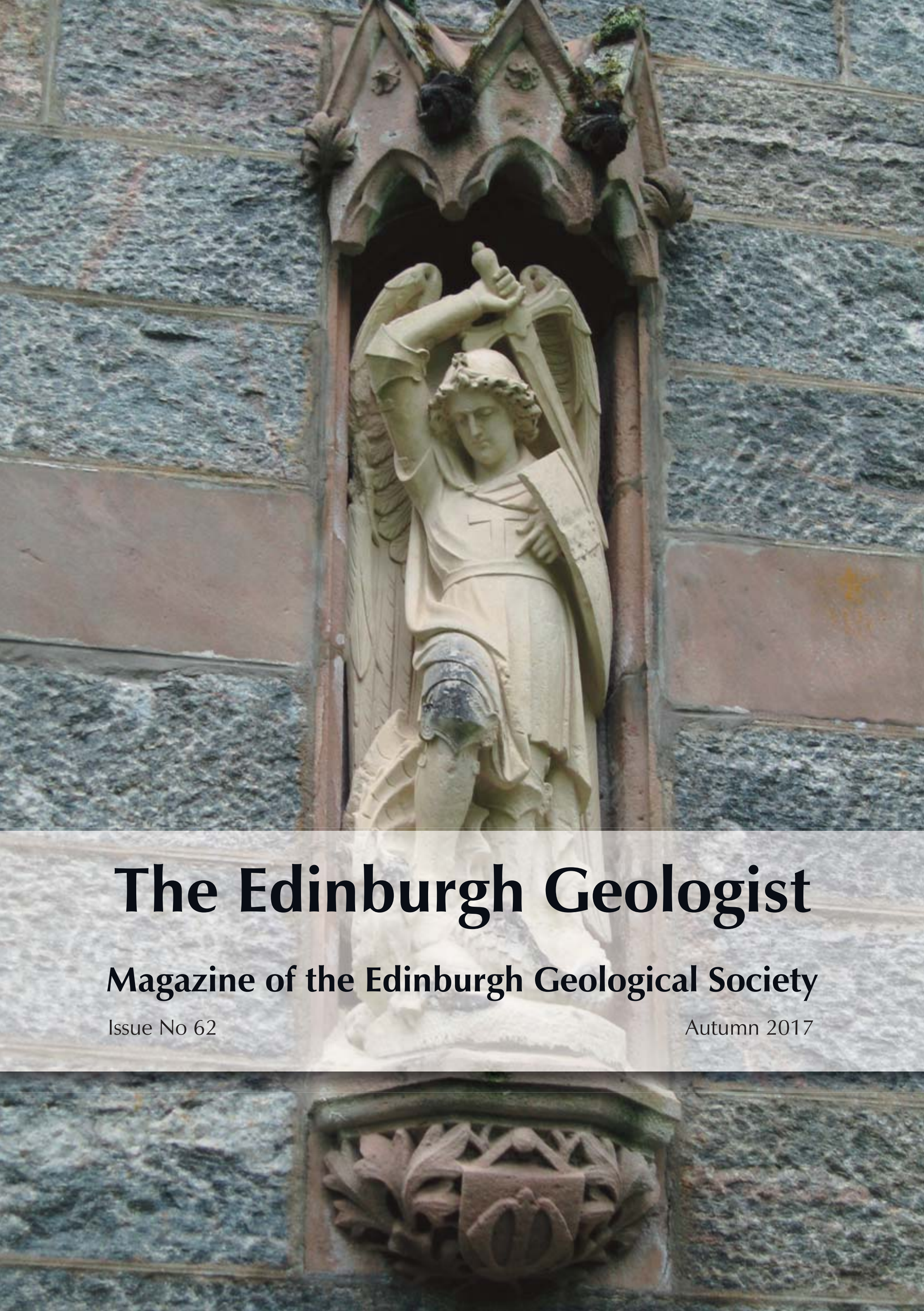

The Edinburgh Geologist

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Cover Illustration

Statue of St Michael, in white marble, in the east gable of St Mary and St Finnan's Catholic Church, Glenfinnan, 1873–74. The church, designed by Edward Welby Pugin in the 'late Early English' style, attractively juxtaposes a variety of stone for the ashlar work – local blue-grey granitic-gneiss marbled with quartz combined with light pink Elgin freestone, the latter also being used for the window and door surrounds. Photograph by Andrew McMillan. For more on the use of building stone across the Scottish Highlands see Andrew's article on page 4.

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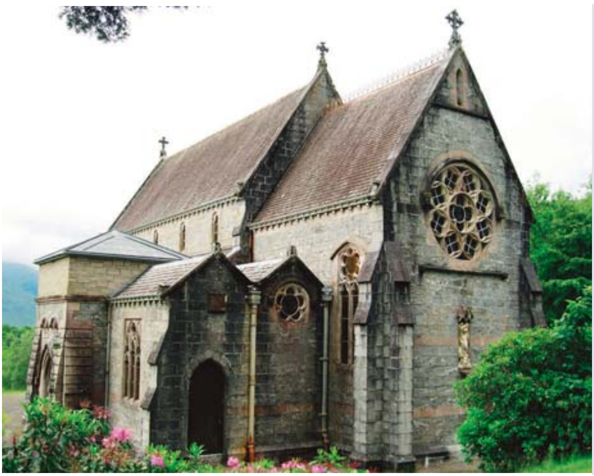
The Edinburgh Geological Society was founded in 1834 with the twin aims of stimulating public interest in geology and advancing geological knowledge. We organise a programme of lectures and excursions and also publish leaflets and excursion guides. For more information about the Society and membership,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

Inspirational geology — what did it for you?

An editorial ramble by Phil Stone

Much of geology's popular appeal lies in its fundamental framing of our 'sense of place': our much-loved scenery and a cultural landscape influenced by local natural resources. If that's your kind of geology then you will enjoy our first two articles in this issue of *The Edinburgh Geologist*. First, Andrew McMillan completes his two-part review of building stone use across the Highlands, introduced by our cover picture, and as a bonus he has consolidated both parts of the story into a single pdf that will be available online as a supplement to *EG*62. In our second article, Angus Miller laments our neglect of Scotland's geoheritage and its potential for tourism, but also highlights steps being taken to redress that situation.

Or perhaps it was fossils that first got you into geology. If so, there's a good chance that once upon a time you collected a few of them. Whether your collection was scientifically well-organised or accumulated along the random lines of a 'cabinet of curiosities', you will have enjoyed them for the glimpse they provided of life in ages past. It was not always thus. The recent small exhibition at the National Museum of Scotland — Fossil Tales — took us back to a time when fossils were



The setting for our cover picture: St Mary and St Finnan's Catholic Church, Glenfinnan. The church is a memorial chapel to the MacDonalds of Glenaladale, the family with whom Bonnie Prince Charlie stayed prior to the raising of the Jacobite standard at Glenfinnan in August 1745. Photograph by Andrew McMillan.

endowed with mystic status and put to some unexpected uses. Probably best-known of the fossil legends had Saint Hild(a) (614–680 AD) petrifying the snakes of Whitby—and being immortalised taxonomically for her trouble with the ammonite genus *Hildoceras*. To improve on her efforts, local entrepreneurs were soon carving heads onto the fossil ammonites even though the lack of heads was 'officially' put down to a beheading curse issued by St Cuthbert (634–687 AD), who was also credited with 'beads'—crinoid columnals claimed to have been derived from his rosary.

At least across the fossiliferous outcrops of Medieval, Mesozoic England

The Jurassic ammonite* Dactylioceras *'improved' according to the myth of St Hild(a). https://commons.wikimedia.org/wiki/File:Snakestone_(15240494805).jpg

ammonites and crinoids would have been relatively commonplace and so were not perhaps endowed with mystic powers beyond the benefits accruing from their religious association. Not so up in the Highlands of Precambrian Scotland where a fossil would have been a rare sight indeed. Judging by the examples in the National Museum's exhibition, echinoids in particular were deemed to have notable supernatural value. So, for example, specimens of the Cretaceous sea urchin *Echinoconus* were sold in 17th century Scotland as 'stones of miraculous efficacy against perils by fire and water'. And should your horse need treatment for an infestation of bot fly larvae here's what to do: take one belemnite and soak overnight in water, then let the horse drink the water. It's not clear how many times you could reuse the same belemnite before the 'palaeo-homeopathic' effect wore off.

It's easy to scoff at such superstition, but in these post-truth days of fake news and alternative facts it seems that we can all be susceptible to a belief in arrant nonsense. Healing crystals and the like are pretty harmless, but what of geology's role in emotive and challeging topics such as anthropogenic climate change or politically-sensitive estimates of its scientific antithesis, Scotland's hydrocarbon potential? Fearlessly (and with a fine specimen of *Echinoconus* at the ready), *EG* tackles the latter issue with Professor Roy Thompson's assessment of whether fracking for gas and oil can boost the Scottish economy as North Sea hydrocarbon production declines. I'm sure that not everyone will accept Roy's conclusions—though hopefully objecting on scientific grounds rather than wishful thinking—but one thing I hope we can agree on is that there is a very important difference between a resource and a reserve: politicians and media people please take note.

Then again, for those of a certain age, it was the plate tectonic revolution that fired-up a fascination for geological processes. Hard to believe that it all happened fifty years ago, with the Geological Society of London hosting a 'Plate Tectonics at 50' symposium in October this year. But perhaps it was only revolutionary from the American perspective. For those of us brought up on Arthur Holmes' *Principles of Physical Geology* a rather hazy concept of continental drift was always lurking in the background. And the idea of the Atlantic closing and then opening again wasn't too shocking as we'd known about that curious, trans-Atlantic fossil distribution since before the days of Ben Peach. Nonetheless, plate tectonics cut through the haze and geology was never the same again. Maybe you have some reminiscences about how it all suddenly made sense—and how we had to cope with a whole new vocabulary. Why not share your memories in *EG*63.

Of course, for another alternative introduction to geology you can't beat a pebbly beach, and so it was for Gayle Maynard who provides, in our fourth contribution, an original—and perhaps autobiographical—view of a conversion to geological appreciation. I'm grateful to Gayle for letting us publish her piece of creative writing in *EG* and hope that it stimulates more of us to try our hand at some geoliterature inspired by landscape, vernacular architecture, fossils, plate tectonics or pebbly beaches, whatever it was that got you hooked onto geology. If it was all of the above, and more, then you'll certainly appreciate Christine Thompson's book review of *GeoBritannica: Geological landscapes and the British peoples* that concludes this issue of *The Edinburgh Geologist*.

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Geology and building stones in the Highlands and Islands

Part 2 Igneous and crystalline metamorphic rocks

By Andrew McMillan

Following Part 1 (in *The Edinburgh Geologist* No. 61) this article covers a selection of igneous and crystalline metamorphic rocks which have been traditionally used as building stone in the Highlands and Islands. The complete article (Parts 1 and 2 and full bibliography) appears online as a supplement to this issue of *The Edinburgh Geologist*.

Igneous Rocks

Granite

Granites occur throughout the Highlands and Islands but those of the Grampian Highlands are especially important in relation to the building stone industry. Granite is a quartz-rich, ferromagnesian mineral-poor intrusive plutonic igneous rock which varies in crystal size from medium- to coarse-grained. With appropriate grinding and polishing methods, it can be finished to a very smooth surface making it a popular stone for monumental and decorative work. It is also hard, dense and resistant to degradation by frost and sea water, which means that it was commonly used for docks, harbour facilities and exposed structures such as lighthouses.

Scottish granites range from Neoproterozoic to late Palaeogene in age. Many were exploited locally as a building material and setts. Today, granites are principally quarried for crushed rock aggregate but some quarries are producing building stone. The principal granite quarries were in Aberdeenshire. Almost all the significant quarries were coastal or linked to a coastal port to facilitate export by sea. Granite was also worked in Mull and Lochaber in the western highlands. Granite was valued for its attractive appearance, with stone from the different regions having different characteristics, for example the deep red granite from Ross of Mull and Peterhead, the salmon pink of Corrennie and the silver grey varieties of Aberdeen.

In Aberdeenshire from the 19th century the granite industry was of huge importance to the local economy, and materials and skills were so plentiful that much of the city of Aberdeen was constructed from granite despite it being a difficult and expensive stone to work (most of the earliest buildings in the city are of more easily worked sandstone). Within the city, Rubislaw was pre-eminent. This quarry produced a greyish-blue fine-grained granite. It took a beautiful polish and was largely used for building and engineering work as well as for monuments.

The major granite quarries in Aberdeenshire have a long pedigree of supplying stone for prestigious buildings throughout the United Kingdom and beyond. For example, the silver grey coloured granite from Kemnay was used for such diverse projects as the Forth Railway Bridge (1885) the Queen Victoria Memorial, London (1911–24) and, recently as cladding for the Scottish Parliament (2004). Kemnay granite was largely used for building and monumental purposes but also produced large numbers of setts. The most outstanding building constructed of Kemnay granite is Marischal College, Aberdeen, the second largest granite building in the world[1]. Quarries at Peterhead and Longhaven including the Stirlinghill Quarries produced reddish brown, coarse-grained granite, well adapted for both for architectural and monumental

Pink and grey granite in the former St Columba's Church, Inverdruie, Aviemore, now St Columba's Rescue Base (Cairngorm Mountain Rescue). Note the use of sandstone for ornamental work, window surrounds and door arches.

polished work and for heavy engineering projects.

Formerly there were many quarries in Deeside particularly around Ballater and at Inver. Invergelder supplied silver grey granite for Balmoral Castle and other buildings on the Royal estates. Granite at Auchindryne, Braemar was used for Mar Lodge.

The granite quarries in the western Highlands, in particular those on the Ross of Mull and the Bonawe and Ballachulish quarries were directly on the coast, and were favoured for major construction projects such as lighthouses and roadstone. Fine-grained Ben Cruachan granite quarried at Bonawe was of excellent

[1] The largest is the Escorial Palace near Madrid—Ed.

quality for building purposes but was also used for road setts. Close by, the quarries at Craig worked a coarse-grained hornblende biotite granite which could be extracted in large blocks and employed for harbour work, ornamental purposes and for building stone. Granite boulders were also used for building purposes.

Tormore (Torr Mor), close to Fionphort, Ross of Mull produced the largest granite blocks in the UK at 16 m length, and some blocks were exported to the United States. It was used for dock works and bridges such as Westminster Bridge and Blackfriars Bridge, London. The Ross of Mull granite varies in colour from pale to deep red. Other quarries included one, North Bay, on the north side of the Ross which was opened to supply stone for the Skerryvore and Ardnamurchan lighthouses. The older parts of Iona Abbey and the nunnery are built of Ross of Mull granite (some from boulders) and metamorphic flagstone. It was reconstructed using granite from the Black Island Quarry, a name applied to two quarries at Dearg Phort on the Sound of Iona.

In Lochaber red granite was also quarried in Glen Nevis for use in Fort William. The Strath Ossian Granitic Complex provided local grey granite for the estate. Resources of the grey Ballachulish Granite were largely used in Oban as a building stone. It was characterised by numerous xenoliths of black schist which detracted from its appearance. The nearby ‘black granite’ of Kentallen (‘kentallenite’) took a good polish and was in much demand as an ornamental stone for monuments.

In the Northern Highlands, granites and diorites have been exploited at several localities. Large glacially-transported granite boulders often provided suitable resources for local building purposes. In Strath Rusdale, in the Ben Wyvis district, it was said that one boulder was broken up to provide more than enough stone for two cottages.

In the mid-20th century, granite and granodiorite was used for hydroelectric scheme constructions, both as fill and for facing. For example, the dam at Dundreggan, Invermoriston, largely derives from the Cluanie Granodiorite pluton, and Strath Ossian granite was worked in Glen Spean to provide material for the Laggan dam.

Other igneous rocks

Igneous rocks other than granite occur widely throughout the Highlands and on the Scottish islands, especially the Inner Hebrides including Mull and Skye. In recent years they have been extensively quarried, largely for use as aggregate and roadstone. A number of quarries are still in production today for this purpose.

Basic igneous rocks have commonly been exploited locally for building and walling. Basalt of the British Tertiary Igneous Province on the western seaboard forms an important and distinctive component of the built heritage of the area and has been used as the principal rubble stone in many medieval buildings on the islands of Skye and Mull (see Part 1).

Basalt wall of the Skye Gathering Hall, Portree. Note the pink sandstone window surrounds.

Dolerite, coarser grained than basalt, was quarried at Inverlochy (near Dalmally) and used for houses in the district.

Gabbro usually forms some of the coarsest basic igneous rocks. Many of the gabbroic and noritic masses of Aberdeenshire have been exploited as a source of building stone (e.g. for Huntly Castle). Today gabbro is an important source of crushed rock aggregate (e.g. at Pitcaple, Inverurie).

Ultrabasic rocks have been used locally, as for example on Unst where the ochre-brown weathering serpentinites and dunites (composed almost entirely of the ferro-magnesian silicate mineral olivine and its weathering products) form such a characteristic feature of the brown landscape.

Brown-weathering serpentinite-dunite has been used for the local buildings of Baltasound, Unst, Shetland.

Distinctive igneous rocks of felsic and intermediate composition such as porphyritic microdiorite (porphyry), microgranite, trachyte and syenite have proved valuable sources for ornamental stone, setts and paving blocks (e.g. quartz porphyry from Furnace and Crarae on Loch Fyne). Although generally difficult to work, they were valued because of their durability and attractive appearance—they range from fine- to coarse-grained and are strongly or pale coloured. Where natural jointing in the rocks is closely spaced, blocks could be extracted both for sett-making and building stone. An example of the latter is the pinkish syenite of the Ben Loyal intrusion which was quarried and used for buildings in Tongue and district, Sutherland.

Ben Loyal Hotel, Tongue, built of Loch Loyal Syenite.

Crystalline metamorphic rocks

As mentioned in Part 1, joint spacing, cleavage and inherited bedding characteristics determined the ease with which otherwise hard metamorphic rock types could be worked as building stone. Field stones (glacially-derived or from raised beaches) often formed the best building resource from the earliest times. Over the last 200 years many Highland estates opened small quarries to supply local needs for buildings and stone walls.

Gneiss

Typically foliated (banded or striped) gneisses are tough rocks, difficult to work and to dress. Usually they do not readily split along the direction of foliation (c.f. schist, below). As a consequence in the past gneiss was used traditionally as a local source of building material either collected from fields as glacially derived boulders or locally quarried where the joint pattern has enabled slabs to be relatively easily removed. Perhaps the most famous examples of early building with gneiss are on the Island of Lewis. Here, the 5000 year old Standing Stones of Calanais comprise irregular slabs of Lewisian gneiss. Nearby smaller blocks of gneiss were employed in the dry stone walls of Carloway Broch. Exceptionally, some gneisses split relatively easily as on Coll and Tiree where Lewisian gneiss was used extensively as building material. Likewise in Banffshire, gneiss was capable of being dressed and was used locally.

A mixture of squared coursed psammite and banded gneiss, veined with quartz, forms the masonry of Invergarry Hotel, Inverness-shire. The more easily worked red sandstone forms window surrounds and carved work.

Schist

Schist (derived from the Greek schizo, split) is a coarse-grained, finely foliated (banded or striped) metamorphic crystalline rock. The fine scale foliation (schistosity) results from the parallel arrangement of lamellar minerals, most commonly the micas. The schistosity enables the rock to be relatively easily split and this characteristic has been exploited for a variety of purposes including rubblework, stone slabs for standing stones, gravestones. In Argyllshire Dalradian schist from Doide by Loch Sween was used for sculpted stones from Medieval times. In some parts of the Grampian Highlands and western islands rocks described as 'gritty schist' or 'schistose grit' have been used for local building purposes. These rocks may have once been coarse grained sandstones, and although now metamorphosed some rocks may partially exhibit the original sedimentary texture.

Skipness Chapel, Argyllshire, rubblework of gritty mica schist with red sandstone arch.

Green Beds (chorite-schist)

Green Beds (including epidote- and chlorite-schist) crop out as a belt of rocks from the Mull of Kintyre through Loch Lomond to Aberfoyle and Aberfeldy. Typically green owing to the presence of the lamellar mineral chlorite, the rocks are of metasedimentary origin and have been derived in part from basic volcanic sources. Because of their ability to split well, green beds were used for carved monuments including Celtic crosses of the Iona School as well as providing rubble for many medieval castles and chapels. Green Beds were employed for the Tay Bridge at Aberfeldy, recently repaired. Quarries near Aberfeldy supplied that town and Pitlochry. Many small quarries were opened in both green beds and schists at Tarbet, Ardrishaig, Lochgilphead around Loch Fyne to supply local building needs.

Lochranza Castle, Isle of Arran. A gritty green chlorite-schist has been employed for the rubble-work with soft pink Carboniferous sandstone surrounding the doorway.

Metavolcanic rocks (epidiorite)
Metamorphosed basic volcanic rocks including Dalradian metabasalts crop out extensively in Argyllshire. These green and black rocks have also been used as building stone over the centuries. Quarries such as St Catherine's on Loch Fyne supplied tremolite- and chlorite-bearing epidiorite for use in Inveraray and Inveraray Castle and estate buildings. Similar epidiorites were quarried at Lochgilphead and Ardrishaig.

The Cross of Kildonan, Island of Islay carved in chlorite-schist.

Marble
The Highlands and Islands have several true marbles (limestone recrystallised by metamorphism) which, on account of their colour and other properties, were used primarily for decorative and monumental purposes. The decorative marbles are typically variably green-coloured

serpentinite marbles with distinctive textures, although pink and blue varieties also occur. Several of the quarries were active intermittently from the 18th century, and most ceased production in the early 20th century. Of the sources which have been used for monumental work, perhaps the best known are from Tiree, Iona, Skye, Portsoy and Glen Tilt.

Concluding remarks — conserving the heritage

This brief and selective resumé of the building stones of the Highlands and Islands illustrates the wide variety of building stone materials which have been used through the centuries. To assist our understanding of the aesthetic, cultural, historic and economic (e.g. in terms of tourism) importance of stone in the built heritage, there is an ongoing need to record and characterise the various types of building stone which have been used, and attempt to identify and protect existing or even new sources of matching materials. This is not just for use in repair and conservation, but, given a sufficiently viable supply market, indigenous natural stone has the potential to be specified for alterations for extensions to existing buildings, and even for entire new-builds. In that regard, the British Geological Survey is developing a Building Stone Database for Scotland which will offer a publicly accessible web portal aimed at providing some of the knowledge needed to inform best practice in maintaining and conserving the country's built heritage assets. Readers interested in learning more about this project or wishing to contribute to it are invited to contact the BGS Building Stones Team whose work is described at http://www.bgs.ac.uk/mineralsUK/buildingStones/home.html.

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Geotourism: Promoting Scotland's geological stories

By Angus Miller

Siccar Point, just 35 miles outside Edinburgh, is widely recognised as one of the world's most important geological sites, and is well known and appreciated by generations of Edinburgh geologists. Although I've visited many times in recent years, I'm always greatly impressed by the wild coastal scenery and the dramatic exposure of James Hutton's famous unconformity. Siccar Point is easier to find and appreciate than ever before, there are leaflets, signposts and interpretation boards. Even so, most days you are unlikely to meet more than a handful of people there; visitors from overseas find it quite startling that we don't shout more about our best geological asset. Without a doubt, in many other countries a site as significant as this would have a visitor centre, rangers on duty and quite possibly even restricted access.

Visiting geologists from Chile enjoy Hutton's Unconformity at Siccar Point; a recent study has found that there are fewer than five visitors per day on average.

Siccar Point is just one of Scotland's geological treasures, this is a country with unrivalled variety in a small geographical area. Everyone has their favourites. Try to plan a trip around Scotland that includes all the geological highlights and very quickly you have an itinerary that will take weeks! The recent 100 Great Geosites project organised by the Geological Society of London demonstrated this, with 38 of the UK's top geology sites in Scotland[1].

'Geotourism' encompasses two audiences: (1) the general visitor, who might be unaware of geology but enjoys the views and the scenery of a place, and can deepen their appreciation of the landscape by learning about the stories behind it, and (2) the more specialist visitor who already has an interest and appreciation of geology and is interested in visiting geological localities. There is an analogy in the recent interest in the restored *Flying Scotsman* locomotive which has drawn large crowds: the general public, who enjoy the spectacle of a working steam locomotive, but also the enthusiasts who understand the underlying engineering and history and get a huge thrill from the close personal experience.

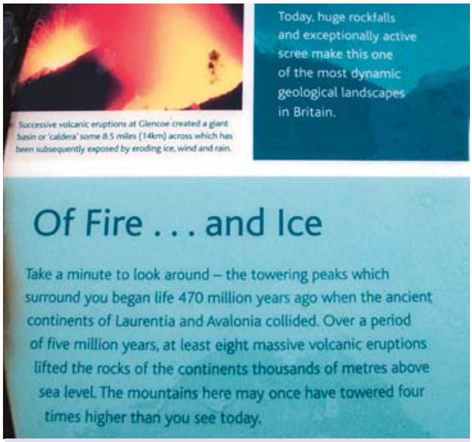
Scotland has great potential for geotourism in both markets. For the general visitor, we already know that Scotland's scenery is the number one draw: sites such as Edinburgh's Old Town, Staffa and Skye are very popular, and these are places where the geology has a direct influence on the key features that draw the tourists. We can add to this appeal by building on the 'sense of wonder' that our landscape inspires, explaining the underlying story but also highlighting the links from geology to scenery and culture. We can draw attention to the variety of landscapes across Scotland to encourage the general visitor to explore further, to extend their visits beyond the hotspots of Edinburgh, Loch Ness and Skye.

For geologists and those interested in geology (which must number millions of people around the world), Scotland is often already on the 'bucket list', through awareness of James Hutton, or the Moine Thrust, or the volcanic variety of sites such as Mull, Skye and Glen Coe. I have worked recently with groups of American visitors already interested in geology, who are willing to visit Scotland 2 or even 3 times to explore our geological variety: one visit, even for two weeks, is not enough! There is certainly potential to do more to market Scotland as an international destination for the geo-aware, encouraging people to visit 'the home of geology', to explore a very rich variety of geology in a small geographical area, with links to many aspects of the historical development of the science of geology.

However, if we are to market Scotland as a geotourism destination, resources are needed to support more visitors. Are the current arrangements at Siccar Point adequate? Across Scotland, a lot of information and resources already exist. There are a few visitor centres where geology is a primary focus (such as Knockan Crag in the North West Highlands Geopark), or where the local geology is explained as part of a wider introduction to an area (as at the excellent Atlantic Islands

Centre on the island of Luing, south of Oban). There is a wide range of published material: excursion guides, books, maps, leaflets and some web content. Around Scotland there are many interpretation boards with geological information. The Edinburgh Geological Society certainly plays a part in this, with our long history of publishing Excursion Guides (much of the content now available for free from the Earthwise website[2]), some information boards (including one in Princes Street Gardens) and more recently the efforts of our Geoconservation Groups to produce leaflets about local sites, that are distributed via local outlets and the EGS website.

So there is plenty of information available, but the distribution is patchy and the level of information (and its accuracy) is variable. The three existing Geoparks in Shetland, Northwest Highlands and Lochaber stand out as exemplars of what can be done when local communities engage with their geology: organising events, running visitor centres and creating interpretive material that is available in a range of formats for a variety of audiences. But away from these hotspots, many of Scotland's best geological sites have no appropriate information either at the site or online to encourage people to visit and explore the rich stories of the landscapes and places. One particularly poor example (ironically in a Geopark) is the roadside information panels provided by the National Trust for Scotland in Glen Coe that incorrectly describe many aspects of Glen Coe's geological history.



Interpretation board at Glen Coe that misses the point that the surrounding peaks of volcanic rock formed in major caldera-forming eruptions involving significant subsidence—and gives an age that is 50 million years too old.

Of course, information or interpretation needs to be aimed at a specific audience—no one product will be suitable for all. The Knockan Crag Visitor Centre is one of the jewels of interpreting Scotland's geology, located by a main road in the Moine Thrust Zone, and it illustrates the issue very well. It is very popular, the car park is often busy and tour buses from cruise ships that call into Ullapool routinely stop there. I've heard positive comments from many people, including those who profess to know nothing about geology. The mix of scenery, geology and the history of science appeals, and it is presented in an engaging way—clearly this centre is successful in explaining and interpreting the local landscape and telling the historical story of the discovery of the Moine Thrust and the development of ideas about mountain building processes. There is a good case to be made that other geological sites in Scotland should have similar investment in interpretation. However, this style of sharing Scotland's geology isn't for everyone, and the Knockan Centre has been accused of dumbing down the story of the Moine Thrust. Different content and styles of interpretation are needed for different audiences.

Face to face with Peach and Horne at the Knockan Crag visitor centre.

When the Scottish Geodiversity Forum was established in 2011, one of our aims was to bring people together to promote Scotland's geology. The Forum took over the running of scottishgeology.com and has worked to encourage better promotion of Scotland's geology through Scotland's Geodiversity Charter, workshops, conferences and projects such as the Hugh Miller Writing Competition. This year we have secured funding from the Heritage Lottery Fund for a project that is part of the Year of History, Heritage and Archaeology 2017. The aim is to celebrate Scotland's geological heritage by providing high-quality information about a network of places across Scotland where people can see the best of Scotland's geology, and organising a Geoheritage Festival throughout October. For now, we are focusing efforts on a list of the 50 "best places to see Scotland's geology". Of course, this is a list with potentially hundreds of entries: it was impossible to agree on a list of just 50 places, but with much compromise we have selected 51! This is a very different list from the 100 Great Geosites, because it has a different focus: these are places where people can see and enjoy Scotland's geological story, so the geology needs to be easy to appreciate and understand. We also wanted sites that are already routinely visited by people, that are accessible (which discounted St Kilda and the west coast of Jura, for example). Finally, we wanted the selection to have good geographical coverage of the whole of Scotland, from Unst to Southerness, and to cover all aspects of Scotland's geology including glaciation and active processes.

The 51 Best Places to see Scotland's geology will be launched in October 2017 with high-quality, introductory information about each place, accompanied by good illustrations, on scottishgeology.com[3]. Throughout October, there will be more than 30 events across Scotland that will promote these places, encourage people to visit, and raise awareness of Scotland's great geological stories. The information being prepared is very much aimed at the general public, but it will include links to further information. So it will provide a good overview of Scotland's geology for local people and visitors, and highlight ways in which people can find out more.

Clearly there is still a long way to go before there is uniform provision of interpretation of Scotland's geology for the different potential audiences. Sometimes we seem to be making little progress, as can be seen by the continued struggle to properly fund Scotland's Geoparks. Recently Geoparks around the world have been given a significant new UNESCO designation, so that they are now called UNESCO Global Geoparks. This is major step that will have an impact internationally and has great potential to draw visitors to these areas. However, Scotland seems to be turning its back on this new designation. Despite widespread local community support and great efforts to develop income streams, there is no interest from the Scottish Government in committing the relatively small amount of on-going funding that will secure the Geoparks' future. Positive developments on the Isle of Arran (where local organisations are enthusiastically investigating the potential of becoming a new Geopark with the backing of North Ayrshire and Arran Council) are offset by uncertain futures elsewhere.

So, there is much work to do to provide information and resources to enable local people and visitors to better appreciate Scotland's geology. The potential rewards, economically and culturally, are great. As well as boosting the tourist economy by encouraging more visits and spreading the current tourism bonanza beyond the hotspots, there are more subtle rewards when communities discover a sense of place and a pride in their geological heritage. Is there widespread awareness of these potential rewards? Definitely not! However, it is quite easy to understand why this is when there is general ignorance about the richness of our geological story: ask any young person educated in Scotland how much they have been taught about Scotland's geology or our geological pioneers such as James Hutton. There are many people fascinated and engaged with Scotland's geology, but very few of them have had that interest ignited in our formal education system.

Geotourism in action at Hutton's Section in Edinburgh's Holyrood Park. Scotland has much to offer geotourists, from the 'sense of wonder' of the general visitor engaged by Scotland's magnificent scenery, to those with specialist interest drawn to the 'home of geology'.

So, if you've ever shaken your head in disbelief at an interpretation board that misses an obvious story about local geology, or visited an internationally important site such as Siccar Point and wondered where all the other visitors are, or seen someone's eyes light up when they discover you know something about geology and might just be able to answer a question about the rock they've found or the mountain they've climbed—get involved! There are many different aspects of the challenge of promoting Scotland's geology, and plenty of ways for individuals and organisations to make a difference and contribute to the economic and cultural benefits of geotourism.

Further information

1. https://www.geolsoc.org.uk/100geosites

2. http://earthwise.bgs.ac.uk/index.php/Category:Edinburgh_Geological_Society

3. http://www.scottishgeology.com/where-to-go/

Angus Miller is Chair of the Scottish Geodiversity Forum and runs his own business—Geowalks—offering walks and tours exploring Scotland's geology.

chair@scottishgeodiversityforum.org

Can fracking, for gas and oil, power the Scottish economy?

By Roy Thompson, GeoSciences, Edinburgh University

"Scotland['s] set for [an] oil bonanza that heralds a new golden age for the North Sea lasting for another century" Independent Scottish business pressure group (N56).

"There can be little doubt that Scotland is moving into a second oil boom" Alex Salmond, Scotland's First Minister (2007–2014).

These are bold, long-term pronouncements made during the run-up to the referendum on Scottish independence in 2014. Are they realistic? Before discussing their veracity and reliability this short article positions the quotes within a geological context by summarizing the history and utility of Scotland's earlier oil booms.

Shale oil

The first commercial oil-works in the world were established in Scotland by James 'Paraffin' Young. His venture began on Thursday 17th October 1850 when he took out a patent for the low-temperature distillation of coal and shale. Young had discovered how to obtain paraffin oil and paraffin wax by heating rocks in a furnace. Works were established at Bathgate where local, exceptionally high-yielding, cannel coals formed the basis of the new industry.

Soon, when the coals ran out, Young switched to the more extensive, but lower-yielding, underlying oil shales. Production was initially on a small scale. Nevertheless the oil-shale industry prospered. There are more than 187 old shale mines and pits in Scotland, and at least 142 abandoned works where retorting, distillation and refining once took place. The vast majority of these enterprises remained small in scale and short-lived. Yet production prospered, improved retorts were introduced and by 1865 the industry employed 30–40 000

Oil shale is an organic-rich, fine-grained sedimentary rock. In Scotland the main oil-shale sequences occur in Lower Carboniferous rocks. Solid remains of freshwater algae accumulated in a shallow lake complex lying near the equator. The lake basin occupied most of what is now West Lothian, extending at times into Fife, Midlothian and Lanarkshire.

people. Production eventually peaked in 1912 when more than three million tonnes of shale were mined to yield 1.7 million barrels of crude oil and over 54 000 tons of sulphate of ammonia. Eventually Scotland's first golden age of oil came to an abrupt end in 1962, with the closure of the Westwood oil works.

Today, all that remains of the vast, old workings are faded warning notices, one old office building and a few miners' rows. No furnaces. No retorts. No industrial buildings. Much of the waste, however, endures to form the area's unique red slag-heaps, or bings. The burnt shale-debris rapidly weathers to leave a surprisingly free-draining, cohesive substrate and unexpectedly steep, yet stable, slopes. For many years saving the abandoned oil-shale workings has not been a top priority for local communities. Recently, however, an excellent museum has been established as part of the Almond Valley Heritage Centre. Also several bings have been landscaped and reclaimed as green space. Two, Broxburn (the Ayers Rock lookalike) and the Five Sisters, are today legally protected as Scheduled Ancient Monuments and their vegetation left to regenerate naturally. The unusual setting and nature of these exhausted industrial landscapes provide attractive areas for walking. So much so that the author, as a change from 'bagging' Munros, has bagged all 21 surviving bings.

Oil and gas

Scotland's next golden oil age opened in December 1969, with the surprise discovery of the Montrose oil field. An Amoco-led group had actually been prospecting for gas 130 miles east of Aberdeen, but struck oil instead. Soon afterwards the truly giant oil fields of Forties, Ekofisk and Brent were proven, confirming that the North Sea would become one of the world's great petroleum provinces. The tectonic history, which gave rise to the oil, was dominated by an episode of late Jurassic to earliest Cretaceous crustal extension. In broad terms the rifting related to the breakup of the supercontinent of Pangaea.

As is well known, conventional petroleum systems require an organic-rich source rock which, when geothermally heated by burial, can generate hydrocarbons; a reservoir, composed of a porous unit, in which oil or gas can accumulate; and lastly an effective seal, which prevents hydrocarbon escape. While the source rock responsible for virtually all of Scotland's offshore hydrocarbons is straightforward — the Kimmeridge Clay — the reservoirs are exceedingly varied. Some are structural, others sedimentological. Some reservoir rocks pre-date the

Kimmeridge Clay. This high-yielding source rock, of late Jurassic to earliest Cretaceous age, was deposited as mudstone and siltstone in land-locked marine basins. When sufficiently deeply buried the organic remains (principally dead plankton) become heated to temperatures of 50–150°C and start to be thermally broken down to produce oil. The Kimmeridgian is also notable in the USA as an important unit for shale-gas fracking. The Haynesville Shale in East Texas and Louisiana is a prime example with close similarities to the North Sea source rocks.

source rocks, the two having been juxtaposed by later faulting episodes. Others are contemporaneous; yet more as young as Eocene. Most reservoirs are sands but deposited in an astonishingly diverse array of marine settings and capped by various impermeable layers.

All these reservoirs and traps have had to be accurately pinpointed while buried beneath thousands of feet of overlying rock. Many North Sea reservoirs are very small, in area no bigger than a town. Drilling is the final arbiter of the likely productivity of oil and gas plays, but arguably the most important tool for exploring the North Sea and for gaining an impression of the subsurface has been detailed seismic imaging and interpretation. Following an initial exploration phase, Scotland's fields were quickly brought on-stream using innovative financial investment vehicles, specially tailored to cope with the very risky milieu of offshore drilling, and skilfully conjured up by coalitions of accountants, bankers and lawyers.

Oil first arrived onshore in 1975. Complete production profiles are plotted in Figure 1. The overall double peak, and intermediate slump, is often attributed to fluctuations in the price of oil. But this cannot be, as corresponding behaviour is not found for Danish or Norwegian fields. Instead the dip relates to repercussions following the Piper Alpha disaster in 1988, when UK oil production was deliberately cut back in order to allow extensive work programmes to implement new safety measures.

Once due allowance is made for the Piper Alpha effect the North Sea can be seen to be a mature basin. Today the most straightforward way to assess Scotland's likely remaining offshore oil wealth is a forward projection of the data of Figure 1. Using this approach I estimate an ultimate resource of 31×10^9 Bbl, with 11% still remaining to be recovered over the next decade. My total coincides closely with geologically grounded estimates, dating as far back as the mid-1990s, which were based on field-by-field appraisals of the porous volume of reservoir sands.

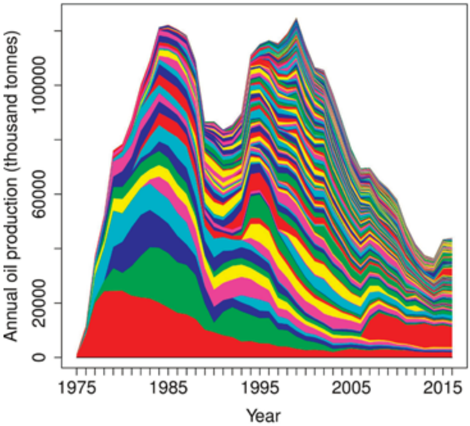


***Figure 1** Offshore oil production for 261 UK fields (1975–2016). Each coloured 'stripe' shows a different field. Note the steady fall in both field size and field longevity over time. Buzzard (first oil, 2007) is the only notable exception. Accordingly, recently discovered fields have typically generated <10 million Bbl of recoverable oil with lifespans of <16 years.*

Shale gas

In the United States the recent advent of extended-reach drilling and hydrofracturing has opened vast new energy sources, such as black shales, and has significantly altered the domestic energy landscape (Figure 2). As an alternative to our dwindling North Sea oil supplies, equivalent sources are currently being sought in Scotland. Companies want to drill beneath the Central Belt for gas trapped within Carboniferous shale formations, and to liberate it by creating a dense network of connected spidery cracks by injecting fluid under high pressures (of up to 500 bar) and high flow rates (upwards of 50 gallons/sec).

On the environmental side, the evidence of the risks and benefits of fracking is fiercely disputed. Much of the furore, in the USA, has been driven by the lack of detailed chemical disclosure of hydraulic fracturing fluids. A typical US well costs around $8 million to drill, plus a similar sum during the production phase. Fracking involves injecting 5 million gallons of water (obtained from rivers, lakes, public water supplies or retreatment plants) plus proppants to keep incipient fractures open, plus 15 000 gallons of

***Figure 2** Aerial view (B. Gordon, EcoFlight) of hydraulic fracking pads. Looking north across part of the Jonah tight gas field (of Late Cretaceous age) in Wyoming.*

other chemicals. Hydrochloric acid is added to help clear out cement debris in the wellbore. In addition gelation agents, which improve proppant placement, friction reducers, corrosion inhibitors, an iron precipitation control, disinfectant biocides to control bacterial growth, oxygen scavengers and scale inhibitors are all basic additives.

A second major anxiety is earthquakes. Interestingly, induced quakes are not necessarily caused by the fracking process itself, but by the disposal of the huge volumes of flow-back and brine-laden waters produced along with the gas. In the US and Canada wastewaters are disposed of in deep wells. This practice serves to separate the waste from drinking supplies but it can have secondary consequences. Since the start of wide-spread fracking, felt earthquakes have become hundreds of times more common. The reason is that the wastewater disposal reactivates old, deep-seated fault lines. Further worries are greenhouse-gas emissions and leakage.

Local geology introduces additional snags. The structural geology of the Central Belt is not straightforward. The Carboniferous strata lie in a series of small sub-basins and can be subject to remarkably abrupt and extensive lateral change. In addition faults are encountered every ½ mile or so. Figure 3 provides an example. In this abandoned opencast section a syncline plunges into the photograph, decreases upwards in fold-amplitude, is shifted laterally by a fault, and is interrupted by a lava. Such profound discontinuities must inevitably create difficulties during extended-reach fracking and lead to well underperformance. Furthermore Scotland's low thermal gradient (22–30°C/km) and weak Tertiary exhumation history suggest the great majority of its shales, with the possible exception of those contained within deep synclines (e.g. Clackmannan, Midlothian-Leven, Solway), will barely have reached gas-generating temperatures.

Glossary

Bbl*: Blue barrel (1Bbl = 0.14 tonnes)

Gas-in-place: Modelled estimate of the total volume of gas stored in a reservoir.

Reserve: Volume of hydrocarbons that can be profitably extracted from a reservoir using existing technology.

Resource: Hydrocarbons that may eventually become producible. Includes reserves as well as known oil and gas deposits that currently cannot be technologically or economically recovered, and even guesstimates of undiscovered potential reserves.

tcf*: Trillion cubic feet.

*: Americanized Imperial units reign supreme in the petroleum industry.

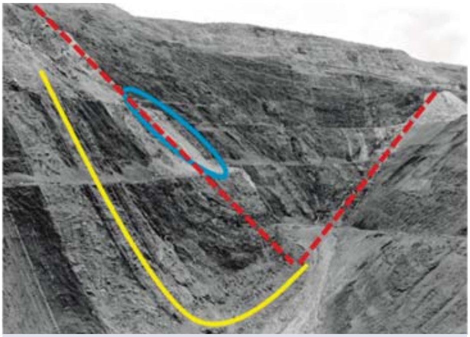


Figure 3 Carboniferous shales and coals in a plunging syncline (yellow curve) at Westfield opencast site (nr. Glenrothes). A lava (blue oval) underlies the coals just beyond a strike-slip fault (red dashes). BGS image P000196.

How could Scottish shale gas be accessed? KPMG, in their recent report for the Scottish Government on unconventional gas extraction, adopt a central estimate of 20 pads generating up to £6.5 billion of investment and creating 1400 jobs. Pads are areas of up to about 8 acres, which when cleared and levelled, would house the drilling equipment and the enormous assemblage of pumps, diesel engines, fleets of water trucks and sand mixers needed, along with wastewater impoundment dams. Pads have appeal as they concentrate industrial activity, so reducing the total noise, traffic movements, surface disturbance, and number of access roads and utility corridors. But are 20 pads really a viable means of generating a US-style shale gas industry in Scotland? The number of hydraulically fractured wells in the US is thought to have reached over 200 000. Gas-in-place estimates for Scotland broadly cover an area stretching from Glasgow & Motherwell, to Stirling & Falkirk, across half of Fife to Pittenweem, and then south through East Lothian to Penicuik. How can that heavily populated area, of around 800 sq. mile, possibly be fracked from just 20 pads? The effective footprint that can be hydraulically stimulated from a single pad in Scotland is likely to be small on account of the complex geology, inconsistent stress field and geo-mechanical incompatibility of extended-reach drilling with shallow targets. I envisage an efficiently designed, Scottish, multi-well pad would drain an area of around one sq. mile, as in recent pad placements in Tioga County, Pennsylvania or Septimus-Montney, Canada.

In Scotland matters are rapidly coming to a head. The Scottish Government is currently promising to take *"a final decision [on the future of fracking] by the end of 2017"*. But what, despite the environmental risks, might the potential economic and fuel-security benefits be? The total in-place gas resource estimated for Carboniferous shales is 49.4–134.6 tcf, with an additional oil-in-place resource of 3.2–11.2 x 10^9 Bbl. To me the key question is not the size of the technically recoverable resource, but what is a realistic assessment of future deliverability. In short, how can the reserve rather than the resource be physically estimated using current geological knowledge to the full? I suggest the best methodology is to employ an analogue approach. Production-decline curves, for other parts of the world, when combined with an appraisal of the key geological parameters which control recovery, allow the reserve to be quantified.

My results, for gas yield per unit area, are summarised in Figure 4. Note the crucial control of depth on total production. Depths should be neither too shallow (too cool for effective gas generation), nor too deep (methane and other hydrocarbon gases formed, but broken down leaving nonhydrocarbon gases (CO_2, N_2, H_2S) and depleted residues (pyrobitumen)). The diagram shows how Scottish shales with their modest organic carbon contents and shallow depths, not to mention their unremarkable thermal history and heavy faulting, barely correspond to even the poorest US-producing regions (e.g. Lewis, Conasauga, Ohio). Furthermore their frackability (ease of cracking or fracturing) remains unproven but could well be slight on account of their low quartz-plus-dolomite content. All in all Scottish shales may well have a success factor of zero.

In comparison to Scotland, the North of England has a gas resource estimated at 1300 tcf. Its simpler geology with deeper, thicker shales corresponds reasonably well with superior US provinces. Consequently if fracking is not commercially viable in the North of England it certainly won't be in Scotland. The Scottish Government would be well advised to wait and see what happens south of the border.

A new golden age?

In conclusion I return to the concerns broached at the outset. If geological estimates of Scotland's remaining offshore oil reserves and of prospects for onshore gas are both so poor, how can the N56 view that Scotland

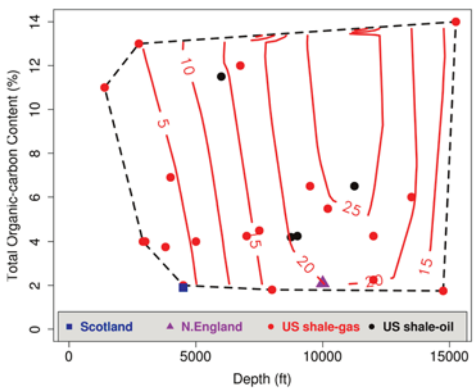


Figure 4 Depth vs. total organic content. Contours (red lines) of estimated ultimate recovery (Bcf/ sq. mile) in 24 US shale-systems. Systems outwith the black dotted polygon.

is set for a new black-gold bonanza of an additional 24 x 10^9 barrels of conventional reserves, plus a further 21 x 10^9 from unconventional (i.e. fracked) sources, be tenable? It can't.

The reason for the huge gap in expectations is twofold. First the N56 think-tank presented no geotechnical evidence, from either drilling or production tests, for major new conventional reserves anywhere offshore. Secondly they asserted that the offshore Kimmeridge Clay Formation can be fracked. Yes, the Kimmeridge is a rich, hybrid source rock. Yes, at 15 000 ft. below the central North Sea graben it can contain abundant oil and gas-in-place. But no, that does not make it an offshore reserve with any likelihood of becoming commercially recoverable within a reasonable time frame. The economics of offshore fracking are particularly bad. First, a top-rate US-style shale well typically yields only about 1/25th of a UK oil well. On top of that fracturing costs considerably more than conventional drilling, especially offshore. Lastly, when faced by such hefty economic disparities an appeal to an increase in oil prices does not provide a way out. Remember there are many developmental possibilities, if oil prices rise, for virgin giant fields around the globe, especially subsalt and deep-water. As a consequence expensive Scottish hydrocarbon is not going to suddenly become in demand.

Coal-bed methane

Finally it is worth noting that coal formations, if saturated with water, can contain copious amounts of methane gas adsorbed onto mineral surfaces. The methane desorbs if the water is pumped off the coals and the gas can then be accessed by production wells, often with minimal recourse to fracking. The potential for coal-bed methane, as opposed to underground coal gasification (which Scottish Ministers have determined will have no place in Scotland's energy mix at this time), appears to be locally very promising for the few relatively thick coal seams that escaped 19th and 20th century mining. It would be a fascinating happenstance if a 21st century source of hydrocarbon, in Scotland, returned us full circle to Young's original, masterly idea of generating hydrocarbons from coal.

Additional information, data sources and references

http://www.geos.ed.ac.uk/homes/thompson/

Roy Thompson,
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The Eternal Student and The Keeper of Time—A dialogue

By Gayle Maynard

Eternal Student: I cannot lie... It was my love of pebbles.

Keeper of Time: *What was?*

Eternal Student: The reason I took the time, of course. Isn't that why I'm here?

Keeper of Time: *Please continue. It was your love of pebbles...*

Eternal Student: Yes. Red ones,
brown, speckled,
grey with streaks of white,
smooth and shining at the water's edge,
then baking in the sun.

Keeper of Time: Go on.

Eternal Student: The time—a summer's day,
the scene—Ardlamont Bay with Arran in the distance...
Such beautiful stones!
And as I walked I came across one large and broad...
and fluid!
It was as if some Hand had taken greys and whites and pinks, caused them all to swirl and swish together, then left it there for me to see.
A masterpiece!

Keeper of Time: *And so...*

Eternal Student: And so I had to know! I had to understand how this had come to be.

Keeper of Time: *And so you chose... I see from my records here, to take some time Monday afternoons "exploring the geology of Scotland's coast".*

Eternal Student: Indeed.

Keeper of Time: *And?*

Eternal Student: Yes?

Keeper of Time: *And can you give a satisfactory account of the time spent? Have you anything more to say?*

Eternal Student: *(dreamily)* And broken up by ice and flood and wave...

Keeper of Time: *I don't follow.*

Eternal Student: I was just thinking it might make a good line for a poem. I'm awed by the forces in nature to change landscapes and... well... to create... pebbles.
Indeed, pebbles in all their humble glory are evidence of *past* energy, bodies acted on and changed! Amazing!

By the way, did you know they say the earth is billions of years old?

Keeper of Time: *I know a lot of things.*

Eternal Student: And of course there was Siccar Point.

Keeper of Time: *Yes?*

Eternal Student: Part of the sea's old bed, displaced by ructious parts beneath to form the start of uplands. So, exposed and pushed, colliding with and joining then the land that was, none guessed into its ancient past … till Hutton, of course.

A singular man that James Hutton and an Edinburgh man, you know.

Keeper of Time: *That seems beside the point.*

Eternal Student: Perhaps.

Keeper of Time: *Have you more to say before I close this record?*

Eternal Student: Just that I dreamt the stones had lived...
Igneous, sedimentary, metamorphic and their hearts' substance, the minerals which met, combined and danced together:
– in burning frenzy, igneous;
– sedimentary, slow pas de deux of passing partners;
– metamorphic, the contortionists' bolero.

It was time well spent.

Keeper of Time: *I shall add it to the record.*

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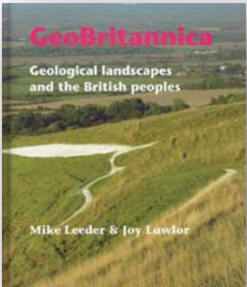
In 2014 Gayle did a short course on 'the Geology of Scotland's Coast', part of Edinburgh University's Open Learning (taught by Angus Miller). The above was her submission for that year's Martha Hamilton (Open Studies) Writing Competition, for which she received third prize.

Book review

GeoBritannica: Geological landscapes and the British peoples by Mike Leeder & Joy Lawlor. Dunedin Academic Press, Edinburgh. 2017. Hardback, 281 pp. Price £24.99. ISBN 978-1-78046-060-4



GeoBritannica by Leeder & Lawlor is an attractive book, beautifully illustrated with high-quality and well-chosen photographs, together with eye-catching maps and diagrams. It immediately makes one want to pick it up and devour its contents.

Within its glossy covers is an account of the geological foundations of the many and varied landscapes of the island of Great Britain, which the authors call 'the Island'. But that is not all: it is also about the influence of Britain's geology on the daily life, work and creativity of the generations of people who have lived here since the last glaciation. The authors themselves have been conscious of, and mentally shaped by, landscapes from their earliest years, one becoming an academic geologist, the other an artist, art teacher and English graduate. The book is a collaborative attempt to marry Britain's geological past, landscapes and raw materials with the social, industrial and artistic history of its inhabitants. It is written for those interested in both the sciences and arts and assumes a basic secondary-school knowledge of geology, history and culture. Its antecedents include such classics as A E Trueman's *Geology and Scenery in England and Wales* and *A Land* by Jacquetta Hawkes, both published over half a century ago, and more recent accounts such as *The Hidden Landscape* by Richard Fortey.

The book is divided into seven parts and 34 chapters. Part 1 introduces the book's main themes: the richness and diversity of Britain's landscapes; the British peoples' relationships with landscapes and the underlying geology; the rise of scientific enquiry into the Earth's origins and development; and geology and landscape as represented in works of creativity. Part 2 then recounts how, through objective observations in the field, geological maps were made and how subsequent developments, such as radiometric dating techniques, greatly clarified the length, complexity and causal processes of Earth's history. Part 3 follows with an account of Britain's geological history, set in the context of plate tectonics and the Pleistocene glaciations, and plentifully illustrated with maps and reconstructions.

Parts 4 and 5 look at Britain's geological resources and how they have underpinned Britain's economy, shaped communities and inspired literature, sculpture and painting. The constructional and artistic activities of Britain's inhabitants are discussed in Part 6. Here it is argued that not only has our creativity been inspired by landscape but our appreciation of landscape has in turn been shaped by the works of architects and builders, sculptors, painters and writers. Finally, in Part 7, Great Britain is divided into seventeen 'GeoRegions', each one the subject of a chapter in which its geology and landscapes are summarised, together with the essence of its human heritage. These chapters are brief appetisers, to be sampled when planning a visit, perhaps, to an unfamiliar area of Britain. An extensive bibliography provides more detail.

Do the authors draw a convincing connection between Britain's geological heritage and the sum of human activity on this island? They certainly do; and *GeoBritannica* should bring geoscience to life for non-scientists while showing scientists that one can appreciate and interpret the natural world through feeling as well as through analysis.

I do, however, have some criticisms. Non-geologists will struggle with some of the terminology and complexities of British geology. Although there is a glossary, some of its definitions lack clarity. There are small but unsettling inaccuracies, such as the attribution of the Iron Bridge to Thomas Telford or the confusion of the Scott Monument with the statue it houses. Some geological maps and cross-sections require so many colours that it is difficult to distinguish all the shades and hence reliably identify the rocks they represent. The text is sometimes irritating, for example in its use of unfamiliar words ('corried', 'riffing'), and occasionally baffling, as in the analogy drawn between Anglesey and Orkney in Chapter 30. Careful editing would have picked up on these and other minor flaws in what is otherwise a highly unusual, enlightening and thought-provoking book. Read it and have your horizons expanded.

Christine Thompson

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All previous issues are available online at www.edinburghgeolsoc.org/publications.

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