Geological history of the Upper Loch Torridon coastline

The coastline next to the hotel consists almost entirely of only two rock formations: the Lewisian Gneiss Complex and the Torridonian both of which are very old and belong to the Precambrian era of geological time. The Lewisian Gneiss is composed of a variety of igneous (once molten) and metamorphic rocks (changed by extreme heat and pressure when tectonic plates collide) and is about 3 billion years old (abbreviated to Ga) which is about two thirds of the age of the Earth at 4.54Ga.

The Torridonian is an informal name for the reddish-brown sandstones which overly the Lewisian Gneiss (abbreviated to Lewisian here) and is about 1 Ga old, but its more formal name is The Torridon Group. Thus, there is a very considerable time gap between the gneiss and the overlying sandstones, which geologists refer to as an unconformity, during which no rocks survive due to erosion.

These sandstones not only constitute one of the major units of British stratigraphy (layered sedimentary rocks) but form many of the majestic mountains in the NW Highlands Geopark, but as seen in seismic cross sections, they also lie under the sea in the Minch, extending over a N-S distance of 330 km. The sandstones themselves are known to geologists as medium to coarse grained arkoses due to the high feldspar content which constitutes about 40% of the rock. In detail, the feldspar contains both K-feldspar and Na-plagioclase varieties, which suggest a source from continental rocks that had been eroded rapidly (otherwise the feldspar would most likely have weathered to clay). From geochemical data, these sandstones have probably only been very slightly affected by weathering since deposition and from palaeo-current directions (the approximate flow directions measured) the source of all this sediment was from the west, far beyond the present-day Hebrides.

The total thickness of the Torridon Group on land was at least 4 km thick and 6 km deep offshore in the Minch, which gives an estimated total volume of over 150,000 cubic km of sediment, making it the most extensive sedimentary rock group in Britain. The uncertainty of the total depth on land is due to several factors – the fact that there is no single location which spans the entire group, and that the group is cut in half by faults which have an unknown amount of movement.

In the mountain above, the Lewisian is the grey, hummocky rock in the foreground, with the darker Torridonian on top.

This vast volume of 'Torridonian' was deposited on the edge of a continent known as the Laurentian shield, by the erosion of what may have been the largest mountain chain the world has ever known, called the Grenville belt. Remains of this vast mountain range can still be seen in Canada and the Appalachians today. Their erosion produced a huge quantity of stones, sand, silt and mud which was deposited in a sedimentary basin by eastwards flowing, braided rivers (covering wide areas and not constrained in valleys), within a hot and dry environment, with much flooding and temporary lakes forming. Much like Utah today.

The Torridonian has long been assumed to have accumulated in a rift environment (think of the modern day East African rift here) within the Neoproterozoic 1,000 to 542 million year old (Ma) supercontinent of Rodinia, which formed about 1.2 billion years ago from mountain building events when the Earth's tectonic plates collide.

The Applecross Formation (a rock unit with distinctive physical or chemical features which are visible on a 1:50,000 scale map) was probably deposited in a 70-80 km wide rift valley, a large enough basin to have deformed the crust with the vast sediment load, just like the weight of ice during the past 2 million years lowered the Scottish crust, giving us raised beaches which are common on the west coast.

Eventually, when these rivers reached the sea, a gigantic delta formed (like the Mississippi or Nile) which contained about 10km depth of sediment. Eventually this deltaic sediment was caught up in a later orogeny (mountain building event) which we see in Scotland and produced the rock succession known traditionally throughout the NW Highlands as the Moine.

A modern equivalent of such a vast delta at the present day would be the Ganges River system, which has carried trillions of tonnes of sediment from the rapidly eroding (and still rising) 2,000 mile long Himalayan mountain range.

After such a long period of time, there are in fact only traces of the Grenville mountains left in Canada and USA, but enough to provide the clues to interpret the geological history of what is now the Scottish Highlands.

The lake deposits at the base of the Torridon Group occupy deep palaeo-valleys in the Lewisian (i.e. in valleys in the Lewisian before the Torridon was deposited) with valley sides up to 300 m high, as seen between Gairloch and L Torridon. These valley filling sediments are referred to as the Diabaig Formation (a body of rock having a consistent set of physical characteristics that distinguish it from adjacent bodies of rock). The Diabaig is comparatively thin however, since the bulk of the Torridon Group is red sandstone, divided into two Formations: the coarse-grained, pebbly Applecross Formation below, and the fine-grained, pebble-free Aultbea Formation above.

Fossils

The Torridonian has long been regarded as unfossiliferous (without fossils) largely because it was regarded as being deposited long before complex life forms had evolved and was clearly a desert like Formation. However, as far back as 1907, small spore-like objects had been spotted under the microscope, in phosphate rich lenses within the grey shaly beds within the Diabaig Formation.

The first simple bacteria which evolved (Prokaryotes) in the sea 3.6 Ga ago and provided the first oxygen whereas the first cells with a nucleus (called Eukaryotes) evolved 2 Ga years ago and in 2011 it was announced that the oldest terrestrial Eukaryotes found in the world were actually preserved in these phosphate nodules around Loch Torridon! They lived in the freshwater lakes, and are thought to have been the ancestors of life on land, leading 500 Ma later to lichens, and mosses.

In 2021 a paper was published which described these billion-year old, multicellular organisms which under the microscope can consist of a solid, spherical ball of tightly packed cells, enclosed in a single layer of elongated cells. They have been given the scientific name of Bicellum brasieri and are believed to be part of the Holozoa group of organisms which includes animals and their closest single-celled relatives. Their importance lies in the simple fact that they demonstrate that simple cell division had taken place (in the evolution of life) long before more complex life (like trilobites for example) can be recognised in the geological record.

The phosphatic lenses also contain microbial mat-like structures (stromatolites) which represent primitive bacteria (cyanobacteria, formerly known as blue-green algae), and which are well known from other very old sedimentary rocks throughout the world. These organic traces were preserved because the depth of burial was not sufficient to heat the Torridonian rocks sufficiently to destroy them, unlike the time-equivalent metamorphic Moine schists in the Highlands which was strongly metamorphosed (extensively changed by heat and pressure).

The cyanobacterial mats have in fact changed very little in the past billion years as similar structures can be seen in temporary lake deposits today. They represent some of the earliest life forms on Earth. These early cells are known as prokaryotes and contain a single strand of DNA, but do not have a cell nucleus or any other specialised cells. Cyanobacteria continue to thrive today and are related to algae.

Upper Loch Torridon

On this coastline the lowest part of the Torridon Group is known as the Diabaig Formation, which is relatively thin and comprises sandstones, siltstones and breccias (rocks made from fragments of earlier rocks). These are interpreted as alluvial desert fan deposits formed on the flanks of palaeo-valleys (those that existed in the past) and this geological description will focus on the nearby Diabaig Formation and its overlying companion, the Applecross Formation.

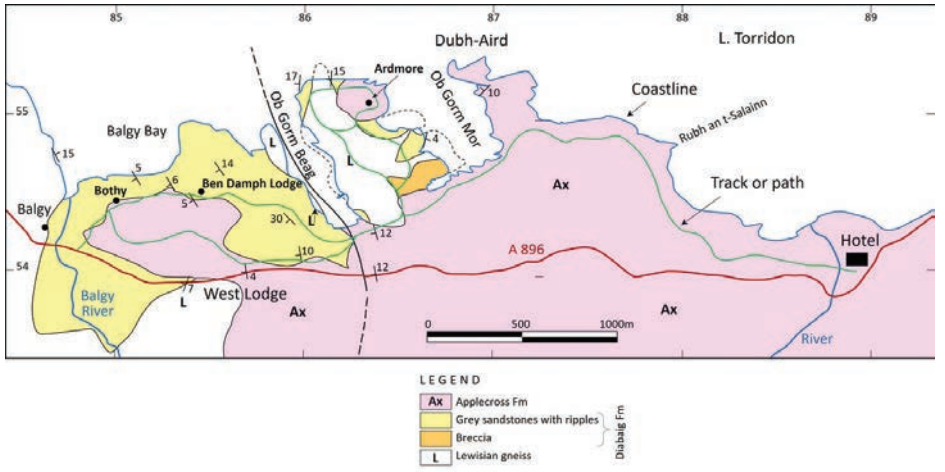
The Diabaig can best be seen along the southern and eastern shores of Ob Mheallaidh, the southern shore of Corran Badan Mhugaidh bay, with a small sliver at the north-western tip of the eastern shore of Ob Gorm Beag (below the OS trig point on Mas an Aird Mhoir).

But the Diabaig Formation is rather special for another reason.

The rock slab below this information board clearly shows wavy surfaces preserved in the grey, fine-grained rock. And elsewhere in the exposures along the coast, both desiccation (drying out) cracks and even rain prints have been preserved.

The wavy surfaces are called ripple marks, just like the ones we see on a sandy beach beside the sea or inland lake today and so it is very likely that they formed in the same way as they do today, by wind agitating the sediment in shallow water. But how would this have happened in a vast predominantly sandy desert?

These shales (very fine-grained rock) are believed to have been deposited from fresh water lakes because of their low boron content and lack of primary carbonate. The lakes also appear to have been shallow because there are many mud-cracked surfaces.

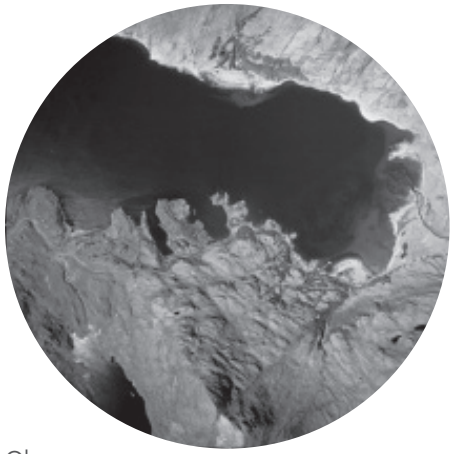


The gradual thickening of the shales towards the south suggests that there was a single large lake that developed over the drainage system as a result of regional warping. The gently erosional upper surface of the shales marks the arrival of a great flux of coarse sandy sediment and water – the Applecross Formation.

The Diabaig sandstones and breccias are all feldspar-rich arkoses. The lacustrine (lake derived) shales however, have a quite different source as they contain far too much potassium (K) and iron (Fe) to have come from the local gneisses, due to the mica (a thin shiny mineral) content of the shales. This is to be expected

because the rivers carried mud and silt in suspension from distant mountains, whereas sand and pebbles could have fallen in from nearby hills.

The nearby shore of Loch Torridon has many peninsulas and embayments which are in fact palaeo-valleys, that is, valleys up to 250 m deep eroded into the underlying Lewisian Gneiss (in Precambrian times) and which were filled by the overlying Torridonian sediments around 1 billion years ago, and selectively eroded again by the Recent ice age. A case of an ancient topographic relief coming back to the surface again after a billion years or so and now invaded by the sea. In general, these palaeo-valleys trend north-westwards, parallel to the foliation in the gneisses, but the original river flow directions cannot be determined from the topographic reconstructions. These valleys are, from west to east in the Upper L Torridon area, Ob Mheallaidh, Balgy River, Ob Gorm Beag and Ob Gorm Mór.



Ob

Mheallaidh bay is surrounded by well-exposed Diabaig Formation and on the south side the grey shales exhibit wave ripples which trend roughly in a SE direction, and on the south-eastern corner of the bay, a bed of massive breccia lies on the gneiss surface near the HWM, passing upwards into grey shale with thin phosphatic layers. A small exposure of Diabaig breccias are also exposed on the west side of Balgy Bay, clearly containing blocks of the local Lewisian, ranging in size from 10 cm up to a metre, and overlain by sandstone. Overlying sediments near Balgy are mainly grey sandstones with films of greenish-grey siltstone and abundant wave-induced ripples, again trending in a SE direction.

On the eastern side of this palaeovalley, these grey sandstones are overlain by red sandstone with planar cross-bedding (see below) in sets about a metre thick, with pebbles of quartz and feldspar up to a centimetre in diameter.

In Ob Gorm Mór, the Diabaig Formation consists of gneiss breccias and red sandstones overlying the basement topography, with ripple marked sandstone enveloping gneiss blocks at two places (Grid refs).

Nearby, the contact between the Diabaig Formation with the overlying Applecross is sharp and locally erosive, as seen by up to metre deep gullies cut into the breccia. The Applecross Formation is composed entirely of medium to coarse grained sandstone with trough shaped bedding.

Self-guided route

Self-guided route about 6km long

1

From the Hotel, walk west over the bridge and along the Ben Damph track for about 4 km until you can see a bothy about 100m ahead, then turn sharp right down a short tractor track to the beach, and head east toward the first exposure at grid reference NG 85093, 54638 where you will see pale brown sandstone of the Diabaig Formation (Fm). It has a shallow (10 deg) dip west and although covered with a black organic growth which is very slippery (CARE) you should be able to see a 10 cm thick layer of rubbly conglomerate.

If you continue up the track beyond this gorge and then take a path on your left (where the vehicle track takes a sharp deviation to the right), there is a very pleasant path around the northern end of the peninsula, where you will by now recognise when you come across the red Torridonian rocks again as you approach the house. Rejoin the Aird Mhor track and head east back along the original Ben Damph lane back to the Hotel.

2

Nearby, alongside the wall above the high-water mark (HWM), there is a 1m thick outcrop of well layered brown shale (NG 85033, 54657) at the base, covered by a 1m thick layer of tough sandstone which exhibits ripples on the top surface.

3

Just beyond, at the end of the wall along the HWM, there are several large fallen blocks of greyish sandstone beneath some birch trees, with promient rippled surfaces.

4

Continuing eastwards along the HWM, at NG 85263, 54704, there is a triangular exposure less directly below the new (2022) Ben Damph Lodge (just visible on the skyline). Note that the rippled silty beds at the base are grey while the upper part of the exposure is red. Weathering has highlighted the ripples as thin wavy lines on the vertical (joint) surfaces. The ripples are also prominent on the uppermost surfaces of the outcrop.

5

Only a short distance further on as you walk towards the Rubha Molach Mor headland, there are extensive exposures of rippled surfaces within the grey Diabaig Fm on the HWM, partly covered by brown seaweed at NG 85328, 54938.

6

On the eastern side of the headland, you will see a gully in the low cliffs on your right at NG 85510, 54964, which displays prominent cross bedding on either side. This was caused by changing river direction and new channels being cutting across previous layers.

7

At NG 85490, 54942 Diabaig Fm breccia lies above the older Lewisian rocks. This is called an unconformity, a surface which represents a considerable time gap, in this case about 2 billion years! What happened to this part of the Earth's crust during this enormous stretch of time is, of course, unknown since there are no rocks present to tell us!

At NG 85790, 54760 you will have reached the southern end of this small inlet so proceed up the grassy bank through an area of new tree planting with plastic deer protection tubes around the young trees, leaving a low, rounded hill (of Lewisian) to your left. Follow the edge of this hill with a flat peat filled valley to your right along a compass direction of 140°. This flat valley in fact marks the line of the Lewisian-Diabaig unconformity. As you proceed, keeping this rounded, well wooded hill to you left, cross a small stream and descending to the beach at

NG 85725, 54798, close to the southern end of the Ob Gorm Beag inlet, you will see the breccia – Lewisian junction once again.

The route you have walked since leaving the coast at exposure 7 above, represents a two billion year time gap, just a pity it has all been covered by the peat since the ice age!

From here, walk due south to intersect the track between Balgy (to your right) and Torridon hotel (to your left) and proceed east on the track towards the Aird More peninsula to NG 86776, 54632. Here you will be very close to a SW-NE sea inlet with prominent red cliffs on the far side.

Although it will not be easy to spot from this distance, those cliffs opposite are made of breccia – perhaps 4-5 m thick. While it is quite possible at low tide to cross this embayment, the seaweed is both abundant and very slippery, so to save you the trouble, the photo below shows what it is like close up.

Note the rucksack for scale at the base of the cliff.

There are also faint white laminations which could well be billion-year-old algal structures called stromatolites:

From your viewing point on the track, continue to head east for a short distance to where there is a prominent wall on the seaward side and an historic but redundant gate on your right, at BG86906, 54673. The cliff like exposure here is part of a considerable thickness of the Applecross Fm (which overlies the Diabaig seen on all previous exposures). Note in particular the variable thickness of some of the beds, and the occasional more shaly beds which exhibit signs of ripple marks and where erosion generated the overhang, possibly at a time when sea level was higher after the ice age.

Reverse your steps back west towards the bothy and take the vehicle track (and past the gate) towards the heart of the Aird Mhor peninsula. Soon you will come to a gorge with very steep sides, with loose angular blocks on the left and, by contrast mostly smooth and often shiny Lewisian rock surfaces to your right which exhibit prominent ice scratches from the glaciers.

And if you look carefully enough, there is evidence of a vertical dyke (igneous intrusion) on the same cliff. *(The dyke is part of the Scourie dyke swarm trending SE-NW and generally basaltic in composition. The dykes were intruded 2.4-2.0 Ga and subsequently metamorphosed to amphibolite (dark grey-black hornblende-rich rock) in the Laxfordian orogeny around 1.7 Ga).*

If you continue up the track beyond this gorge and then take a path on your left (where the vehicle track takes a sharp deviation to the right), there is a very pleasant path around the northern end of the peninsula, where you will by now recognise when you come across the red Torridonian rocks again as you approach the house. Rejoin the Aird Mhor track and head east back along the original Ben Damph lane back to the Hotel.

Appendix

Sources: Text and diagrams have been taken from: *The Later Proterozoic Rocks of Scotland: their sedimentology, Geochemistry and Origin.* Geological Society Memoir No 24 by A D Stewart. 2002.

J Fenton: Wester Ross Rocks, the Geology and Scenery of Gairloch and District. 2015. (https://www.jeremyfenton.scot/Wester%20Ross%20Rocks.pdf)

Dr John N Bennett FGS