Wester Ross ROCKS

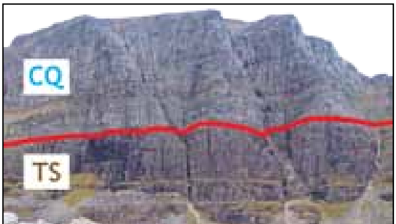
The Geology and Scenery of Gairloch and District

CONTENTS

It is very difficult for us to get our minds round the time involved in creating this landscape. The red scale opposite imagines the Earth's age (4570 million years) as one day.

The human race has been here for less than one minute, and recorded human history has lasted less than four seconds.

Our Lewisian Gneiss is the oldest rock in Western Europe, starting at breakfast time and being baked until 3.00 pm!



Cover: Coire Mhic Fhearchair (p34)

This Guide summarises the geology of central Wester Ross, and gives a brief introduction to the relevant parts of the science of Geology, the study of rocks. This is the key to explaining the uniqueness and the spectacular scenery of the area; it is the unique rocks which make it is so different from the rest of Scotland. *But* a guidebook is no substitute for seeing the rocks themselves: note pages 31-36, "Places to Visit".

This area, along with Coigach and Assynt to the north, played a vital role in the early development of geological ideas, and has been intensely studied since then; it is of worldwide importance.

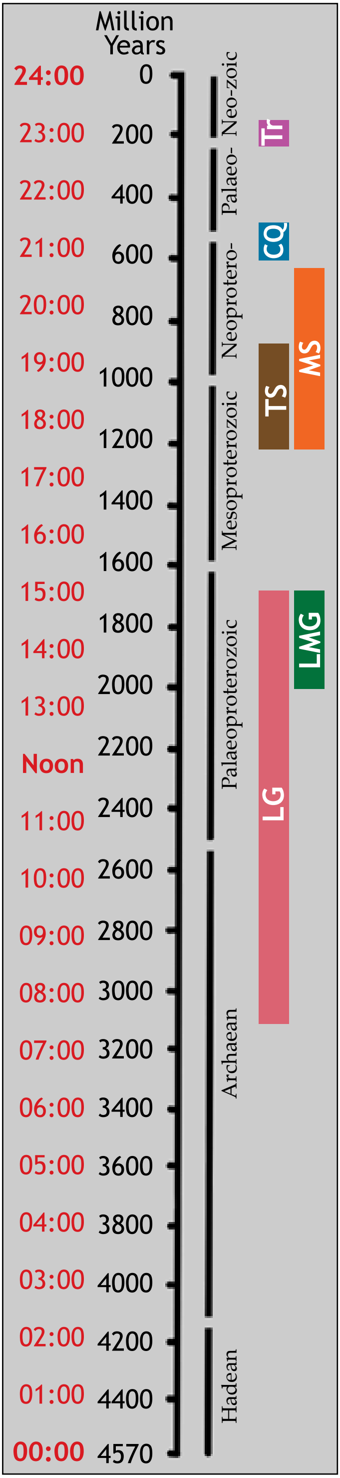
The basics of our geology are reasonably simple: see the **yellow boxes** which are largely non-technical. But once you delve deeper, things become complicated. This booklet has to pack in a lot of information, and is not all easy: beware!

Pages 2-8 give some technical Geological background; it is all relevant to Wester Ross, but you may prefer to skip to page 9 and refer back later.

Jargon Warning. Geologists use a lot of technical terms. Only useful or interesting ones are given here. Most are in **bold print** when first met (**Lithosphere**). Some more important ones are given in blue print where they are defined, and the page number of this definition is given superscript elsewhere (**Protolith**, protolith[7]); these are also listed in a small glossary on the last page. Also **(p9)** means "see page 9".

Enemies. In this part of the world there are several natural enemies of geologists. Many rocks have **LICHEN** growing on them, which disguises them. Many outcrops are **WEATHERED** by air and water, which changes their surface colour (mostly to grey!). Although the area has more exposed rocks than most, the rock is often **OVERGROWN** by moss, heather, bracken etc.

Maps. The **geological maps** in this booklet are only sketches, produced with the kind permission of the **British Geological Survey: ©NERC**. A BGS geological map or the iGeology app is recommended; the **BGS Gairloch map (1:50,000)** is excellent, and can be ordered online; the other local 1:50,000 maps are sadly unclear and out of date.



Main Colours and Abbreviations used:

	LG	**Lewisian Gneiss**	p10
	LMG	**Loch Maree Group**	p14
	TS	**Torridonian Sandstone**	p17
	CQ	**Cambrian Quartzite** etc	p21
		Moine Schist	p23
		Triassic / Jurassic	p22

See back cover for a quick key

my = **million years** (age/ago)

! An exclamation mark highlights some especially interesting features: e.g. the **GOLD** found in one place, rock damaged by a **METEORITE**, signs of early **LIFE**, landscapes a **BILLION** years old...

The story of Wester Ross started 3100my (million years) ago when micro-continents were formed, made of Granite-type rocks. These were then buried deeper in the Earth's crust and turned into a metamorphic rock called Lewisian Gneiss. They suffered a series of further changes and additions, including the Loch Maree Group rocks, until 1670my ago several of these micro-continents joined together and became the foundation of North-West Scotland, the oldest part of Britain.

These rocks were then worn down and rose to the surface to make a bumpy landscape, perhaps like the Gruinard area today. On top of this, 1200-950my ago, a huge quantity of sand and stones was laid down by rivers. In time this turned to sedimentary rock, the Torridonian Sandstone.

This was worn down in turn, and it was under the sea when the next layers of rock were laid down on it; these include Cambrian Quartzite, and later Triassic Sandstone.

430my ago, a continent collided with eastern Scotland, pushing up the Caledonian mountains, and driving a rock called Moine Schist west towards our area; luckily this “Thrust” stopped in time, and Wester Ross escaped being buried.

Finally, our landscape was formed by millions of years of erosion, the finishing touches being put to it by the Ice Ages. The result is the wonderful scenery of hills, glens, crags and lochs which we enjoy today, made from the ancient rocks.

If you want to skip these technical pages, go straight to page 9!

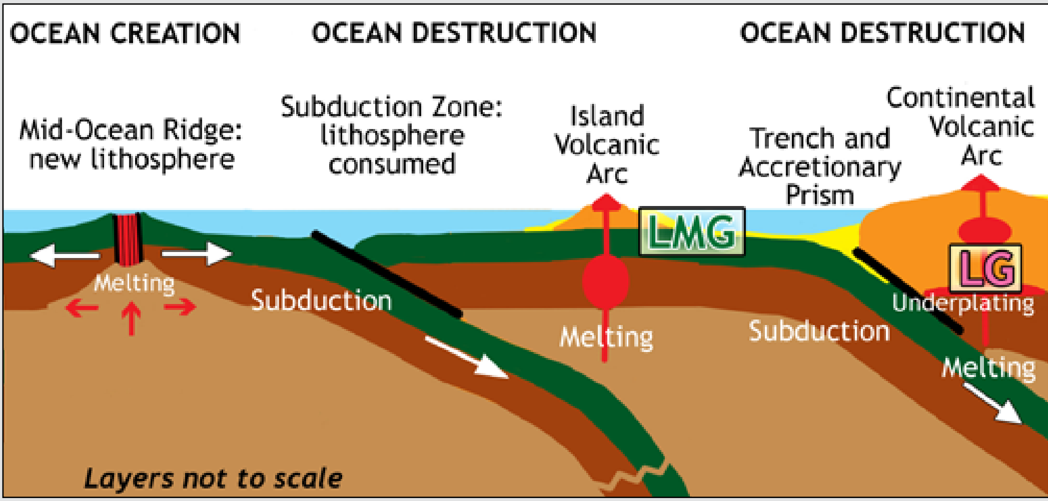
PLATE TECTONICS

In the past 60 years geologists have developed Plate Tectonic theory to explain the continents and oceans of our world. The Earth has a solid Crust (like ice on water). This consists of thinner ocean floors (like pack ice) and thicker continents (like icebergs); these float, not on liquid, but on an almost solid layer of rock called the Mantle. The crust is divided into large plates, which move very slowly (2 to 10 cms a year), colliding and dividing. Oceanic crust is regularly destroyed by being swallowed down into the mantle below in one place, and created in another; the oceans are thus nowhere more than 200 million years old. Continental crust is lighter and is not destroyed, and so is much older, although continents can collide to form mountain ranges, or split to open up new oceans.

- **Oceanic Crust**, 7-10km thick, made of dense mafic[4] rock. *([4] = see page 4)*
- **Continental Crust**, 25-70km thick, made of both mafic and lighter felsic[4] rock.
- Top of Mantle, forming with the Crust the relatively rigid **Lithosphere**.
- Upper Mantle **Asthenosphere**, which at >1280° is softer and can flow.
- **Sediment** forms when crustal rocks are eroded: mud, sand, pebbles etc.
- Liquid rock, **Magma**, can intrude into or be formed in the lithosphere.

Why do plates move? (1) Convection currents form low in the mantle; the rock rises (very slowly and still virtually solid), spreading when it hits the lithosphere and pushing it sideways. (2) In subduction[3] the mass of the descending part of the plate pulls the rest after it. (3) Mid-Ocean Ridges are higher than the rest of the oceanic crust: their mass tends to sink and make the plates spread outwards.

Ocean Creation. In the middle of an ocean, the plates move apart (a **Divergent Boundary**). Rock from the asthenosphere rises and melts, forming magma; this rises to create new oceanic crust. There may be undersea eruptions, and **Black Smokers** (hot springs carrying minerals) may form *(e.g. mid-Atlantic).*

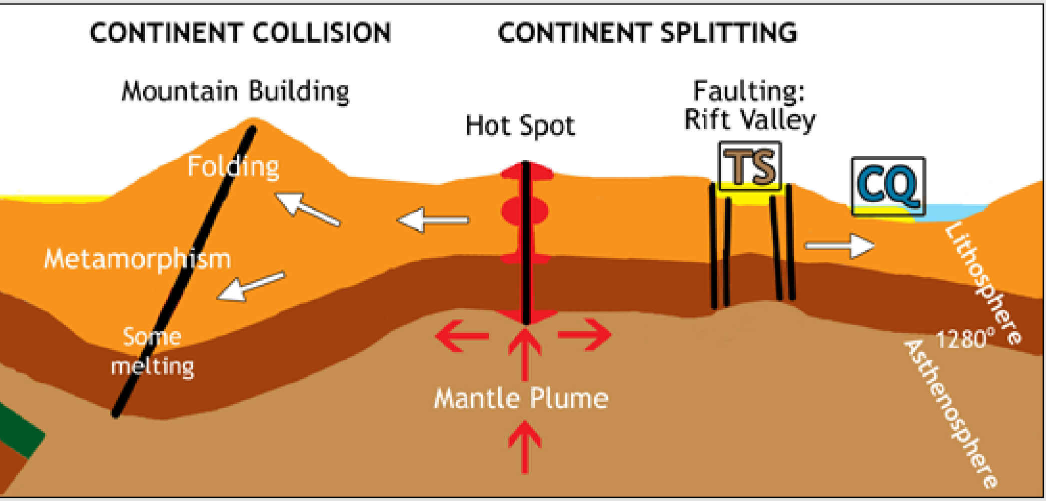


Ocean Destruction. Where two plates meet (a **Convergent Boundary**), one is pushed down into the asthenosphere, a process called **Subduction** ("taking-under"). It is carrying water which rises, reducing the melting temperature of the mantle rock above it. This rock partially melts and rises to meet the crust; it may find its way up through the crust to form a **Continental Arc** or an **Island Arc**, a row of volcanoes *(e.g. Andes, Pacific west rim)*. Sea-bottom sediment may be scraped off from the subducting plate into a deep ocean **Trench**, forming an **Accretionary Prism** which may become sedimentary rock; some of this may be carried down by and incorporated into the subducting crust, as in the LMG (Loch Maree Group). Sometimes magma may add to the bottom of the crust rather than intrude into it; this process of **Underplating** is thought to be the origin of the LG (Lewisian Gneiss).

Continent Collision. Continental crust never subducts because it is too light and buoyant. An ocean may narrow until it disappears completely, and the continents on each side of it collide; the join is called a **Suture**. This forces up high mountain ranges: **Orogeny** or **Mountain-Building** *(e.g. Himalaya, Alps)*; the base of the continent sinks deeper, displacing the asthenosphere, to maintain **Isostatic** balance (like an iceberg which sinks until it floats with 10% above the water level). Rock forced deep underground is likely to be metamorphosed by the pressure and temperature.

Continent Splitting. Sometimes, probably due to a **Hot Spot**, a continent may split and a new ocean form. A hot spot is thought to be caused by a large-scale, very slow convection current in the virtually solid rock of the mantle called a **Mantle Plume**. The land may rift as a result forming a rift valley (**Graben**; *e.g. East Africa)*, sometimes with associated volcanoes. A hot spot stays in the same place as the plates move past it; if it is below an ocean, the result may be a series of volcanic islands *(e.g. Hawaii; Iceland has formed because a hot spot is currently below a mid-ocean ridge)*.

The Wester Ross Connection. Our rocks (Lewisian Gneiss, Loch Maree Group, Torridonian Sandstone, Cambrian Quartzite) were initially formed at various points in these processes as shown on the diagram. Later mountain-building episodes caused the metamorphism of the LG and LMG; the Caledonian episode caused the Moine Thrust (p23). A hot spot caused the Atlantic Ocean to start widening (p25).



ROCKS and MINERALS

Rocks are made out of Minerals. About 4000 minerals are known, but you only need to know a few! Most of the important ones belong to a family called Silicates, made from the elements Silicon plus Oxygen (= Silica) and various others. Quartz, which is easily recognised, is pure Silica. Feldspar, which is very common, is a Silicate which also contains Aluminium. The most common elements in the earth's crust are: Oxygen (46% by weight), Silicon (28%), Aluminium (8%), Iron (6%).

Igneous rocks (and the rocks which derive from them) can be graded according to how much Silica they contain in their minerals. It is worth studying this simplified table, but be warned: **rocks in the field often appear as chaotic mixtures!**

Felsic and Mafic Rocks: a key concept. (The old names Acid and Basic are still used.) Note that when molten rock solidifies, it is said to "**freeze**"!

	FELSIC ROCKS (Acid)	MAFIC ROCKS (Basic)
DEFINITION name derived from:	**more than 65% Silica** **Fel**dspar **S**ilica	**less than 53% Silica** **Ma**gnesium **F**e=iron
Source	Continental crust	All of Oceanic crust Some of Continental crust
Colour	**Pale colours**	**Dark colours**
Weight (Density)	Lighter (less dense)	Heavier (more dense)
Viscosity when molten	High (sticky)	Low (runny)
Melting point: magma (being heated)	Lower temperature Melts first	Higher temperature Melts last
Freezing point: solid (being cooled)	Lower: typically c700° Last to freeze (crystallise)	Higher: typically c1200° First to freeze (crystallise)
Weathering	More resistant	Less resistant
Soil formed (nutrients)	Less fertile	More fertile
Igneous rock types (crystal sizes)	Fine: Rhyolite Coarse: **Granite**	Fine: **Basalt** Medium: **Dolerite** Coarse: Gabbro
Volcanoes	Steep, explosive	Broad, gentle
Typical associated minerals	*High in Silica:* Quartz, Feldspars, Micas	*High in Iron & Magnesium Oxides:* Olivine, Pyroxene, Hornblende, Biotite; also Plagioclase feldspar (Ca)

There is also **INTERMEDIATE**, between Mafic and Felsic; and **ULTRAMAFIC** (<45% Silica) which includes the rock from which the upper Mantle is made, Peridotite.

Minerals (mineral names are normally given in *italics* throughout)

Minerals grow into crystals as they freeze, or as they precipitate from liquids. If they have space, these crystals may grow freely into the fine shapes seen in reference books, which are rare here (**Euhedral**); but most often their shape is dictated by the minerals around them (**Anhedral**).

Some minerals which are important in this area:

Quartz. Pure Silica: very hard, resistant to chemical and biological attack, thanks to its strong 3-dimensional structure (**Tetrahedron**) in which all four Oxygen atoms are shared with neighbouring molecules. It is usually **white** or **transparent**, but is often coloured by impurities (small amounts of other elements) making it rosy, smoky, milky, amethyst etc. When molten rock cools, it is the last to freeze, so it fills the gaps between other minerals (e.g. in the protoliths of LG). Under high temperature and pressure it dissolves in water, and readily forms the cement in sedimentary rock (e.g. TS); it also very often forms **veins**, filling cracks in all kinds of rock. Because it resists weathering, it may be left standing out on its own when its neighbours dissolve.

Feldspars. The most common minerals in LG and TS; they form at least 50% of the Earth's crust. They are Silica + Aluminium (Al) + Potassium (K) / Sodium (Na) / Calcium (Ca) in various combinations. Under chemical weathering feldspars may turn into Clay Minerals, tiny thin plates. The two types are hard to tell apart except by experts; both can be pink due to traces of oxidised iron, and they give that colour to the TS and LG rocks.
Orthoclase (Potassium; aka K-feldspar): **pink to white**; glassy but duller than *quartz*.
Plagioclase (Sodium/Calcium): **white, pink or grey**. Not a single mineral, but a series from felsic *Albite* (Sodium) to mafic *Anorthite* (Calcium).

Micas. Hydrated Potassium & Aluminium Silicates: Water + Potassium + Aluminium + Silica. They tend to form thin **shiny plates**, which can easily be split apart; the plates are strong Silica, but are held together by weaker bonds of Aluminium and Potassium. Large sheets may be found in pegmatite (p13), small flakes in LG and TS; it is important in the LMG where it makes rock into Schist (easily splittable). Two types:
Muscovite: **pale** or transparent, or may be tinted.
Biotite: **dark** (iron): has magnesium and iron replacing some of the aluminium.

Hornblende. The main mineral in the LMG amphibolite, and also found in dykes[6] and "mafic bodies" in the LG. One of the Amphibole family, complex silicates with Iron, Magnesium and Calcium. **Black or dark green**. Forms long crystals, often visible.

Other key minerals include: ***Epidote*** (common, pale green), ***Pyroxene*** group, ***Chlorite***, ***Iron Oxides***. An interesting Iron Oxide is ***Magnetite***: it will attract small iron filings or turn a compass needle, but it's easiest to test it with a magnet (in BIF, p15).


Quartz vein


Pink feldspars & quartz


Mica in quartz


Hornblende in LG

Igneous Rocks (Protoliths[7])

All rocks are originally Igneous (= fiery) **Magma**, molten rock from deep underground, which "freezes" to become solid rock. If it freezes quickly, for example after erupting onto the surface (where it is called **Lava**), it becomes a fine-grained rock such as Basalt; if it freezes slowly, deep underground, larger crystals have time to form and it becomes a coarse-grained rock such as Granite. In this area igneous rock is only seen in a few basalt dykes. But most protoliths[7] were igneous: granite for the Gneiss, dolerite for the Scourie Dykes, basalt for the Amphibolite.

Magma (molten rock) is formed in three ways:
(1) As solid rock rises in a convection current, its pressure reduces and its melting point lowers so that it can melt.
(2) The addition of liquids (**Volatiles**, mostly water) helps the process by lowering the melting point; e.g. magma forms above a subducting[3] ocean crust.
(3) Rising magma causes the crust itself to melt.

Once magma is formed, it rises because it is less dense than the surrounding rock, and because it is squeezed by it. It tends to pool in large **Magma Chambers** in the lithosphere (p2). Then it may (1) erupt upwards in a volcano; (2) spread (**intrude**) through cracks, forming **Dykes** (vertical cracks which are thus filled with rock) or horizontal **Sills** (horizontal cracks); or (3) stay in the chamber where it cools very slowly (taking up to a million years) to form a **Pluton**, a large body of granite or similar rock, which may be revealed by later erosion (*e.g. Cairngorms*).

Mafic or Felsic? [4] The continental crust is mostly made of felsic rocks, but the rock from which magma comes is mostly mafic. How come? Felsic minerals tends to separate from mafic minerals and rise above them in three ways (refer to page 4):

(1) **Partial Melting.** As a rock gets hotter, felsic minerals melt first (at a lower temperature) producing felsic magma which, being lighter, can flow upwards, and leaving behind mafic rock.
(2) **Partial Freezing.** As they cool, mafic minerals crystallise first and sink down through the magma, leaving felsic magma. This is called **Fractional Crystallisation**.
(3) **Gravity.** Felsic rock is lighter, so tends to migrate towards the surface.

In the early Earth more heat was available and these processes were more active.

Igneous, granite

Metamorphic, gneiss

The same minerals, but in the gneiss they have been formed into bands (foliated): pink and white *feldspars*, and translucent (grey) *quartz*

Metamorphic Rocks (LG, LMG, Moine)

When rocks are forced deep underground, usually during mountain-building events, they may be altered by the high pressure and high temperature there into Metamorphic (= changed) rock types such as flaky Schist or stripy Gneiss.
NB This happens in virtually **solid rock** (if it actually melts, it turns back into igneous rock). And it happens **very slowly**, perhaps taking millions of years.

Metamorphic rocks may be **Meta-igneous** (or Meta-basalt etc) or **Meta-sedimentary** depending on the original rock which has been metamorphosed, their **Protolith**.
The age given for a metamorphic rock is normally that of its protolith.

Changes:
(1) The **minerals** in the protolith may change their texture, or they may change into completely new minerals as atoms move around; the latter change is limited by which elements are available. Most are crammed together and so crystallise anhedrally (p5).
(2) Under pressure the rock often develops layers, called **Foliation**, as similar minerals gather together. In gneiss, the rock becomes banded (*see picture opposite*), often with lighter and darker stripes of felsic and mafic minerals[4]. *Quartz* tetrahedrons (p5) clearly like to be with each other, and you can often see large white veins or lumps.
(3) The rock may be twisted, squashed, folded etc into irregular shapes without breaking: **Plastic** or **Ductile Deformation**: as opposed to **Brittle** when it breaks up.
(4) Sometimes the felsic minerals in the rock reach melting point but the mafic minerals stay frozen, and the result is **Migmatite**: a mixed metamorphic/igneous rock consisting of dark mafic rock set in lighter-coloured swirling felsic minerals (p13).

Foliated rocks include **Schist** ("splittable", with mica) and **Gneiss** (banded). In this area, gneiss started as granites (*picture opposite*), LMG amphibolite (hornblende schist) started as basalt, and LMG semipelite (biotite schist) started as a kind of sandstone.

When does Metamorphism occur? The main situations are:
(1) In mountain-building episodes[3] (**Regional Metamorphism**): most common here.
(2) At the edges of a magma intrusion, forming a ring (**aureole**) round it (**Contact Metamorphism**): not found here.
(3) When rocks slide violently past each other in a **Fault** or a **Shear Zone** (**Dynamic Metamorphism**) rocks are broken up, folded, damaged or recrystallised, and new rocks may be formed by brittle or plastic deformation. See p13 (Shear Zones).
(4) In sedimentary rock when it is buried under a huge weight (**Burial Metamorphism**); but surprisingly the TS has survived unmetamorphosed (p20).
(5) When a meteorite has struck with great force (**Shock Metamorphism**): see p18.

The intensity of regional metamorphism is **Graded**: **Low-grade** is 250-400°, e.g. slate; **Medium-grade** is 400-600°, e.g. schist; **High-grade** is 600°+, e.g. gneiss.

Metamorphism can be speeded up by the presence of fluids such as water (which is common, for example, in subducting ocean crust[3]).

[*Metamorphism is also defined more precisely in terms of the set of minerals (**Facies**) which are typically formed under certain pressures and temperatures. For example, our Gneiss was Granulite facies, about 700-900deg at 20-40km deep; but later much of it was re-metamorphosed to the Amphibolite facies, about 400-700deg and 10-25km (this is returning to a less intense grade, and is called **Retrograde**). This terminology will not be used here!*]

Sedimentary Rocks (TS, CQ, Tr)

All rocks on the surface are attacked by weathering and broken down into stones, gravel, sand or mud. A new mountain range may be worn down to nothing within 50 million years! The remains are carried away (eroded) to form layers of sediment. These are buried and turned into solid rock by the pressure, and by the precipitation of minerals from water which act as cement. The obvious examples in this area are the red-brown Torridonian Sandstone (laid down in fresh water on land) and the white-grey Cambrian Quartzite (laid down in the sea).

Most sedimentary rock (70-80%) is **Clastic**, i.e. made from particles (grains or **clasts**) of older rocks (as opposed to **Crystalline**, igneous and metamorphic rocks in which minerals have frozen as crystals). Another type is Biochemical or Biogenic, such as Limestone from sea shells etc, of which only a little is found here.

Lithification. This is the process of hardening into rock. Sediment is compacted by the pressure of overlying layers. Then the tiny spaces between the grains are filled by a **cement** precipitated from water; in the TS this cement is *quartz*, which crystallises anhedrally (p5) around the grains of *feldspar* and *quartz*.

Lithification is the first part of a process called **Diagenesis**, which also includes later changes to the buried rock under high pressure and temperature: e.g. the TS has become exceptionally hard; the coarser types sometimes appear crystalline rather than clastic; and many tiny *quartz*-filled veins may be caused by the dissolving of the cement (p20). However, above about 200° any changes become Metamorphism.

Weathering and Erosion: the processes which turn rock into sediment. Weathering weakens rock and breaks it up; erosion carries it way.
(1) **Physical Weathering.** This includes **Jointing**, the formation of cracks (**Joints**) in the rock, both vertical and horizontal. In igneous rocks this may be caused by cooling (e.g. hexagonal columns in basalt). But more commonly here it results from the release of pressure when the weight of rocks above is removed by erosion. Most rock outcrops have joints, and will eventually fall apart. Cracks can become filled with a mineral such as *quartz*, precipitated from water filtering through them, making "**Veins**". Connected with this is **Frost Wedging**, when water in cracks freezes and expands by 9%, enlarging the cracks: very common here!
(2) **Chemical Weathering.** Most minerals, even *quartz*, dissolve slightly in water (Dissolution). Water also reacts with many minerals, e.g. *orthoclase feldspar* breaks down into clay minerals (Hydrolysis); along with oxygen in the air, water can cause rust in minerals which contain iron (Oxidation). Chemical weathering can work together with Physical, rounding the edges of joints: e.g. everywhere in the TS.
(3) **Erosion.** It is left to gravity, glaciers and rivers to carry away the sediment.

Weathering varies between different rocks; mafic rocks are less stable, but *quartz* (silica) is very stable, more so than *feldspar*. Weathering also causes the generally grey appearance of many rocks by damaging the minerals on the surface.

See TORRIDONIAN SANDSTONE for more on Sedimentary rocks (p17-20).

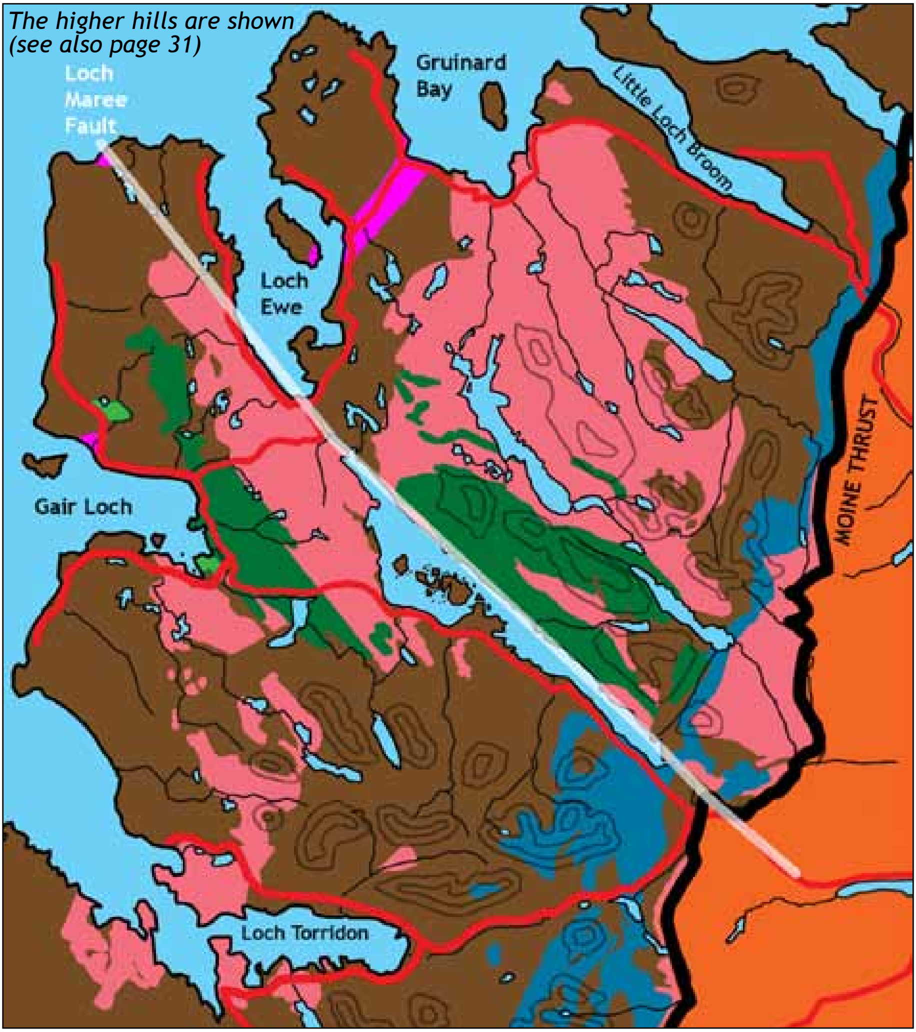
One rock may lie **unconformably** (at an **unconformity**) on another: this means that it was not laid down immediately after the rock below, but comes from a later period: there is a gap in the geological record (e.g. there may have been much erosion).

WESTER ROSS ROCKS

Simplified Map of the main Wester Ross Rocks (ages in millions of years).

	Lewisian Gneiss Complex	3125-1670	Ancient basement, metamorphic
	Lewisian Loch Maree Group	pre-1900	Later addition, metamorphic
	Torridonian Sandstone	1200-950	Red multi-layer sandstone etc
	Cambrian Quartzite etc	540	White sandstone etc
	Triassic and Jurassic	250-200	Sandstone and limestone
	Moine Supergroup	(430: p23)	Mica schist etc

NB Imagine the map with no sea or lochs! This area was part of a continent.



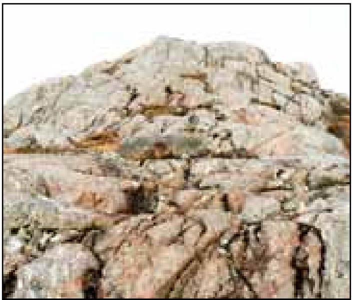
LEWISIAN GNEISS COMPLEX (LG) 3125-1670

Gneiss is a Metamorphic rock (p7); it started as granite-type rocks which were then buried deep under a continent and changed by high temperature and pressure. The Lewisian Gneiss is called a "Complex" because it is not simply one type of rock, but a series of rocks which had varied and very complicated histories over a period of 1400 million years (about a third of Earth's age!). They are ancient "basement" rocks: rocks like them form the foundation of most continents. Our gneiss has been studied more than any other such rocks: it is one of the few places in the world to provide evidence of early movements in the earth's crust.

Gneiss is a **rough crystalline (p8) rock, varied in texture and colour: white, grey, pink, with many dark patches: often weathered to grey: usually well-foliated[7]: often folded into swirling shapes.** Its dense crystalline texture makes it very resistant to weathering.

This gneiss is an **Orthogneiss**: i.e. its protolith[7] was igneous, rather than sedimentary (which would be called Paragneiss); usually it is felsic[4], made of *feldspars* and *quartz* with some *mica* and other minerals including pale green *epidote*. It started as **granitoid** (granite-type) rocks, was sent 40km underground, and was metamorphosed at high grade[7]. Later almost all of it suffered re-metamorphism at medium-grade.

Sometimes it is rather dark, containing more of the mafic mineral *hornblende*: this is called Hornblende Gneiss, and may have started as tonalite (see p11) or (very dark) gabbro. It also has in it many lumps and bands of darker rock, known as "**early mafic bodies**": mafic[4] material such as gabbro or basalt caught up in the formation of the gneiss, mostly *hornblende* and *pyroxene*, black or dark green, sometimes banded with lighter veins and stripes which are mainly *feldspar*. More obvious are numerous broad mafic dykes[6] which intruded later, known as the **Scourie Dykes**.


Lewisian gneiss


Colour variation

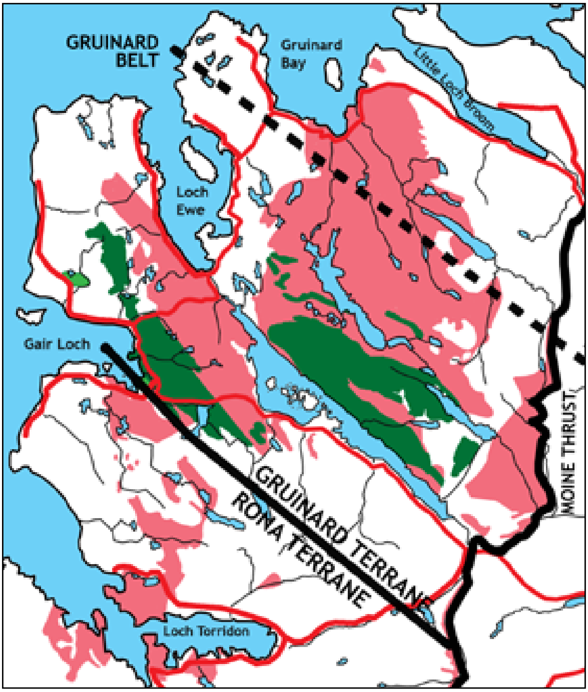

A small early mafic body

The explanation for this apparent chaos lies in the rock's very long and often violent history. It is very difficult to unravel the details of the story, but many geologists have studied the chemistry and the structure (folds etc) of the rock in enormous detail.

! The LG is the oldest rock in Western Europe. It is not (as was once thought) the oldest in the world, which is in NW Canada: 4 billion years. Other older rocks (also mostly Gneiss) have been found in Canada, Australia, Greenland, and the Baltic area. Our gneiss is related to that of Greenland and Labrador: we were once all parts of the continent of Laurentia.

Areas: Diabaig, Gruinard, Loch Ewe SW, Shieldaig (both), Tollie. **Hills:** A' Mhaighdean, Beinn a' Chaisgein Mor/Beag

It used to be thought that all the Lewisian Gneiss was the same and went through the same processes. But recent research and better methods of dating have shown that it actually consisted of separate **Terranes** (a terrane is a large section of the crust which has the same geological history), which only joined together at about 1670my. These are, from the north: Rhiconich, Assynt, **Gruinard, Rona** (or Southern), plus the later **Loch Maree Group** and **Ialltaig**. The Outer Isles have another four, although they are more related to Greenland, to which we were once joined, than to the mainland. This jigsaw formation may seem unlikely, but is apparently found in basement rocks elsewhere in the world. Conditions in the early Earth caused many micro-continents to form; these later joined together to form larger continents, stable "**shields**" which still exist. Our gneiss is a small corner of a shield which has split off, and is unique in W. Europe.



All the white and blue areas on the map above no doubt have LG under them, and it probably underlies the whole of Northern Scotland, north of the Great Glen (see p23: "inliers"), plus the continental shelf to the west; there is even some in Shetland.

We are concerned with the Gruinard and Rona Terranes, and the LMG / Ialltaig pair (p14-16). **Gruinard**'s borders are Lochinver and the Gairloch Shear Zone[13], but it may be divided into two by the Gruinard Belt (see map). **Rona** includes Torridon, Applecross and Rona. The green areas form the LMG and Ialltaig Terranes.

	Protolith date	First Metamorphism	Re-Metamorphism
Gruinard Terrane	2840my	2730my	2490my and ?1670my
Rona Terrane	3125 / 2820my	uncertain: ?2700my	1670my

The Story:

(1) Protoliths[7]. These were plutons (p6) of three similar granitoid rocks: Tonalite (more mafic), Trondhjemite and Granodiorite, together known as the TTG suite which is found in many ancient crustal rocks, made from *feldspar* (majority *plagioclase*) and *quartz*, with some *biotite*, *hornblende*, etc. We cannot be sure about processes so early in Earth's history, but it is thought that subduction[3] was shallower then, and the rocks originated from repeated underplating (p3) by magma on the base of the crust; this magma became more felsic through fractional crystallisation (p6), and eventually cooled to form these granitoid rocks. The oldest LG protolith dated so far is at Torridon, **3125my**.

(2) Archaean Gneiss. Next the protoliths[6] were sent down perhaps 40km deep and turned into **gneiss** by high-grade[7] metamorphism. This was presumably caused by continental collisions and mountain-building[3], still in the Archaean period (timeline, p1), and happened at **2730my** in Gruinard; the Rona date is still uncertain.

(2) Inverian events. These affected Gruinard, causing re-metamorphism at medium-grade[7]; the changes are hard to distinguish from those in (5) below. **2490my**.

(3) Scourie Dykes. At about **2400my to 2200my**, the region to which the LG belonged must have been stretched, because many cracks formed in it, mostly aligned NW-SE. Into these was intruded mafic[4] magma which hardened into rock, mostly dolerite (*feldspar* and *pyroxene*). The geological map of the gneiss now has numerous dark stripes across it, known as the **Scourie Dykes**[6], dark grey/ green intrusions. They are useful to a geologist for dating: pre-dyke and post-dyke events can easily be distinguished by seeing if they affected the dykes.

***(4) LMG and Ialltaig.** These separate terranes were formed and added to the LG before 1900my: see p14-16.*

(5) Re-Metamorphism. At a series of major events around **1670my**, most of the gneiss was re-metamorphosed at medium-grade[7], along with the Scourie Dykes and the LMG. The same events created huge **folds** such as the Carnmore, Tollie and Torridon **Antiforms** (arch-shaped), and the Letterewe **Synform** (U-shaped): see p14 diagram. The cause of all this was the collision of the separate terranes[11] to form the single Complex which we see today.
(The general name **Laxfordian** used to be applied to these events, but it is now thought that the terranes should be treated separately.)

Swirls in grey gneiss

Mapped Scourie Dykes

Small Scourie Dyke in gneiss

Complexity! (road cutting)

Typical Changes due to Re-Metamorphism:

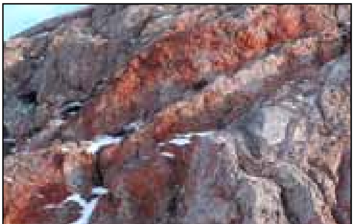
- The new metamorphism was at a different (lower) temperature and pressure, meaning that some **minerals** were changed; e.g. *pyroxene* turned into *hornblende + biotite*.
- The **foliation**[7] became stronger and finer, often as if the minerals have been squeezed into thin parallel lines, with a lot of small-scale folding.
- The **Scourie Dykes** were deformed and often merged with the surrounding gneiss; and they were metamorphosed into an unfoliated and unbanded amphibolite, **dark with light specks**: 50-75% *hornblende*, *plagioclase*, a little *quartz* and *biotite*.

• Many parts were hot enough for felsic[4] minerals to melt, producing varied forms of **Migmatite** (p7).

• New igneous rocks were intruded in a few places. Small sheets of pink **Granite** are found in the Tollie area, cutting the Scourie Dykes and the gneiss. More common are large or small patches of **Pegmatite**, a conspicuous pink or white granite-like rock with very large crystals, crystallised in water. Here it consists mostly of *feldspar* and *quartz,* and sometimes *mica*. It has been dated to 1694my ago.

• Major **Shear Zones** (or Crush Belts) developed at several places, mainly caused by the coming-together of the terranes[11]. **Shear** is deformation caused when rocks slide past each other, as in a fault (p26) or fold (p14 diagram). New rocks are made such as **Mylonite** (finely foliated, made by extreme crushing and re-crystallisation), **Pseudotachylite** (grey-black glassy rock formed by rapid frictional melting), **Cataclasites** containing pieces of **Crush Breccia** usually in a quartz matrix. Often the rock just looks very damaged and chaotic!


Migmatite


Pegmatite


Highest gneiss, A' Mhaighdean

So the LG we see today has been thoroughly changed and re-changed, affecting the minerals and the fabric of the rock and ending up with remarkably varied (even chaotic!) and interesting rock. The effects of re-metamorphism are greater in some areas than in others, and small areas survived relatively unchanged: for example, north of Gruinard River, Tollie Rock, north of the Diabaig road. Smaller relics also survive surrounded by re-worked rock.

However, these differences are often visible only to experts; it is enough to admire the rock and wonder how each colour, shape or texture got like that!

! Remember, all this happened deep underground. Imagine that you are standing at the point where the gneiss was first created: look up into the sky — the surface of the ancient world may have been 40km (25 miles) above you!

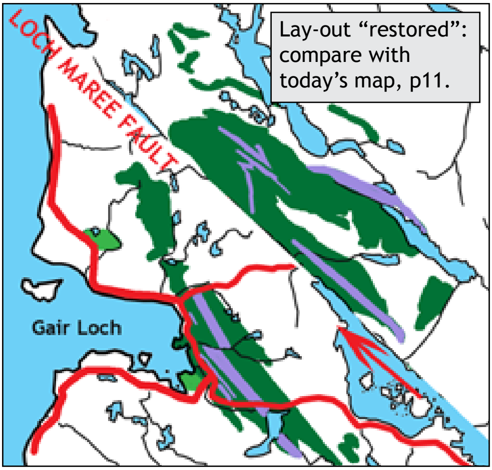
During the next 400 million years there was a lot of erosion by sea and weather; the gneiss rose to the surface and was ready to be covered in Torridonian Sandstone. Much of this sandstone covering too was later removed until the gneiss which we see today was revealed in all its beautiful complexity; but much of it is still covered by sandstone, all the other rocks of Northern Scotland, and the sea.

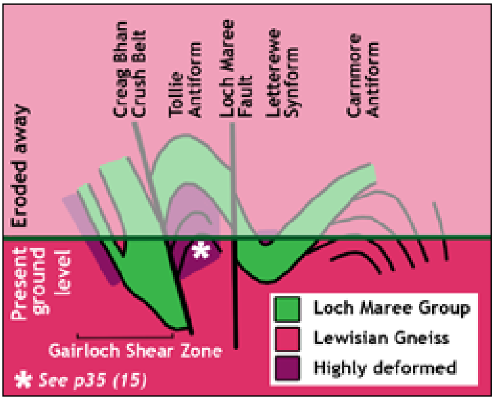
LANDSCAPE. Today the LG forms rough, rocky land with many small hills and lochs ("Knock and Lochan": Gaelic *cnoc* = small hill), or bigger ones in the Great Wilderness. The rock is lumpy and rounded, usually with an overall grey or pinkish appearance, clearly crystalline (p8). See page 30 for views of billion-year-old LG landscapes.

LOCH MAREE GROUP (LMG)

pre-1900

The rocks of this unique and important mixed Lewisian group were laid down about 2000 million years ago under an ocean. They were then incorporated into the Lewisian Gneiss after subduction[3], and metamorphosed. They are now found (1) NE of Loch Maree, where they form mountains; and (2) around Gairloch, where they form smaller hills. They are much studied by geologists and their students, telling us a lot about conditions in the world 2 billion years ago.





The group has two main rocks, whose protoliths[7] were basalt and sandstone. Together they form a so-called "subduction-accretion-collision complex"! This means that as the basalt was **subducted**[3], sediment was scraped off its surface to make an **accretionary** prism in an ocean trench (p2-3). Some of this sediment was caught up in the basalt and carried down with it. The two were then folded and re-folded together until they formed alternate strips, then mixed into the LG Gruinard Terrane during a continental **collision**. All this happened **before 1905my**; then at **1670my** the rocks were altered by medium-grade[7] metamorphism, along with the LG.

The Loch Maree and Gairloch sections are thought to be the same formation, separated by the movement of the Loch Maree Fault (p25). The map above imagines the original position before the fault moved! Compare it with the map on page 11. The cross-section shows how the two parts might have been linked as parts of a giant fold system.

Major Rocks:

Amphibolite (Hornblende Schist)

The protolith[7] of this meta-basalt came from an ocean floor (it was like Iceland's basalt), and was metamorphosed after being attached to the LG. It is a variable mafic rock, with 35-80% *hornblende* (an amphibole), 10-50% *plagioclase*, <10% *quartz*, *biotite* from none to over 10%; iron in the hornblende and biotite makes rusty patches.

It is found in various shades of green, sometimes blue-ish, weathering to grey (a slightly greener shade than the gneiss). Variable near-vertical foliation[7], usually conspicuous, gives smooth faces but often very rough texture in cross-section, sometimes even looking igneous. It is sometimes striped, with *hornblende*-rich and *feldspar*-rich bands. The *quartz* likes to clump together in thick veins and lumps.

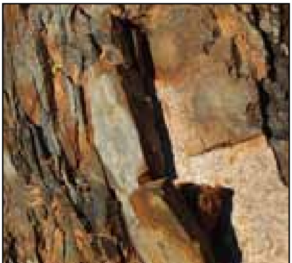
Area: East of Gairloch, NE of Loch Maree. **Hills:** Gairloch "Miniatures" (An Groban etc), Beinn Airigh Charr to Beinn Lair

Semipelite / Pelite (Biotite Schist)

Amphibolite

The protolith[7] of this meta-sediment was Greywacke, a muddy sandstone with clay and sand in it, laid down on the sea bed; ages from grains of zircon in it are **3100my to 2000my**. Semipelite has 60-80% *silica* and *feldspar*; Pelite has less than 60% and is only found north of Loch Maree (from the Greek *pelos,* mud); it also has *biotite* which contains iron, explaining the rust.

It was metamorphosed to form a soft schist; because of its softness and schisty (splittable) nature, it has been eroded to form **lower, smoother, mostly overgrown ground below the amphibolite ridges (p26). It is grey to nearly black, usually seen weathered to a rusty brown.** *Best seen in road cuttings and upper Flowerdale.*

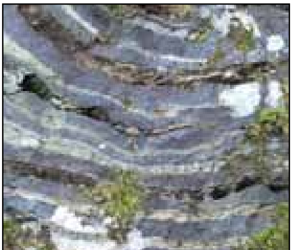


Semipelite

Minor Rocks: *(detailed geological map needed)*

There is a fascinatingly varied collection of other rocks. Their main site is a narrow strip parallel to the Old Road SSE from Flowerdale, very overgrown and difficult to find. The three "schists" are hard to distinguish in the field!

• Three show evidence of **EARLY LIFE** (**biogenic**):



Banded Iron Formation

Marble. Two types: Calcite (white) or Dolomitic (yellow, with *Magnesium*). They are poor quality deformed limestones, made from organic remains (microbes). It was quarried to make lime, at map refs 855 722 (p33 top), 811 724 (Shieldaig), 818 748 (Flowerdale). (*Picture overleaf*)

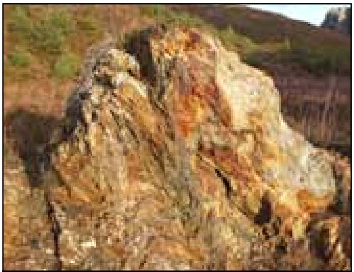
Banded Iron Formation (BIF). This is found in most Archaean basement rocks around the world, 2600-1800my old. It contains dark *magnetite* (an iron oxide, p5) and pale *quartz* in alternate bands of various thicknesses. It was laid down in a shallow sea in which there was plenty of iron (probably from hot springs) and silica but as yet no free oxygen, and oxygen was supplied by early bacteria; the bands might be explained by the occasional death of the bacteria after a bloom (like an algal bloom today), or by some seasonal factor. This is the only BIF in the UK; it is mined in Australia. Take a magnet to help identify it! See page 32 (4).

Graphitic Schist. This brown-weathering fine grey schist contains *quartz* and *muscovite mica* with 50% *Graphite*, pure Carbon which may be biogenic (or not!).

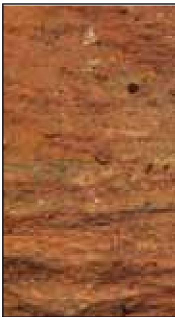
• Three show evidence of **UNDERSEA HOT SPRINGS**, black smokers, where minerals were deposited or altered **hydro-thermally** (by water + heat).

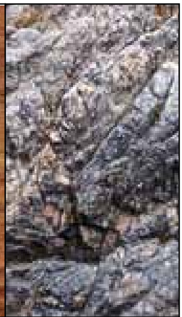
Sulphide Deposits. Black smokers bring up a rich cocktail of minerals, mostly composed of metals and sulphur, and the results can be seen at one point on and beside the Old Road, where there has been drilling: see p32 (4). Copper, Iron and Zinc have been found, with tiny amounts of Gold and Silver caught up in some of the minerals. These deposits were discovered in 1978 and drilled in 1979-83 (87 holes up to 600m deep), but found not to be worth exploiting. (*Picture overleaf*)

Quartz-Chlorite Schist. This is the most plentiful rock in the Old Road deposits, and is also found in narrow bands elsewhere. It is greenish-grey, weathering rusty brown; it looks very like the amphibolite but is softer (and so more easily eroded) and more splittable (schistose); it contains *chlorite*, a complex mineral (hydrated Aluminium Iron Magnesium Silicate). It is thought to have started as basalt which was altered hydrothermally.


Sulphide deposits

Garnet-Biotite Schist. Yet another brown-weathering rock. It is rich in ***Garnets*** (a mineral forming small red-brown crystals) and chemically somewhere between the semipelite and the amphibolite. It is thought that it may have been hydrothermally altered basalt mixed with some local sediment.


Q-C Schist


Marble

As a postscript, there are two more rocks, both **GNEISS**, and both found along the SW edge of the LMG:

Ard Gneiss. This started as granitoid rocks (Granodiorite and Tonalite) **1905my** old, and was intruded into the LMG rocks, which therefore must be older than it. It is now a varied gneiss, thoroughly deformed, often full of small *feldspar* lenses or eyes (Augen Gneiss, *right*). Bands of amphibolite which are coarser than the LMG version are enclosed by it. It is found at each end of Gairloch Beach and each side of the harbour, continuing in a strip SSE as far as Dubh Loch. *Easily seen on the beach-harbour path.*


Augen Gneiss

Ialltaig Gneiss. This is probably older than the LMG: protolith[7] about **2000my**, high-grade[7] metamorphism about **1875my**, and some medium-grade with the LMG. The LMG has no high-grade metamorphism, so the Ialltaig gneiss must have joined it after 1875my: hence it is treated as a small **separate terrane**[11]. It is meta-Diorite, more mafic[4] than the LG, speckled in appearance, with many garnets. It makes fertile soil, and is found in two small areas: one is east of North Erradale (*seen above the road*); the other forms the rough overgrown Ard Ialltaig peninsula between Lochs Shieldaig and Kerry (south Gairloch) between two shear zones which have a lot of mylonite.


The highest LMG: from Beinn Lair

LANDSCAPE. Today the amphibolite forms steep hills of all sizes. Its strong foliation gives it a sharper appearance than the LG, and it is a greener shade of grey. The semipelite underlies smoother and lower ground alongside amphibolite ridges (p26).

TORRIDONIAN SANDSTONE (TS) 1200-950

1200-950 million years ago, thick layers of Sedimentary rock were laid down on top of the Lewisian rocks; these are called Torridonian. They came in two phases, and in each phase there are distinct formations. They consist of sandstones, shales and conglomerates, mostly a reddish-brown colour because of the feldspar in them, and may have been 8km thick. Today this unique rock has been worn down and sculpted into the wonderful mountains of Wester Ross and Sutherland.

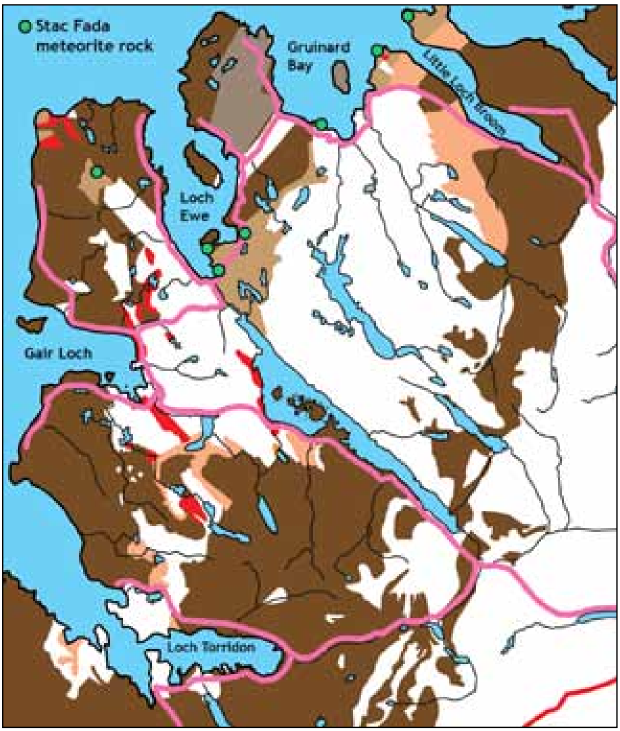
1500my ago, the super-continent of Columbia began to break up, and by 1200my the continents of Laurentia (North America) and Baltica (Scandinavia) had separated; Scotland was on the eastern edge of Laurentia. This process caused rifting, and a fault-bounded basin (graben, p3) developed between the Minch Fault and a fault possibly somewhere near the Moine Thrust. Here the Torridonian sediments were deposited.

Metamorphic rock has foliation[7]; sedimentary rocks have **Bedding**, and the layers are called **beds** or **strata**. In the TS, you can see beds made of many types of "sandstone":

- **Conglomerate**, made of stones which have been rounded by tumbling down rivers, held together by a matrix of sandstone.
- **Breccia**, a more common type of conglomerate here which has un-rounded stones, from scree slopes or wide rivers. This is normally found at the bottom level (**basal**).
- **Sandstone** proper, made of grains of *feldspar* of both types, giving the **reddish-brown colour**, and *quartz*; the cement is precipitated *quartz*. Other minor minerals may also be present. The amount of *feldspar* implies that the sand was laid down by rapid rivers in a dry (torrid!) landscape; *feldspar* quickly decays to clay in water. Strictly, a feldspathic sandstone is called **Arkose**.
- **Shale** or mudstone, very fine-grained; this may be red or grey, and was laid down in shallow lakes. It may have ripple marks etc (p19).

Group		Formation	Map Code
TORRIDON		Aultbea	TCAU
younger		Applecross	TCA
↑		Diabaig	TCD2/3
older			TCD1
STOER		(3 formations)	TAD/S/T

Standard codes used on geological maps



STOER GROUP

About **1200my ago**, the Stoer Group of rocks was laid down by rivers in a broad basin on a highly eroded and hilly landscape of Lewisian rocks; some of the sediment was local Lewisian, some from other mountains to the **west**. Three distinct types or formations have been identified, originally totalling about 2km thick but now much eroded. They are most easily seen north of the River Ewe as far as Aultbea.

(1) **Clachtoll Formation** (TAT): **gneiss breccia and red sandstone**; the lowest and oldest. *Seen north of Loch Kernsary.*

(2) **Bay of Stoer Formation** (TAS): **pebbly red sandstone**. *Seen at Inverewe.*

! Within this there is a very interesting layer about 20 metres deep, named the **Stac Fada Member**. It is **deformed (not in beds), and has a grey-speckled appearance**. It is mostly found along the coast (green dots on the map, p17). This is evidence of a large **meteorite**, an "ejecta blanket". Evidence includes: shock metamorphism of *quartz* and *biotite*; grey patches of vitrified material; chemical composition typical of meteorites, including *iridium*. The crater may be under Lairg in Sutherland or the Minch, indicated by gravity lows. It was probably an asteroid about 3km diameter which made a crater 40km wide and 8km deep (in the world top 15), melted rocks, and threw up a huge cloud of vapour and fragmented rock (like a pyroclastic flow). It is very rare to find such evidence as it is usually eroded away, but here it is recorded in the 1200my old rock, now exposed by faulting and erosion along the coast. The final proof of its origin came in 2015, when the mineral *reidite* (shocked *zircon*) was found in it. This had previously been found at three meteorite sites (Germany, China, USA), but here it is 750my older. *Best seen at Stattic Point (p36).*

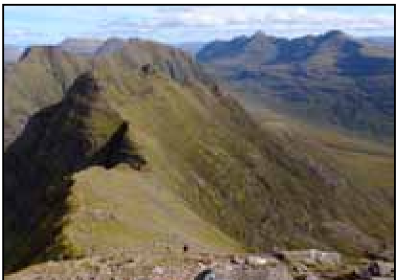
Stac Fada meteorite rock

(3) **Meall Dearg** (TAD): **pebble-free red sandstone & shale**. *Seen at Rubha Reidh slabs.*

[The **Sleat Group** comes next (TB...), but is not found here: it is only seen in Skye.]

TORRIDON GROUP

200 million years later, a supercontinent again formed, named Rodinia (including Laurentia, Baltica, Siberia and Gondwana). In Laurentia, the resulting mountain-building (orogeny) created the Grenville Mountains to the **west** of our area (their remains are seen today in Canada and the Appalachians); the weight of the mountains caused the crust to sink, creating a basin in front of them. These mountains were eroded to produce a huge amount of sediment (stones, sand, silt, mud) which flowed eastwards in fast rivers and was deposited in the basin **1000 to 950my ago** as the Torridon Group, only partly on top of the Stoer Group which had been eroded and also tilted 30° to the NW. The new group is much bigger: the most extensive sedimentary rock group in Britain, from the north coast to Islay (north of the Great Glen Fault). It may have been 5km thick: not 5km high, as it was in a deep basin which subsided further under the weight. The climate was again hot and dry: imagine something like Utah in the USA, but with wide braided rivers, much flooding and temporary lakes forming.



Torridon Hills, from Beinn Alligin

(1) **Diabaig Formation**. This is the oldest, often lying directly on LG. It is subdivided into three members:

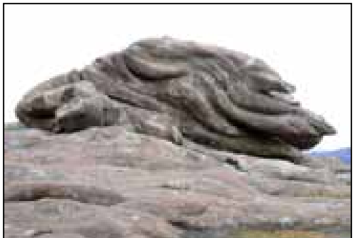
TCD1: The most interesting of the Torridonian rocks. Basal **breccia and conglomerate, mostly from local LG/LMG, and red sandstone beds**: *seen on Gairloch shore and near the road to Poolewe.* Some is made of lumps of itself (**Autoclastic**), perhaps broken up by earthquakes: *seen at Rubha Reidh and Stattic Point.*
TCD2: **Grey shale and sandstone**: *shale seen in burn beyond Sand Archaeology Trail, and Diabaig shore.*
TCD3: **Red sandstone, fine to medium grained, without pebbles**.

TCD1 Breccias

(2) **Applecross Formation** (TCA). The big one, forming the famous mountains. It is a **coarse or very coarse pebbly red-brown sandstone, very jointed**[8] **and rounded by weathering (p8)**. The pebbles include jasper and porphyry. A remarkable feature is that over half of the layers are contorted into strange shapes; there have been many attempts to explain this (one is thixotropic liquefaction of the sediment in earthquakes!), but it remains mysterious. It forms distinctive layered and terraced cliffs. *Seen along much of the coast and in the hills.*

Weathered hill-top TCA

(3) **Aultbea Formation** (TCAU): **medium-grained red sandstone**, always contorted. *Seen at Mellon Udrigle.*



Contorted bedding[17]

LANDSCAPE. Today the TS forms mountains and moorland. The mountains are highly characteristic: steep and isolated with terraced cliffs (see p35 top picture) and sharp ridges, often pinnacled. The moorland tends to be flat and peat-covered: e.g. the series of peninsulas between the sea lochs. The rock itself varies from brown to red, its colour little changed by weathering.

Features to look out for

Ripples, as seen on a beach (which this once was!)

Cracks as seen in drying mud (desiccation)

Cross-bedding: layers of sand are laid down, then the water current or wind direction changes and more layers are laid down at a different angle.

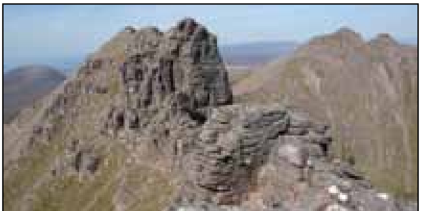
Pebbles in sandstone: sorted into layers (graded), as you can see happening on beaches

An oddity: breccia (TCD1) filling a crack in earlier sandstone (TAD)

Veins of *Quartz*:

(*above*) Thin cracks have been filled by *quartz* precipitated from water

(*below*) Cracks may be caused by shear strain[13]: here the rock has been pulled in two directions



The highest TS, on An Teallach

LIFE!

It has been known since 1907 that the micro-fossils of primitive living cells were preserved in the Torridonian rocks; these were Prokaryotes, simple bacteria, which first evolved in the sea 3600my ago and provided the first oxygen.

Eukaryotes, The first “modern” advanced cells, with a nucleus etc, evolved in the sea 2000my ago, and it used to be thought that they did not move onto land until 500my ago. But in 2011 it was announced that the **oldest terrestrial Eukaryotes** found in the world so far were preserved in phosphate nodules in the 1000my old rocks around Loch Torridon. They lived in freshwater lakes, and are thought to have been the ancestors of life on land, leading 500my later to lichens, mosses etc.

The Torridonian sandstone is very hard; in fact, too hard for a mason’s tools, so it is not ideal for building! The reason is that it was compressed under a huge weight of rock. But remarkably it was never metamorphosed, probably because it was attached to a secure stable base: the Lewisian Gneiss, which, now that it has finished its adventures deep underground, has settled down to be a proper “basement” rock. The sandstone was, however, to be seriously eroded thanks to its abundant jointing and bedding (vertical and horizontal cracks), and before the next rocks arrived it was also tilted 20° to the East and taken under the sea.

CAMBRIAN and LATER ROCKS from 540

400 million years later, in the Cambrian period when life (with hard fossil-forming shells) was really taking off, the next series of Sedimentary rocks was laid down on top of the Torridonian, on the beach and continental shelf of a sea: the Iapetus Ocean, which had re-opened when our continent, Laurentia, split from Baltica and Gondwana (p25). The first and best known of these rocks is the Cambrian Quartzite which whitens the tops and upper slopes of many of the Torridonian hills. Finally, two more rocks were added in the Triassic and Jurassic periods.

Cambrian Quartzite (CQ)

Quartzite is usually a metamorphic rock, defined as having more than 80% Silica; but here it is sedimentary and up to 99% Silica. It was laid down **540my** ago as sand along the tidal zone of the Iapetus Ocean on the SE coast of Laurentia, a 100-mile beach; the *quartz* grains survived the waves, but other minerals were broken down and washed away. *Quartz* cement bound the grains together to make a **greyish-white sandstone**; later the cement recrystallised (diagenesis[8]) so that now it is difficult to distinguish grains from cement. It makes a **hard, sharp, angular rock with cross-bedding and ripple marks, and with closely spaced jointing[8] so that it easily breaks up into blocks and scree** — which can be tiresomely rough or slippery to walk on! It also makes large exposed slabs, because the quartz does not easily break down to make soil. About 100m thick. *(Map p9)*


Cambrian Quartzite


Quartzite slab (note people)

Along with its later neighbours it forms a thin strip from Cape Wrath to Loch Carron; the strip widens in places because of the Moine Thrust (p23). At its base there is sometimes conglomerate, and some lower layers have *feldspar* in them, making them **pink**.

The upper, younger layers (c100m thick) form two special kinds of quartzite, without cross-bedding, containing our first visible evidence of life: **Pipe Rock**. The numerous pipes are made from sediment which filled the tubes or burrows made by unknown worm-like marine creatures. These fossil burrows are named **Skolithos**, and are found worldwide. The cross-sections of the tubes appear as white dots; sometimes a long vertical section can be seen. Sometimes there are wider indented circles, **Trumpet Rock**, which may represent the tops of the tubes, or may be from a different creature.


Pipes and Trumpets

LANDSCAPE. The CQ slopes down to the east, and now it is only seen on the eastern hills: it forms a grey-white capping and often scree slopes, seen most noticeably on Beinn Eighe. Its most spectacular appearance is in Coire Mhic Fhearchair (*on cover*).

Other Cambrian Rocks

Fucoid Beds

On top of the quartzite, still in the sea, several other thin layers of sedimentary rocks were laid down. Fossils have been found in them, including Trilobites which lived in a warm sea. ("Dolomite" is a limestone containing *Magnesium*.)

(1) **Fucoid Beds** (c25m thick): a brown-weathering dolomitic siltstone formed in lagoons from mud and various chemicals, with worm burrows; it produces fertile soil because of its potash content. ("Fucoid" relates to seaweed; this is a mistake, but the name has stuck.)

(2) **Salterella Grit** (c25m thick): a dolomitic quartzite; "salterella" is another worm-like creature.

(3) **Durness Limestone**: from **520my**, a marine dolomite made from algae, laid down 1km thick in deeper water. There is very little here; it is mainly found in Sutherland. It forms very fertile soil.

Found above the track to Heights of Kinlochewe, but only FB easily seen (p33).

The Cambrian rocks were now tilted so that they dipped 10-20° to the East, and the Torridonian underneath was now flat again. Then there was a long interval, during which the five major terranes[11] which make up Scotland came together, and England at last joined us: see pages 23 and 25. We are the Hebridean Terrane; the others are North Highlands, Grampians, Midland Valley, Southern Uplands.

Triassic: New Red Sandstone

Triassic Sandstone

250my ago, this red sandstone was laid down: conglomerate (p17) and varied sandstone beds, made of sediment washed down in rivers and floodplains from hills to the south, in a desert environment. There is not much to be found here: a strip from Laide to Isle of Ewe edged and preserved by faults; cliffs at the east end of Camas Mor; and under the village of Big Sand. Most of it is under the Minch. It is softer than the TS, and so breaks down to make more fertile soil, as seen on Isle of Ewe. *Seen on the shore around Chapel of Sand, Laide; also south end of Big Sand beach, on TCA.*

Jurassic Limestone

Triassic Conglomerate

The sea rose (or the land sank); then, in the Jurassic period **200my**, ago a clayey marine limestone with fossils was laid down in a strip from Sand of Laide to Loch Ewe, overlying the Triassic, but only visible in low cliffs *on the coast about 1km E of Laide. Best seen over the sea in Trotternish, where it shows dinosaur footprints.*

! Oil Exploration

In 1980 Gruinard Bay (with Trotternish, Skye) was investigated for its oil potential, since oil is often found under Triassic/Jurassic rocks. Luckily it was judged not to be worth drilling, as the rock underneath was likely to be ancient TS or even LG!

The MOINE THRUST

While the Torridonian sandstone was being laid down on land, similar sediments were arriving in the sea 200km to the East, when the Iapetus Ocean was starting to form, about 980-870 million years ago. This became the **Moine Schist** after being metamorphosed. At about 430 million years ago the Iapetus Ocean closed as the continent of Baltica moved west and collided with our continent, Laurentia: chaos! The Moine Schist was pushed west over our rocks and a great mountain range developed, the Caledonian Mountains. Fortunately the movement ended, and the "Moine Thrust" stopped in time to leave our corner of Scotland uncovered.

The **Moine Schist** which formed the Moine Thrust belongs to the Morar Division of the **Moine Supergroup**. The Moine rocks, which cover much of Scotland north of the Great Glen, were metamorphosed three times:

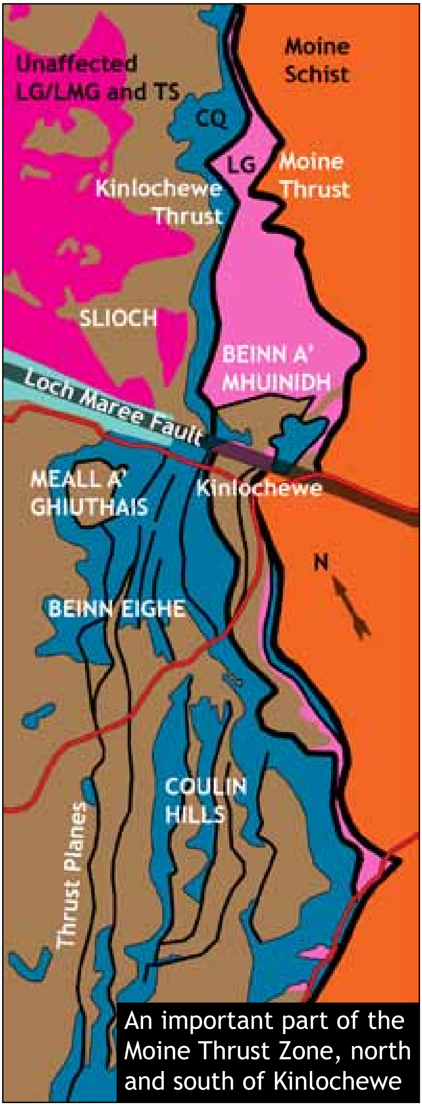
(1) The **Knoydartian** events at 850my, turning them into *Mica* Schist and other rocks.

(2) The **Grampian** event at 470my, when an island arc (p2) terrane[11] collided with Laurentia from the east, forming the Grampian mountains south of the Great Glen but also affecting the Moine Schist; this was the first stage of the Alpine-scale Caledonian mountain-building[3].

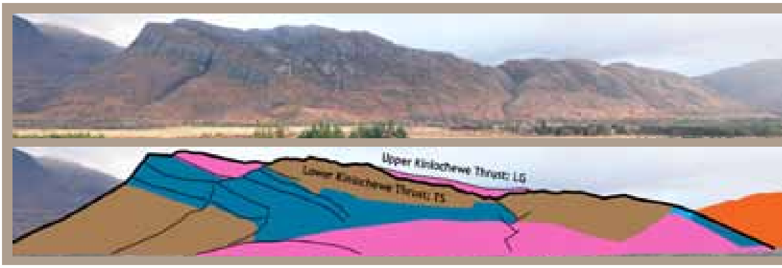
(3) The **Scandian** event at 430my, when Baltica collided from the east, bringing the second stage of Caledonian mountain-building, north of the Great Glen — and the **Moine Thrust**. (At the same time, the continent Avalonia collided from the south, forcing together for the first time the various parts of Scotland, and adding England.)

The Thrust pushed the Moine Schist west between 50 and 100km. Remember that the movement would be very slow (at most 10cm a year), and much of what follows happened deep underground, where plastic deformation (p7) could take place. Interestingly, some portions of Lewisian Gneiss survive today as islands (**inliers**) caught up in the Moine rocks: e.g. part of the Fannich Hills is Gneiss, as is much of Sgurr a' Mhuilinn south of Strathbran.

LANDSCAPE. East of the thrust, the landscape is mostly gentler and smoother than ours because the schist is easily worn down: hence the dramatic change of scenery at Glen Docherty and above Dundonnell.



An important part of the Moine Thrust Zone, north and south of Kinlochewe



Thrust: Beinn a’ Mhuinidh (Kinlochewe), is topped by two thrusts, Upper LG and Lower TS; in effect its top is now upside down

The Moine Thrust is in fact just the most easterly and oldest of a series of Thrusts, but the name is used collectively for them all. The Thrust created a major bow-wave or “zone of complication”; this is mostly less than 5km wide, but around Kinlochewe and in Assynt it is much wider, and these are the most interesting parts. Thrust faults (pushes) and Folds (bends) abound, with older thrusts riding on top of younger ones.

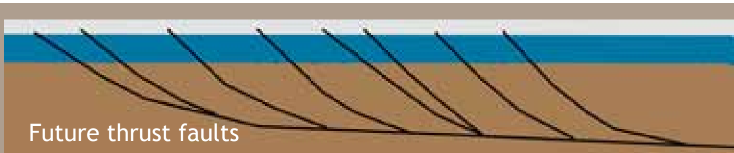
! In the hills north and south of Kinlochewe you can see many **anomalies**: e.g. older rock on the summit above younger, making upside-down hills (Meall a’ Ghiuthais, Maol Chean-Dearg); ridges which alternate between TS and CQ (Beinn Eighe, Beinn Liath Mhor); steeply sloping TS/CQ unconformities (An Ruadh-Stac, Sgorr Ruadh).

To help in understanding it all, you need to bear in mind two main mechanisms:

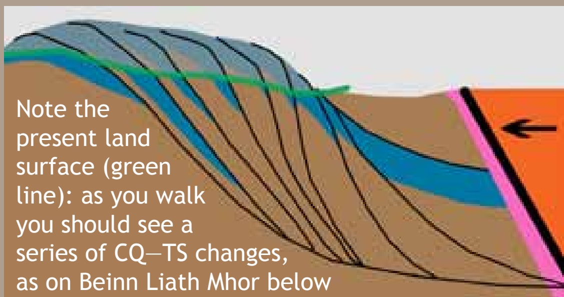
(1) **Thrusting**: a sheet of rock may simply be pushed over another: e.g. Beinn a’ Mhuinidh (twice!), above. A large transported sheet like this is called a **Nappe**.

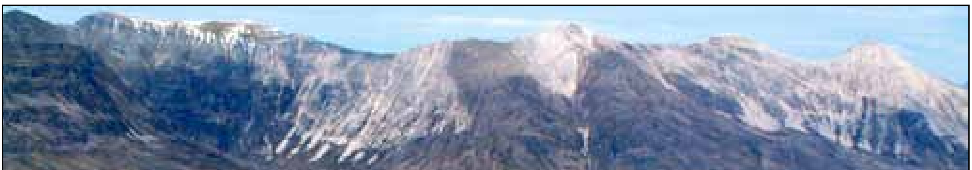
(2) **Imbrication**: Pushing may cause the rock to break into slices (with reverse faults, p26) which are pushed upright and folded at the top. The end result is an “imbricate stack” and, after erosion, an alternating series of rocks under foot: see below.

Imbrication: An imaginary area as it was, and after it has been squashed by the Thrust



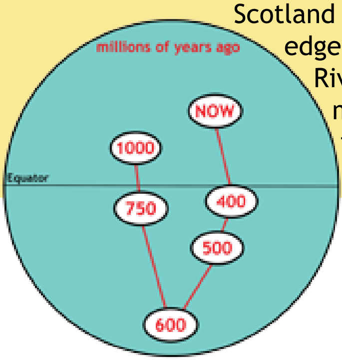
Steep TS—CQ—TS, Sgorr Ruadh





Imbricate CQ/TS sheets on Beinn Liath Mhor (the scree hides much of the detail)

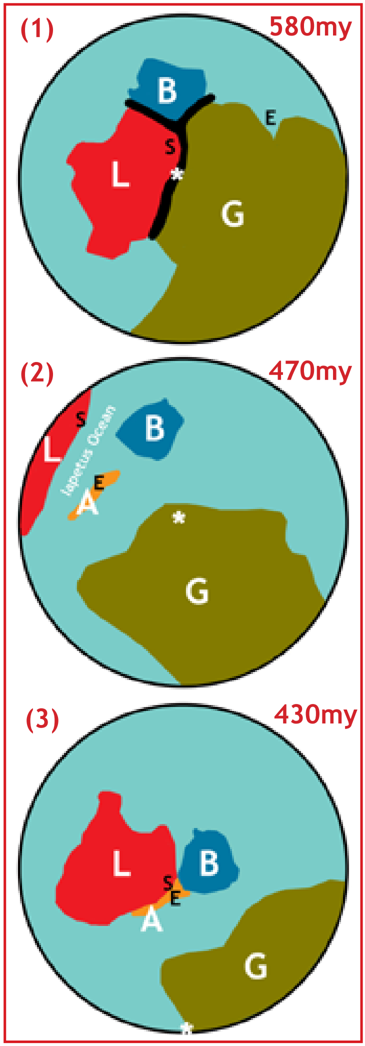
SCOTLAND'S TRAVELS



Scotland used to be a group of five very different terranes[11] on the edge of a continent named Laurentia (after the St Lawrence River in Canada). It stayed with Laurentia as it travelled many thousands of miles around the world, until it was torn off. For its size, Scotland is geologically the most varied piece of land in the world. **!**

The three globes below show part of the story. (Other continents not shown.)

***** = South Pole
S = Scotland
E = England



G = Gondwana: super-continent (also including Africa, South America and the Antarctic).
B = Baltica: Scandinavia.
L = Laurentia: North America and Greenland.
A = Avalonia: including England.

(1) **580 million years ago**
At the South Pole, Laurentia (with Scotland on its edge) and Baltica are about to split off from Gondwana (with England on its edge).

(2) **470 million years ago**
A splinter has split from Gondwana: Avalonia which includes England. Between the separated continents the old Iapetus Ocean has re-opened (p21).

(3) **430 million years ago**
Near the Equator, the Iapetus Ocean closes and the three continents collide, with several effects for us: the five parts of Scotland join (p22); the Caledonian Mountains are built (p23); and England joins Scotland! By 300 my ago other continents will have joined in, to form the super-continent **Pangaea** (= All Land).

Later...

200 million years ago: Pangaea starts to break up
The modern continents start to form, and great cracks open up where the Atlantic Ocean will appear. Scotland has belonged to Laurentia (America) so far, but now abandons it and joins the Eurasian plate.

65 million years ago: Widening of the Atlantic
A hot spot (p3) forms under East Greenland, boosting the widening of the Atlantic (this hot spot is now under Iceland); volcanoes develop down the west coast, e.g. in Skye. In this area there are a few **basalt dykes**, mostly along the coast: cracks which were filled with molten rock. Today the Atlantic is still widening at about 2cm a year ("the speed your finger-nails grow").

FAULTS

The crust of the earth is full of cracks where movement has taken place, called Faults. Most of them around here are now inactive, but a few may still move occasionally. The most prominent geological feature in Wester Ross is one of the latter: the **Loch Maree Fault**. Because movement on faults damages the rock, they create lines of weakness for rivers and glaciers to follow and erode. The Loch Maree Fault is thus the reason for Loch Ewe, Loch Maree and Glen Docherty. A smaller one is responsible for Flowerdale, and an even bigger one for the Minch.

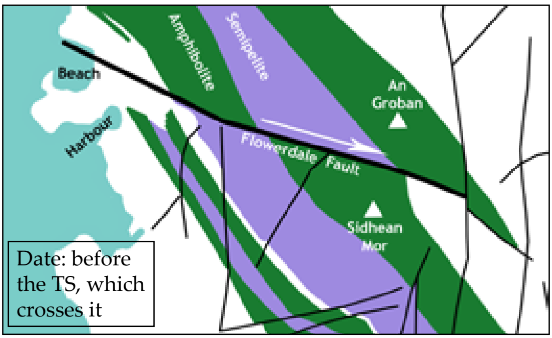
Some technical terms. A fault with left-right movement (**Strike**) is a **Strike-Slip Fault**; strike may be **Sinistral** (left) or **Dextral** (right): this gives the movement of the other side of the fault from where you are standing. A fault with up-down movement is a **Thrust** or **Reverse Fault** if the overhanging wall moves up, a **Normal Fault** if it moves down; the angle of the slope is called **Dip**. A **Rift Valley** is also called a **Graben**; if faulted on one side only, it is a **Half-Graben**. A **Shear Zone** contains the rock damaged or altered by the movement (p13).

The **Loch Maree Fault** is marked by an obvious line from Glen Docherty to Poolewe and on to the sea at Camas Mor (*map p 9)*. It is mostly a dextral strike-slip fault, and has had at least three major movements:


The straight line of Loch Maree's NE shore marks the Fault

(1) After the LMG rocks were caught up in the LG (1900my): a dextral strike of about 14km, splitting the LMG (*see map p14*).
(2) After the Stoer Group TS was laid down (1200my): the area north of Poolewe is thought to have dropped at least 1km (a normal fault). The visible fault escarpment here shifts from the NE side along Loch Maree to the SW side along Loch Ewe. Sandstone at the shear zone[13] around Poolewe is altered by heat and water.
(3) After the Moine Thrust (430my): a dextral strike of about 2km (*map p23*).

The **Flowerdale Fault** in Gairloch, from the Crask viewpoint to the south of An Groban, is a good example of a smaller fault. A dextral strike of at least 1km means that the bands of LMG amphibolite (higher, rougher) and semipelite (lower, smoother) are offset. An Groban and Sidhean Mor should be on the same ridge! This map also shows the many other local smaller faults.



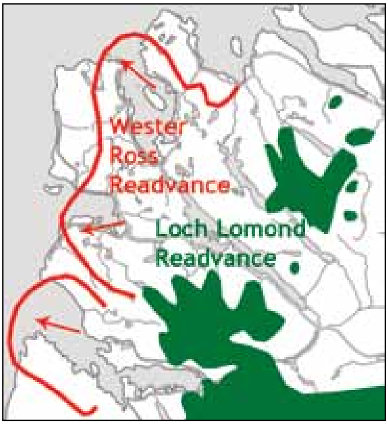
! There are occasional **earth tremors** in the area; in 2013 there were three, at 2.0, 2.8 and 2.8 magnitude. These are assumed to be due to small movements on one of the numerous faults which criss-cross the area, probably caused by glacial rebound (p29).

MAKING A LANDSCAPE (Geomorphology)

For the last 65 million years, Scotland has been above sea level and its outline has been more or less defined. For much longer than that, weathering and erosion had been wearing away the land (including the Caledonian Mountains), and broadly shaping what we see today. Relatively recently, the glaciers of the Ice Ages have been finishing off the job, adding many details such as corries and ridges, and leaving boulders scattered everywhere.

One effect of the volcanic period around 65-55 million years ago was to raise Scotland above sea level and tilt it slightly to the east; thus the west is higher, and the watershed is often near the west coast.

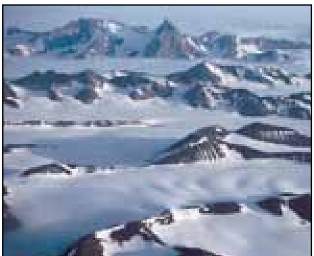
Scotland travelled north from the Equator, until it came into the realm of Ice Ages. The most recent Ice Age began 2½my ago. In the last 800,000 years there have been ten fluctuations; each had 40-100,000 years of cooling followed by a quick warming for 10,000 years. The latest cold period (**Devensian**) started 33,000 years ago and reached its maximum about 22,000 years ago when ice sheets many kilometres thick covered Scotland (obliterating all evidence of previous glaciation). Most glaciers here flowed NW. The ice had retreated by 14,700 years ago, but during and after the retreat there were brief resurgences:



(1) Around 16,000 years ago: the **Wester Ross Readvance**: the front is shown red on the map, deduced from where it left moraines.

(2) 12,900-11,500 years ago: the **Loch Lomond Readvance** (or Stadial) which here mainly affected the hills; e.g. An Teallach had 6 glaciated corries.

The glaciation had many effects which are clear today. Most are caused by the ability of glacier ice (layers of compressed snow) to flow downhill (with, like rocks, brittle and plastic deformation!). As it flows, it **plucks** up and incorporates rocks: pressure melts the bottom of the ice, and water seeps into joints[8] in the rock; this freezes and expands (9%), breaking up the rock which is then removed by the glacier. Rocks and sand in the ice act like abrasive sandpaper on the terrain which the glacier crosses. Our area once looked like this:



Spitsbergen glaciation

Alpine glacier

Icelandic glacier

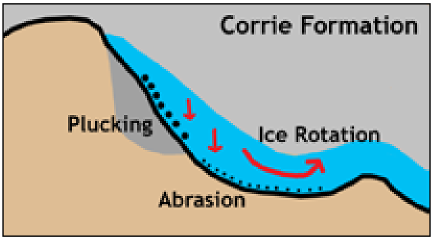
Effects of the Ice

• **U-shaped glens**, made by glaciers following old V-shaped river valleys and faults, and enlarging them *(e.g. Glen Torridon)*. Sometimes a side valley is left "**hanging**" as the main valley is deepened *(e.g. upper Ardessie Burn)*.

• **Lochs and Sea Lochs**: hollows scooped out by the ice and left behind as they retreated *(e.g. Loch Maree)*. Sea Lochs (fiords) typically have a shallower and narrower neck leading to an outer loch *(e.g. Loch Torridon)*.

• **Corries** (also *cirques*; the Gaelic *coire* means *cauldron*) scooped out of the sides of hills. These form when ice builds up on a hill slope; when it is heavy enough to start flowing, rocks are plucked off the slope by the downward movement, making it steeper. The results in this area are remarkable. Often a loch is left in the corrie, because the ice rotates and rises (like a very slow splash) to leave a raised dam-like lip at the corrie's edge. Beinn Eighe, Liathach and An Teallach all have superb corries.

Coire mhic Fhearchair and its loch



• **Mountain ridges** are a speciality of this area. These probably already existed, but have been sharpened and narrowed by the ice. Some tops were above the ice sheet in the later stages of glaciation (**nunataks**), resulting in **pinnacle ridges**, and also in frost-shattered fields of stones (**blockfields**) which are especially common in the CQ. A narrow ridge between two corries is called an **arête**.

River reveals boulders

• **Small burns with big valleys**: this is evidence that in glacial times the burn was a raging meltwater torrent and carved its valley, with the help of stones rolled by the water.

• **Till**: **glacial till** is the mixture of unsorted rock, pebbles, sand and clay created by glaciers which underlies the soil in most places.
It is also called **boulder clay**. Soil erosion reveals that much of this area was covered in boulders. 13,000 years ago there was no soil or vegetation here!

The Valley of a Hundred Hills

• **Moraines** are mounds of glacial till carried by a glacier and then dropped. At its end as the glacier melts it forms a **terminal** moraine; at its sides it forms **lateral** moraines; a **medial** moraine can form in the middle, starting where two glaciers join. A **drumlin** is a small rounded moraine formed under a glacier; an **esker** is a long moraine deposited by a river flowing under a glacier. A very special and well-known example of moraines is seen at the "Valley of a Hundred Hills" in Glen Torridon, perhaps the best example of **hummocky moraine** in Scotland. Several explanations have been proposed; it was probably caused when the Loch Lomond Readvance crossed earlier moraines.


An obvious Erratic: TS on LG

• **Erratics** are boulders carried by the ice and dropped, normally of a non-local rock type. They are remarkably common here.

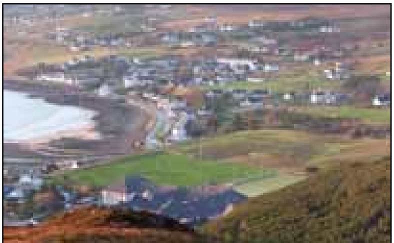

Ice-smoothed rock

• **Ice-smoothed rock** is common here, polished by sand held in the ice. Sometimes an outcrop is smoothed at one end, and rough (plucked, p27) at the other: this is called ***roche moutonnée***, oddly named, because of its shape, after an 18th century French wig style, which was anointed with mutton fat to keep its shape. The ice was moving from the smooth end to the rough.

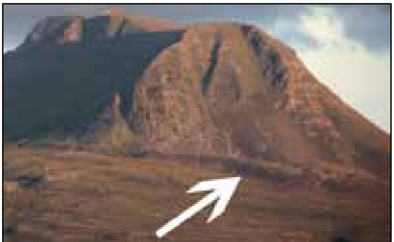
• **Striations** are scratches on very smooth rock made by a rock in the glacier. More common here are the associated **chatter marks**, wedge-shaped cuts made as rock is chipped out.

After the Ice

Several after-effects of the glaciation can be seen:


Gairloch is built on raised beaches

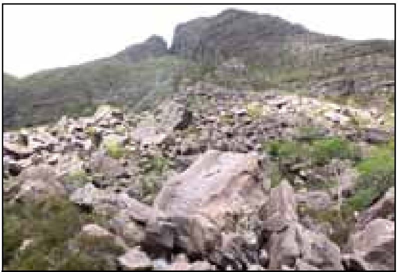
• **Raised Beaches.** As the weight of ice lifted off the land, it rose. This process is called **glacial rebound**, or **glacial isostasy**; the Earth's crust had subsided under the weight of ice, displacing the plastic asthenosphere (p2), and this was reversed when the ice melted. The melting and the rebound were irregular, and at each stage a new seashore formed and older ones were left high and dry. Today you can often see these raised beaches, typically at heights of 5m, 8m, 15m and 30m. Villages tend to be built on them. Scotland is still rising at about 0.6mm a year (outdone by 2mm of sea level rise).


Baosbheinn: protalus rampart

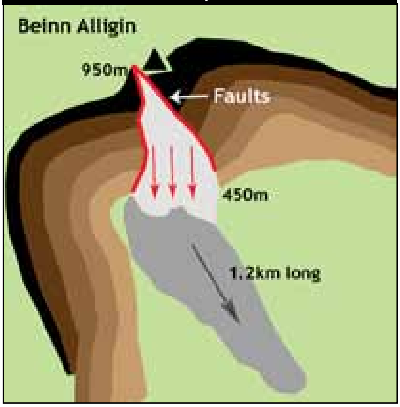
• **Landslips and Screes.** One effect of glacial rebound (e.g. by jointing[8]) and of the weakening of the rock by ice was to create numerous landslides and rockfalls. A **talus** is a slope composed of broken rock at the foot of a cliff, or of a gully where it is fan-shaped (a talus fan). When the rock slides down snow or ice it may form a **pro-talus rampart**, i.e. a wall of stones in front of the talus, across the slope.

The biggest and best example of a protalus rampart in Britain is at the foot of Baosbheinn's north ridge, and is 450m long and up to 55m high; it has been added to by post-glacial and recent rockfalls which have shaped the cliff-face above.

! Another even more impressive "biggest in Britain" title goes to a vast rockfall below Beinn Alligin. One of the most noticeable features of the hill is the Eag Dhuibh (Black Cleft) near the summit; it is the top of a huge landslip in which the whole slope has collapsed, possibly set off by an earthquake, sending perhaps 9 million tons of rock down into the corrie and up to 1.2km across its floor. It used to be thought that the rocks were carried or slid on a glacier, but it has recently been dated to about 4000 years ago, so it was only the energy of the fall which caused the huge spread.



Black Cleft and part of rockfall

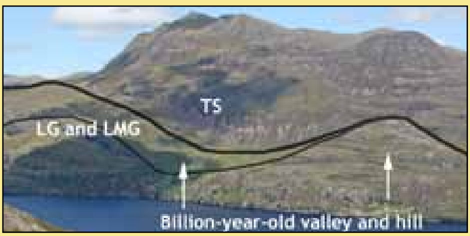


• **Soil** is defined as the mixture of mineral and organic matter in which plants grow. The mineral basis of the soil here is glacial till along with fluvial (river) deposits and minerals from weathered rock. To this is added organic matter (the first plants to colonise the barren post-glacial land were probably lichens and mosses). The nutrient content of the soil decides its fertility; most of our rocks are felsic[4] and do not dissolve easily, forming acid soils low in nutrients (sodium, potassium, magnesium, calcium); more mafic rocks such as LMG amphibolite are more nutrient-rich and help to make more fertile soil.

In our wet climate the rain may remove nutrients from the soil, making it less fertile, and often creating an **iron pan**: a hard impervious layer of oxidised iron, which keeps the soil above wet and so encourages the growth of **peat**. Peat is made of partly-decayed vegetation and grows at very varying rates, perhaps averaging 30cm per 1000 years overall.

Soil, iron pan, glacial till

! Remarkably, there are landscape features in Wester Ross which survive from a billion years ago, well before the glaciers. In places erosion or faulting have cut a cross-section revealing the original Lewisian surface. Here the Lewisian hills on which the Torridonian rock was laid down can be seen on Slioch (*left*) and A' Mhaighdean (*right*). The 1000 million year old Lewisian landscape must have been very much like today's "knock and lochan" scenery.



PLACES TO VISIT

As you tour the area, look out for: characteristic **Lewisian** "knock and lochan" scenery (small hills and lochs), **Torridonian** moorland and mountains, **Cambrian quartzite** white hilltops and screes, the straight lines of **Faults**, **Glacial** effects...

There is plenty of exposed rock to examine, but because of the lichen and weathering the easiest places to study rocks closely are often quarries, road cuttings, rivers and any place where the soil has been recently removed. You will notice a general SE-NW trend in land features; this dates from the original Lewisian terranes[11], but has been emphasised by later erosion and glaciation.

Blue page numbers, e.g. (p19), refer to the companion booklet ***Guide to Gairloch and District***, for non-geological information.

(1) GAIRLOCH

• The shore below much of the village is TS Diabaig (TCD1, p19); breccia is easily seen in the road cutting at the Crask viewpoint north of the main beach. At each end of this beach is Ard Gneiss (p16); you can see Augen gneiss on the path from the beach to the harbour. There is a rare chance to see an unconformity (join), between LMG Ard (Augen) Gneiss and very coarse TS Diabaig breccia at the north end of the beach.
• Behind Achtercairn the hills are LMG amphibolite, and easily reached (p6).
• Walk along Flowerdale (p3) from the Golf Course by the cemetery path to follow the Flowerdale Fault (p26, map): alternate semipelite (low, smooth) and amphibolite (high, rough), but misaligned on each side of the glen. Semipelite is seen in the waterfall area, and the very fine amphibolite mini-mountain An Groban is at the end.
• The belt of LMG minor rocks (p15-16) runs SSE from Flowerdale, but you need a geological map to find it, and even then it is difficult because it is overgrown; it starts with a BIF ridge just west of a walled field. See also (4).

(2) RUBHA REIDH (p9)

• The road to Melvaig and the small road (slow!) beyond to Rubha Reidh lighthouse follow the TS coastline, which is worth visiting (*right*). Coastal TS tends to slope west, due to faulting in the Minch.
• At Rubha Reidh, park as requested in the quarry, which shows a good cross-section of soil and till and a clear iron pan (p30). Walk on down the road, with some nice autoclastic TCD1 breccia (p19) on the left. Then explore the huge slabs to the right of the (private) lighthouse with ripples and other interesting features (Stoer Group TAD; p18-20). Rough paths lead east above the coast for views of sea stacks (TCD1); beyond the impressive bay Camas Mor, the cliffs of Triassic conglomerate (p22) are worth seeing.

(3) SHIELDAIG (p10)

The "Remote Lochs" footpath takes you to Loch Braigh Horrisdale; turn left here, and there is a good area of relatively undeformed LG with clear Scourie Dykes (p12). It is also worth climbing the rocky hill Sithean Mor on the way back. Some fences!
The road continues to Red Point at the end of the typical TS moorland peninsula.

(4) To the RED BARN (p13)

• The road cutting above Kerry Falls is the best exposure of LMG semipelite (which may explain occasional subsidence).

• From the Bad an Sgalaig dam, walk the Old Road (p13) through the wood and a little further to a possible old quarry at a sharp left bend; check the rock in and around this with a magnet (BIF, p15). Continue until you reach some very colourful rocks: sulphide mineral deposits, and signs of drilling for gold etc (p15).
• The misnamed Red Barn is a base for walks into the LG hills, pathless to the north and pathed to

the south. The large area to the north, much of it now a native tree plantation but sparsely planted, is classic "knock and lochan" Lewisian land (p13) (*opposite bottom*).
• A short way above and left of the Red Barn, at map ref 855 722 in a brackened area, there is a former shallow marble quarry (p15) with some rock showing.

(5) LOCH MAREE (p15)

• The south side of the loch is all TS, with fine boulders left by glaciers, terraced cliffs and road cuttings. The loch was created by river and ice erosion along the obvious line of the Loch Maree Fault, now seen in the straight edge of the further shore (p26). Beinn a' Chearcaill is a relatively easy TS hill with plenty of rock exposed.
• The hills opposite are LMG amphibolite, shifted from its original position by the Loch Maree Fault (p14,26). Beinn Airigh Charr on the left is climbed from Poolewe; Beinn Lair, the big round one and the highest point of the LMG, is hard to get at but very worthwhile – the further side has the longest line of inland cliffs in the UK!

(6) MOUNTAIN NATURE TRAIL and SLIOCH (p16)

• Beinn Eighe National Nature Reserve was set up partly for its geology. The unique Mountain Trail which starts at the Glas Leitir car park gives a chance to walk on the Cambrian Quartzite; other Cambrian rocks can also be seen (guide pamphlet available). The hill above the trail, Meall a' Ghiuthais, can be climbed relatively
! easily; because of the Moine Thrust (p24) it is upside down: CQ with a TS summit! On the downhill path, where steps have been cut into the rock, you are on Mylonite created by the thrust (p13), and the TS is full of quartz-filled strain cracks. There is also some extraordinary Mylonite on a small hill at map ref 976 649.
• Across Loch Maree from here is Slioch, a huge isolated pile of TS Applecross sandstone (p19) on top of LG interwoven with bands of LMG rocks. This is a geologically famous view, showing the best example of a "fossil" Lewisian landscape under the TS (p30).

(7) BEINN A' MHUINIDH (p17)

• To the right of Slioch is Glen Bianasdail, first formed by a fault, with a prominent line of CQ cliffs on its SE side. These cliffs are part of Beinn a' Mhuinidh, a remarkably complicated hill thanks to the Moine Thrusts (p24). If you follow the Allt a' Chnaimhean down from near the summit, everything is upside down: LG, TS Diabaig, TS Applecross, CQ; then back onto LG at the bottom. Try to work out what happened!
• Along the track to Heights of Kinlochewe south of the hill, things become even more complicated due to imbrication (p24). By the path is Pipe Rock (p21); there are areas of Fucoid Beds and (less visible) Salterella Grit (p22); there is more CQ, TS and LG; and there is the only accessible example in the area of Durness Limestone. in the river. The Fucoid Beds and the Limestone make much more fertile soil, shown clearly by the green vegetation (*right*), and so are rather overgrown. Across the river the cliffs are Moine Schist, the eroded face of the Moine Thrust.

• Round the corner to the SE, Glen Docherty, created by the Loch Maree Fault and a glacier, plunges down through the Moine Thrust to give a grand approach to Wester Ross. Note the moraines in the lower part of the glen.

(8) BEINN EIGHE and COIRE MHIC FHEARCHAIR (p18)

• From Kinlochewe the Torridon road leads south-west with views of the imbricated (p24) massif of Beinn Eighe: CQ and TS mixed together, and CQ screes on the slopes. Its crest gives spectacular if rather awkward walking mostly on CQ.

!

• The large (often full) Coire Dubh car park is a base for several walks. A good path leads to spectacular Coire Mhic Fhearchair (pronounced *corra veek errachar*), which is a must for geologists and walkers: the best corrie in Scotland? The 350m Triple Buttress at its head shows a clear unconformity (p8) between TS and CQ (*on front cover*). It is worth walking round the loch, anticlockwise: tricky at first across talus fans (p29) from the gullies, but then wander at will among boulders of both rocks.

(9) VALLEY OF A HUNDRED HILLS (p19)

From the Coire Dubh car park, if the light is right you can see clearly the famous 100 Hills (Coire a' Cheud Chnoc) to the south (hummocky moraine, p28). The path to them leads past a mountaineering hut and a waterfall; then you can divert into the hills if you wish. There may be more than 100!

(10) COULIN HILLS (p20)

• The hill country south of Glen Torridon is of great geological interest. Most of the hills are affected by the bow-wave of the Moine Thrust (p23-24), with CQ and TS interleaved; this may be the best place to see such formations. The area is reached by the path past the 100 Hills, or by another from Annat on Loch Torridon.

• There are two particular places which show off at its best the beautiful TS Applecross (p19), both reached by the 100 Hills path. One is found by following the burn up to Lochan Uaine, north of Beinn Liath Mhor; the other is around Meall Dearg, reached by the path over Bealach Ban (map square 93 51). Good walk(s) for a sunny day. *The picture shows TS and imbricated (p24) Sgorr Ruadh from the Meall Dearg area.*

(11) LIATHACH (p21)

You can't miss Liathach as you drive down Glen Torridon. It is the finest example of large-scale TS (supporters of An Teallach might disagree!). Its terraced cliffs rise 1km high above the road, showing clearly the bedding planes (layers) of TS Applecross. The summit and other tops have protective crests of CQ. Glaciers have worked wonders here, making a series of corries and a very narrow pinnacle ridge. It is worth visiting Coire na Caime, the great corrie on the north side (but difficult).

(12) BEINN ALLIGIN (p21)

Loch Torridon is a classic ice-carved sea loch or fiord, with an inner loch separated by a shallow lip from an outer. Beinn Alligin on its north side is another very fine TS hill, this time without any CQ. Geologically the most impressive feature is the great gash (*opposite top*, Eag Dhuibh) which takes a huge slice out of the hill near the summit, and the resulting boulder field in the corrie below (p30). It is worth visiting the latter (the biggest in the UK); but it's a dangerous area — beware of holes between the huge boulders.

(13) DIABAIG AREA (p19)

The road continues to the little village of Diabaig, via a good area of LG. To the north of the road, it is worth following the Allt Airigh Eachainn (from above Loch Diabaigas Airde) and then heading for the TS hill An Ruadh-Mheallan to reach one of the less re-metamorphosed LG areas; there are plenty of varied rocks, mafic bodies and Scourie Dykes. South of the road, there is a path round the peninsula or you can wander at will through the outcrops (more knock than lochan). The shore at Diabaig itself has fine TCD2 grey shale (p10).

(14) A832 NORTH OF GAIRLOCH (p22)

• After leaving Gairloch, the road passes an old wood. To the left here you can see some strange square cut crags; these are especially interesting TS Diabaig TCD1 beds of shale, sandstone and breccia (p19). You can visit them together with a long ramble through varied LG beyond them, perhaps the easiest area to visit the LG.

• On the south side of the road, starting at the highest point, there is more LG to explore: Meall Airigh Mhic Criadh and beyond. This could be linked to...

(15) TOLLIE (p22)

Further along the road is Loch Tollaidh, and beyond it is Creag Mhor Thollaidh: Loch Tollie and Tollie Rock: classic LG.

The remarkable crags behind Loch Tollie (*right*) form the top of the Tollie Antiform, a huge arch-shaped fold (p14); they are highly re-metamorphosed (p12-13). They are worth exploring: take the Tollie-Slattadale path to the first footbridge, then leave it to wander south for 2.5km. Near Meall an Spardain there is a lot of pegmatite (p13). You can return by descending to the path, which follows a Shear Zone, with signs in the rocks of the forces applied when Tollie Rock met the antiform, including Pseudotachylite (p13). Tollie Rock itself is one of the less re-metamorphosed areas; there's some fascinating dark gneiss whose protolith was probably gabbro. And it is in effect a gigantic *roche moutonnée* (p29)!

(16) WEST LOCH EWE (p30)

The road north from Poolewe follows the line of the Loch Maree Fault; here the slopes are on the SW side not the NE, because the land to the NE was down-faulted by 1km or more (p26). In fact the fault splits into two here: one branch follows the coast and the escarpment to Camas Mor; the other is further inland, enclosing a band of LG, and reaches the coast south of Rubha Reidh. There are good LG small hills above between Poolewe and Naast. East of the escarpment, from Inverasdale, is TS Applecross.

(17) To LAIDE (p27)

• The rock in front of the Inverewe Bird Hide is Stac Fada (p18), but very lichened.
• Isle of Ewe is mostly TS, but the more fertile farmed strip at the south end is Triassic Sandstone (p22); this softer rock breaks up to make better soil.
• The best place to see this Triassic rock is on the shore at Laide. You can reach this by a track beside the cemetery and chapel (p32), and return to the road further west at the pier. Good examples of sandstone and conglomerate. (Spot the Pipe Rock stone on the shore!) The only visible Jurassic Limestone is along the coast 1km to the east.

(18) MELLON UDRIGLE (p32)

Along the side road from Laide, around Mellon Udrigle is TS Aultbea. The best bit of TS coastline is found north from there, to Greenstone Point: the first half is still Aultbea, then it's Applecross. It's a very indented coastline with a lot of exposed TS slabs.

(19) GRUINARD BAY (p28)

• The coast below Second Coast is wonderful TS Stoer Group (including Stac Fada), but sadly hard to access.
• Stop at the viewpoint at the top of Gruinard Hill, where the road cutting reveals some remarkably untidy LG full of mafic[4] and granite inclusions and migmatite (p7).
• There are two good geological sites out in the Stattic Point area, reached from Mungasdale. First, on the coast just before the point (map ref 9722 9598) there is on the shore the best example of Stac Fada meteorite-affected rock (p18): a low crag below a sloping slabby area.

Second, a small hill inland from the point (*right:* Carn Dearg na h-Uamha, "red hill of the cave", map ref 974 947) has a remarkable cliff of partly autoclastic (p19) TS Diabaig TCD1, with a softer layer weathered differentially to make the "cave", resting on the older TS Stoer Group (p18-19).

(20) To DUNDONNELL (p29)

Little Loch Broom is a fiord gouged out by a glacier along the line of a fault.
• A good place to stop and view the TS here is Ardessie Burn, which has one of the best collections of waterfalls in the country, tumbling over TS terraces.
• An Teallach is another great TS mountain, with minimal CQ on it and two superb corries. It is near the Moine Thrust, which is very simple here. Walk up the track from Corriehallie and you are on Moine Schist; but to the right there are walkable sloping slabs of CQ overlooking a cliff (p21 picture).

(21) THE GREAT WILDERNESS (p25)

This area between Loch Maree and Little Loch Broom is a miracle of geology and glaciation, a paradise for rock-lovers: dramatic mountains of LG, TS and LMG; lochs in rocky hollows; deep glens; crags everywhere. It is a very remote and complex area to wander in for days with a tent and open eyes.

BOOKS

A selection of available books, roughly in order of difficulty (easiest first)! Some have more to say than others about this area: *** = most relevant.

- * **Land of Mountain and Flood** (McKirdy, Gordon, Crofts) SNH / Birlinn 2009: *popular, well illustrated*
- ** **The Highland Geology Trail** (John Roberts) Luath 1998: *clear and concise, but dated*
- ** **Rock Trails: Scottish Highlands** (Paul Gannon) Pesda Press 2012: *concise, up-to-date, excellent*
- *** **Geology and Landscapes of Scotland** (Con Gillen) Dunedin 2013: *the most thorough general guide*
- * **Scotland** (Peter Friend) Collins New Naturalist Library 2012: *good, but disappointing on this area*
- *** **The Northern Highlands** (British Regional Geology) BGS 1989: *needs up-dating*
- *** The Geological Society has 2 relevant guides: R.G. Park on **LMG** (No. 26), A.D. Stewart on **TS** (No. 24): *these are highly technical (and expensive!)*

To learn more Geology, also try (small and big):
Introducing Geology (Graham Park) Dunedin 2010
Earth: Portrait of a Planet (Stephen Marshak, USA)

Of historical interest (early debates on rock sequence) is Chapter IX of Dixon's **Gairloch** (1886), the classic guide, available from Gairloch Museum.

There are also several popular guides to Rocks and Minerals: e.g. Collins and Dorling Kindersley. And then there is plenty on the internet...

Maps were mentioned in the introduction. There is one covering the whole area and more: **BGS Sheet 57N 06W The Great Glen**. This is a little out of date and not very detailed or easy to read, but gives an overview.

Brief Glossary (blue words)

Bedding = layers in sedimentary rock [17]
Diagenesis = changes in sedimentary rock [8]
Dyke = rock filling a vertical crack [6]
Felsic = pale rock, with high proportion of silica [4]
Foliation = layers formed in metamorphic rock [7]
Grade = temperature of metamorphism [7]
Joint = crack in any rock [8]
Mafic = dark rock, less silica [4]
Mountain-building = continent collision making a mountain range [3]
Protolith = original rock before metamorphism [7]
Shear = sideways strain and deformation in rock [13]
Subduction = ocean crust sinking into the mantle [3]
Terrane = land segment with the same geology [11]

Dating

How do we know the dates given in this guide? Most of them have been worked out thanks to a remarkable mineral called Zircon ($ZrSiO_4$), which is very resistant to erosion, is unaffected by metamorphism, and contains radio-active elements. It can be used for radiometric dating of the protoliths of many rocks. The oldest thing dated on Earth is a crystal of zircon: 4400my!

Who would have thought it?
Rock is simply rock,
the mere solidity on which we stand,
fit for trampling, breaking, building;
neglected, unrecognised.
Who would have thought that
such intricacies of process,
such ingenuities of composition
hide in it? Simply rock?
Not simple to those who struggle to
untangle warp and weft of the long weaving
of this rich robe in which our Earth is clad.
Stop and look!
Recognise the rock and make it glad!

This guide was produced by **Jeremy Fenton** who is responsible for errors and obscurities, but grateful for help given by many people, professional and amateur.
He welcomes comments and corrections (jeremyfenton@btinternet.com) *2/19*

Cambrian Qu. (CQ)


Quartzite


Pipe Rock


Beinn Eighe

Torridonian (TS)


Torridonian (TCA)


Torridonian (TCD1)


Liathach from Beinn Dearg

Loch Maree Group (LMG)


Amphibolite


Semipelite


An Groban from Flowerdale

Lewisian Gneiss (LG)


Gneiss


Small Scourie Dyke


Tollie