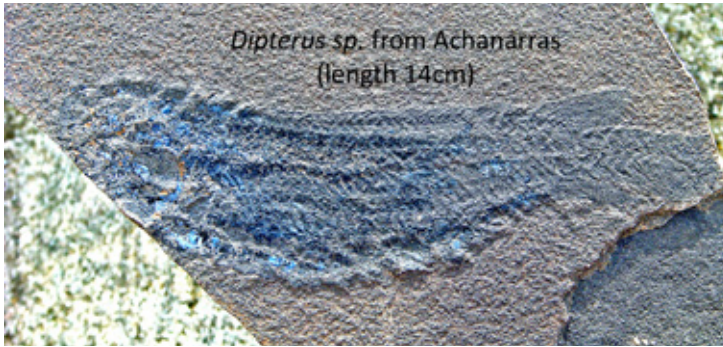
samples, I discovered under a 20x binocular microscope, the distinct line of a delicate whorl (see Fig. 1d), as if its producer had swallowed a gastropod. The whorl is in fact part of the structure of a 'scroll coprolite' and defines more closely the group of fish that produced it. The spiral whorl is fortuitously preserved as a single crystal of white calcite and, on turning the specimen in a bright light source, the cleavage planes light up, as if a light had been switched

on inside the sample. The scroll coprolite, as the word suggests, is cylindrical like a loose roll of paper, and reflects the intestinal arrangement of the fish. Scroll coprolites are said to be generally rare and thought to be the product of lungfish (Hunt *et al.* p277). So, this makes the match a little more conclusive, though never certain.

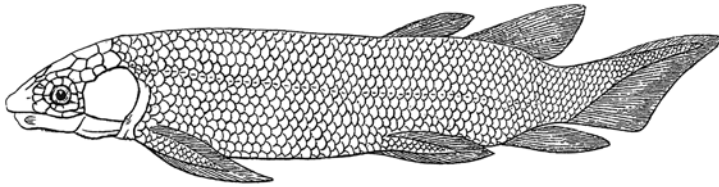
The lungfish was a survivor and could take in air when pools of water dried up and is common throughout the Devonian flagstones of Orkney, that is, in and above the Achanarras-



**Figure 4** (a) *Headshield of lungfish Dipterus is common in the first cycle of the Rousay Formation, showing squarish upper jaw; (b) shows a weathered lower jaw of Dipterus which is more angular; and (c) is a more or less complete Dipterus, 30 to 35 cm, also from the first cycle of the RF. The rounded scales are piled over each other, so originally this specimen may have been longer.*



**Figure 5** A complete, well-preserved though small specimen of *Dipterus* from the Achanarras Quarry fish bed in Caithness.



**Figure 6** Traquair's 1895 reconstruction of Lungfish, *Dipterus*.

Sandwick fish bed. Its full name is *Dipterus valenciennesi*, named after a town in northeast France, once renowned for its fine lace—it's nice to think that Mary Anning might have decorated her bonnet with a piece of Valenciennes lace.

### Further reading

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*Palaeogeography, Palaeoclimatology, Palaeoecology*, **426**, 68–74.

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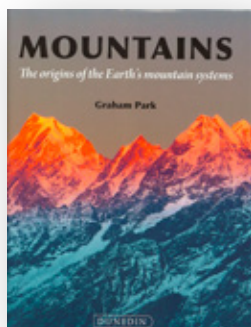
**Geology of Westray:** Leather, D. 2017. Demarcation of the boundary between Middle Devonian Upper Stromness Flagstone and Rousay Flagstone formations in Westray, Orkney. *Scottish Journal of Geology*, **53**, 53–61.

Photographs and specimens from the author's collection.

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## Book reviews

**Mountains—The origins of the Earth's mountain systems** by Graham Park. Dunedin Academic Press, Edinburgh. 2018. Hardback, 212 pp. Price £29.99. ISBN: 978-1-78046-066-6.



Professor Graham Park has accepted the challenge of taking the reader on an extended excursion through the mountain belts that form the major active features on the surface of the Earth. He examines the processes that have acted to form these spectacular eminences, illustrating each example with a wealth of diagrams, maps and cross-sections, accompanied by a goodly number of excellent colour images. The book does not seek to deliver a comprehensive description of any particular mountain range, rather the aim is to provide a sound and robust overview explained in the context of

plate-tectonics. The reader will be left in no doubt as to the grand scale and inter-connection of mountain ranges and the fascination that they hold for the author.

The first two chapters provide a review of the historical development of the ideas put forward to explain Mountain Building (orogenesis) and introduce the geologists who advanced that early understanding. Chapter 3 then sets out the advances in plate tectonic thinking, using the well-known example of the Himalayas to get the reader started on the right track. Chapters 4–8 then set out across the Alpine-Himalayan mountain system and describe the major features of these largely continental collision features. The circum-Pacific ('Ring of Fire') system is described in Chapters 9–12: the complex system of plate boundaries and subduction zones of the Western Pacific, and the north and south American Cordilleran volcanic chains and collision belts that border the eastern Pacific. Chapter 13 deals with the hidden mountain chain, the largely submerged mid-ocean ridges that delineate the spreading plate boundaries. The final chapter then compares these

comparatively young, and often still growing, mountainous zones on Earth with some of the older features recognised by geologists in the earlier epochs of Earth's history, and draws parallels between the old and the young. This book embraces a truly global subject.

The author draws on the prodigious academic literature of recent decades and on his own experience and then sets out to distil that information into a succinct account. No small task, especially when individual nations give different names to the same geological feature as it crosses international borders. Geology often has a glorious disregard for politics! A selection of key references are given in support of each chapter, and a very useful glossary is also supplied.

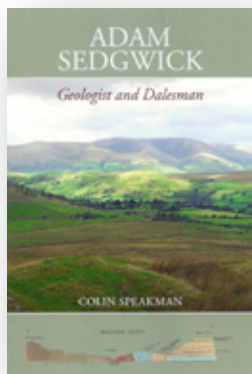
The book is lavishly illustrated with hardly a page lacking one or more figures. Some stunning views of the spectacular mountain topography accompanies the diagrams – but perhaps some images of the equally stunning rocks that can result from the processes that build these mountains would have added to the impact overall. The diagrams are well-drawn with accurate keys and helpful captions, whilst the page size means that they are clearly reproduced at a generous scale.

Perhaps the greatest challenge in writing this single volume will have been to identify, and write for, a well-defined target audience. The book is neither too generalised nor too specialised in its content, but perhaps therefore falls between these two stools. Rather it should be viewed as a book that will stretch and challenge the student of geology, and deliver a large volume of contemporary information. It is not, I think, a synthesis providing a 'quick win' or an 'easy answer', instead it encourages the reader to delve deeper and wider into this fascinating topic. If ever evidence of the huge forces and dynamic processes that shape the Earth were needed, then mountains must be one of the most visible and attractive signs of our dynamic Earth. The reader will learn much about these mountain systems and will, I hope, be encouraged to find out more.

The author has packed a tremendous amount of information into these 212 pages, and whilst an expert may debate the interpretation offered for any particular feature or region, I came across no striking errors. The book will take time to digest and is undoubtedly one to be consulted many times over. Some readers may find it hard to resist marking their own annotations onto the glossy, beautifully-produced pages.

Graham Leslie

**Adam Sedgwick—Geologist and Dalesman** (Facsimile edition) by Colin Speakman. Gritstone Writers Cooperative and The Yorkshire Geological Society, Hebden Bridge. 2018. Paperback, 145 pp. Price £12, ISBN 978-0-9955609-4-9.



Colin Speakman's biography of Adam Sedgwick (1785–1873), a legendary figure in British geology, was first published in 1982. A definitive work, it has been out-of-print for several years, so this new facsimile edition is most welcome. The main text is unchanged, but the opportunity has been taken to improve the print quality of the excellent figures, whilst introductory pages have been brought up-to-date. The book is described as 'a biography in twelve themes' and the approach works well in that the very different aspects of Sedgwick's life are explored in full without the disruption of contemporary but unrelated events.

It says much for the author's skill that at no point is the reader left bewildered by apparent anachronisms.

Although Sedgwick is undoubtedly best known for his geological contributions and pre-eminence at Cambridge University, Speakman ranges much more widely. In four introductory 'themes' he takes his subject, a fellow Dalesman with few advantages in life save innate talent, a determination to succeed, and the fortuitous influence of able teachers, from rural Yorkshire to a University Fellowship. Near the end of the book two 'themes' cover the contrasting activities of the older Sedgwick. There was an extraordinary involvement with Queen Victoria and Prince Albert which transformed the supposed reactionary into a radical activist promoting reforms to the university curriculum. Then, in 'retirement', Sedgwick championed the rights of his local Dentdale community.

Five geological 'themes' form the middle section of the book. Sedgwick's opportunistic conversion from mathematics to geology seems to have been partly a smart career move but perhaps was also driven by a need for outdoor therapy to counter chronic depression. Whatever the motive, in 1818, he was elected Woodwardian Professor of Geology although the position, as Speakman



emphasises, carried little associated prestige. Nevertheless, and despite his lack of formal training, Sedgwick soon became a powerful force in British geological circles.

Sedgwick ranged widely across England in his geological researches, but Speakman rightly highlights one of his discoveries from 1822, in the hitherto intractable rocks of the English Lake District. There, Sedgwick recognised the true relationship between bedding, cleavage and jointing; informed structural interpretations could then follow. Later, as an established senior figure, Sedgwick met the up-and-coming Roderick Murchison and, perhaps surprisingly, a firm friendship developed. So much so, that the two men toured the Highlands of Scotland, explored the Alps and jointly published scientific papers. Their subsequent falling-out over the relative extent of Silurian and Cambrian rocks in Wales enlivens the first of Speakman's two 'controversy themes'; the second is Sedgwick's reaction to Darwin and *The Origin of Species*.

For the first of these two great scientific controversies Speakman sides firmly with Sedgwick as the aggrieved party, as early as page three he has dismissed the "apologists of Murchison" and regards Lapworth's Ordovician interpolation as more to Sedgwick's liking than to Murchison's.

Be that as it may, I doubt that any of the protagonists would approve of the description of the critical graptolites as "minute pencil-like organisms".

The second of the controversial themes, Darwinian evolution by natural selection, saw Sedgwick in prominent opposition; a sad irony given his early influence on Darwin's scientific development. Like the dispute with Murchison, it has been the subject of much research and commentary, with a plethora of publications on both issues post-dating the 1982 publication of Speakman's book. Two that spring to mind are James Secord's 1986 book *Controversy in Geology: The Cambrian-Silurian Dispute*, and Sandra Herbert's 2005 book *Charles Darwin, Geologist*. As an addition to the 2018 facsimile edition a complete review of the more recent literature would have been too much to ask, but it is a shame that the opportunity was not taken to draw attention to the more important recent contributions by means of a supplementary bibliography.

That omission aside, it is still difficult to fault Speakman's biography. It is a beautifully crafted assessment of Sedgwick's life and demonstrates that there was much more to the man than can be gleaned from two famous controversies.

Phil Stone

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