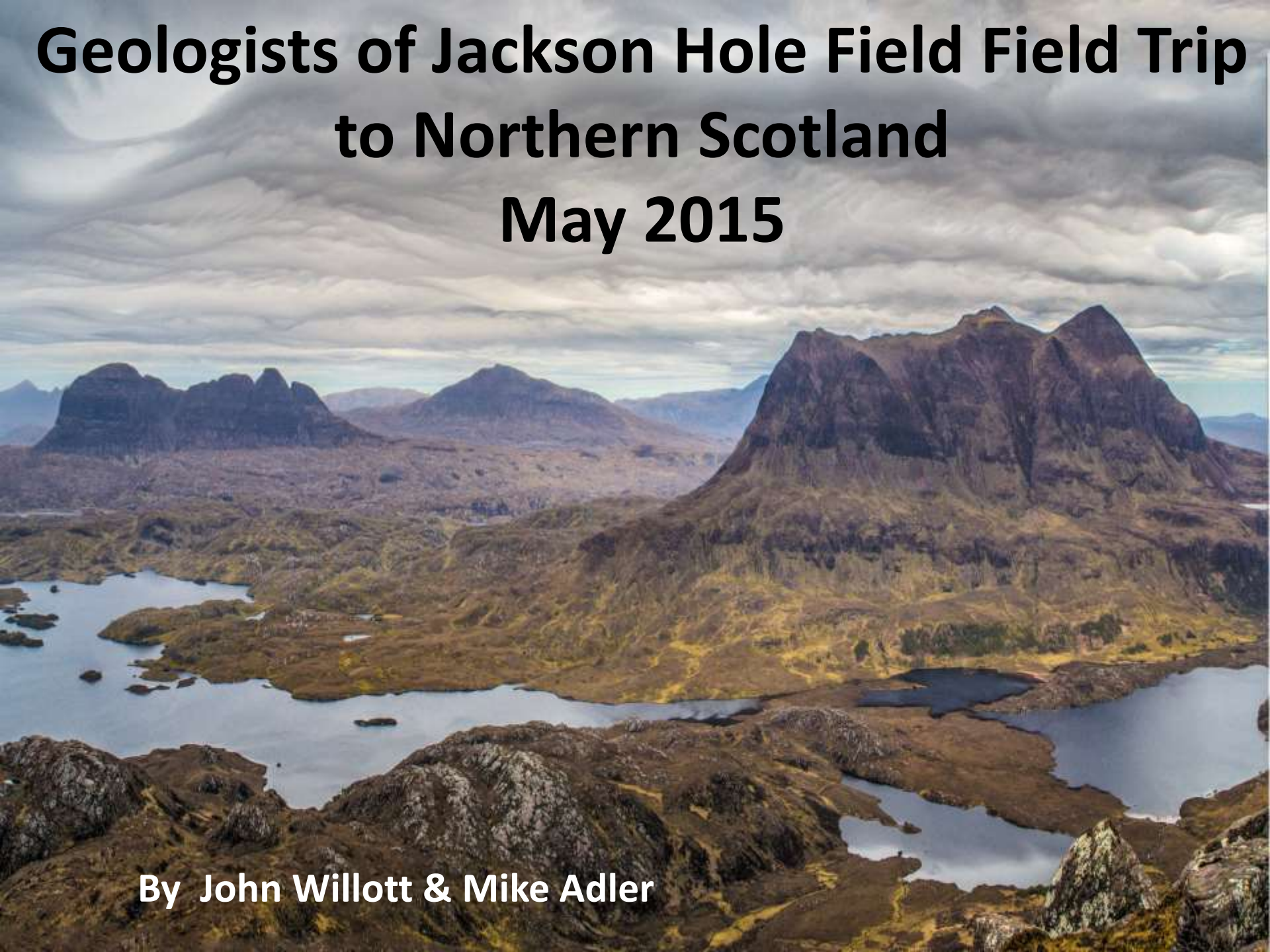
Geologists of Jackson Hole Field Field Trip to Northern Scotland May 2015

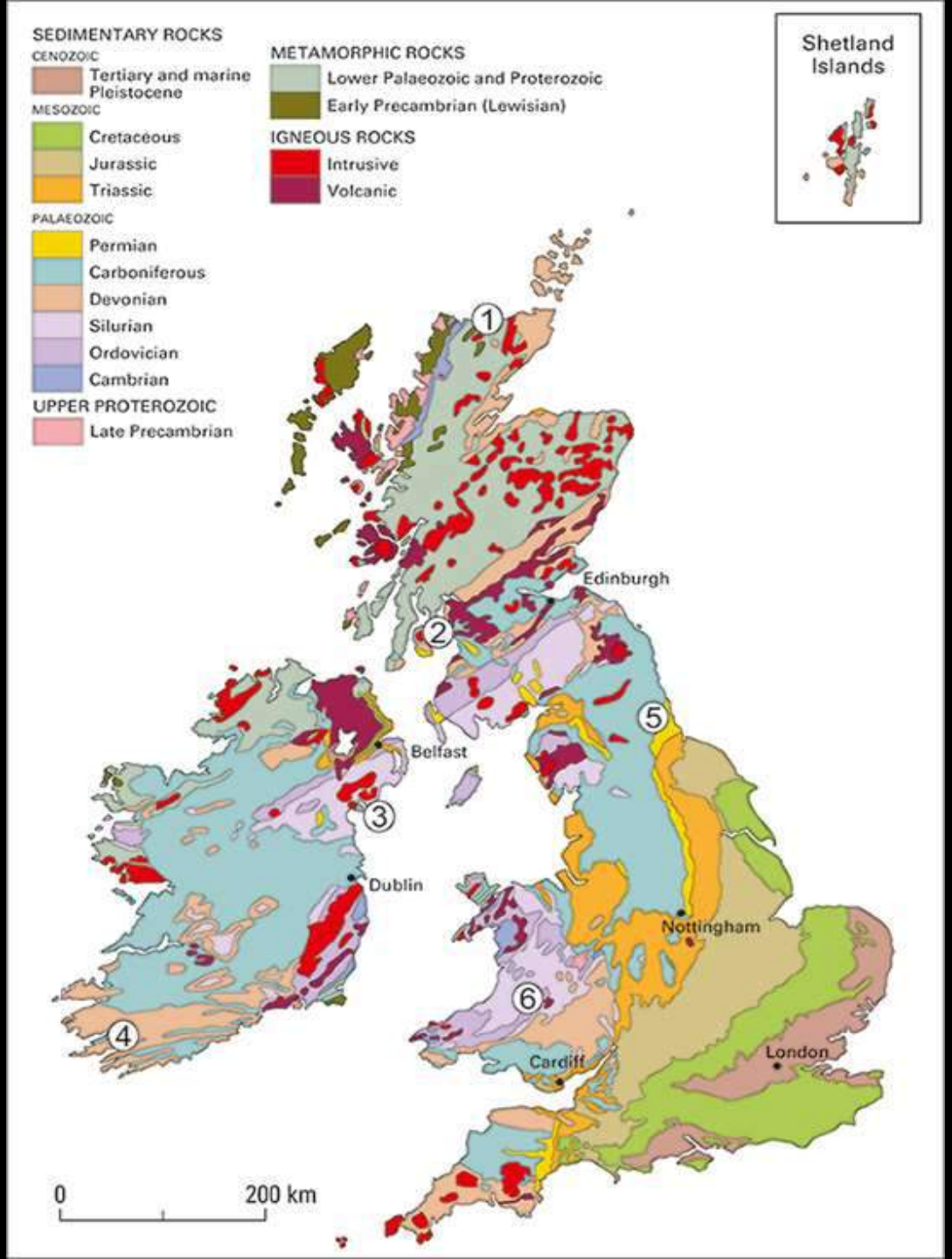


By John Willott & Mike Adler

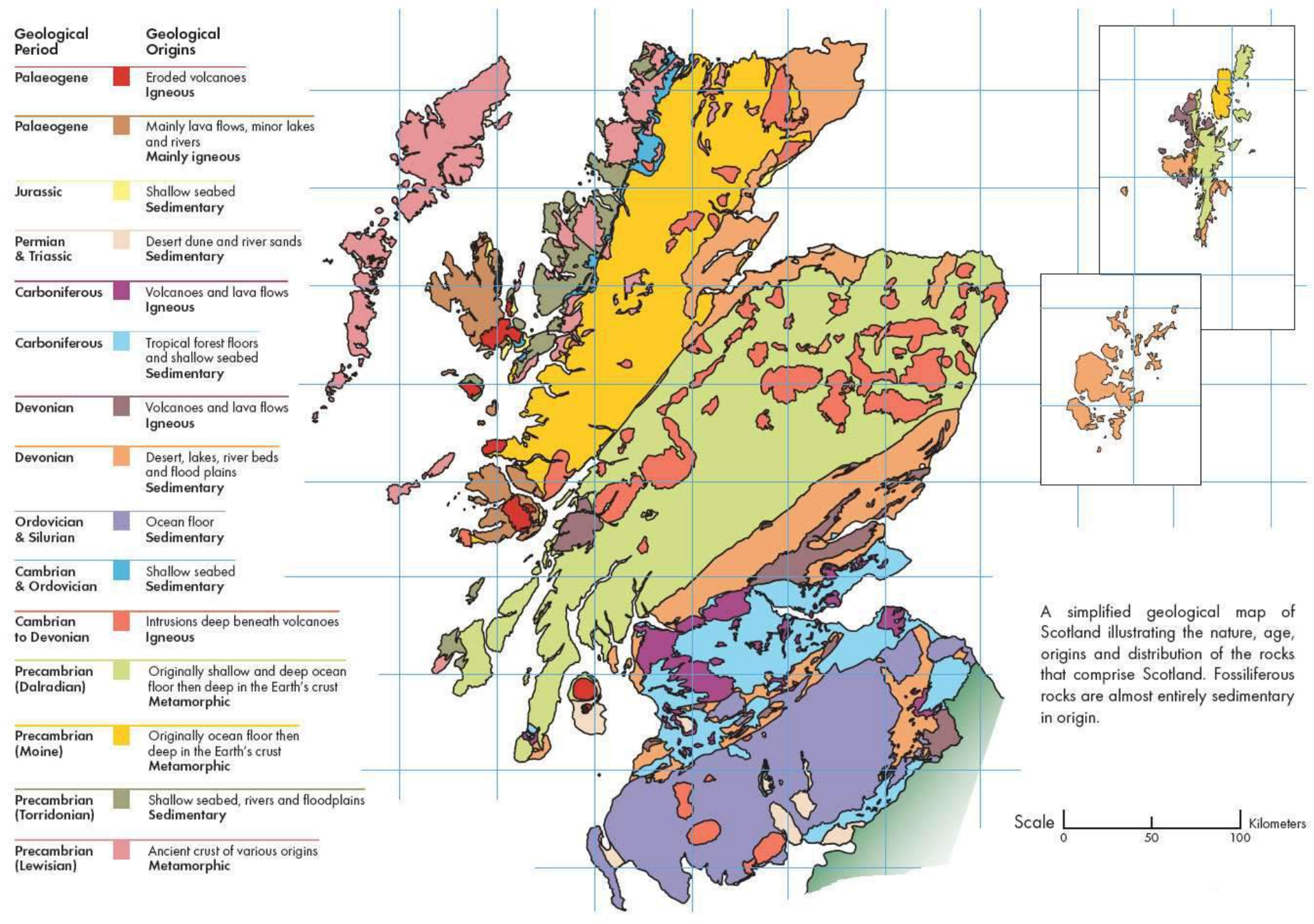
Outline

- Formation of Scotland – Plate Tectonics
- Geology of the Northwest Highlands
- Geology of Skye

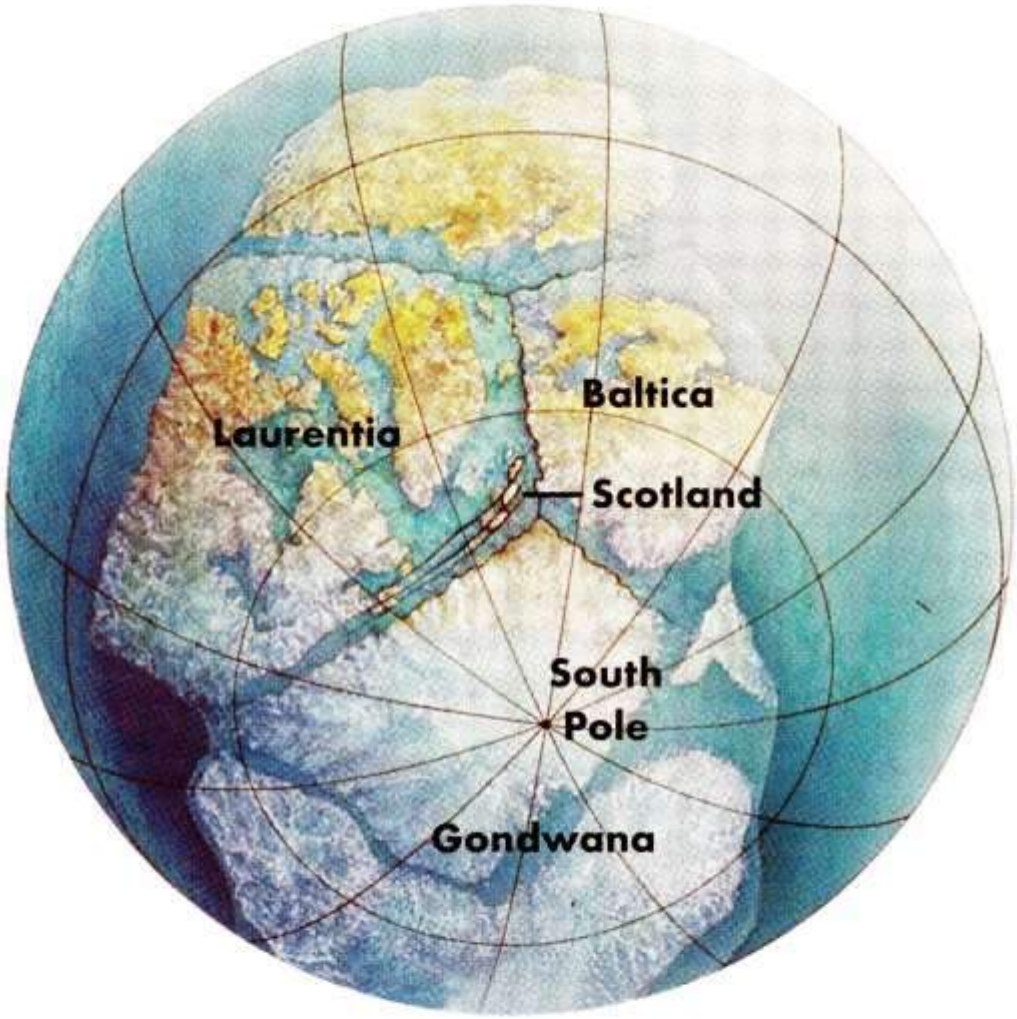
Geologic Map of Great Britain



Map of Northern Scotland



A simplified geological map of Scotland illustrating the nature, age, origins and distribution of the rocks that comprise Scotland. Fossiliferous rocks are almost entirely sedimentary in origin.

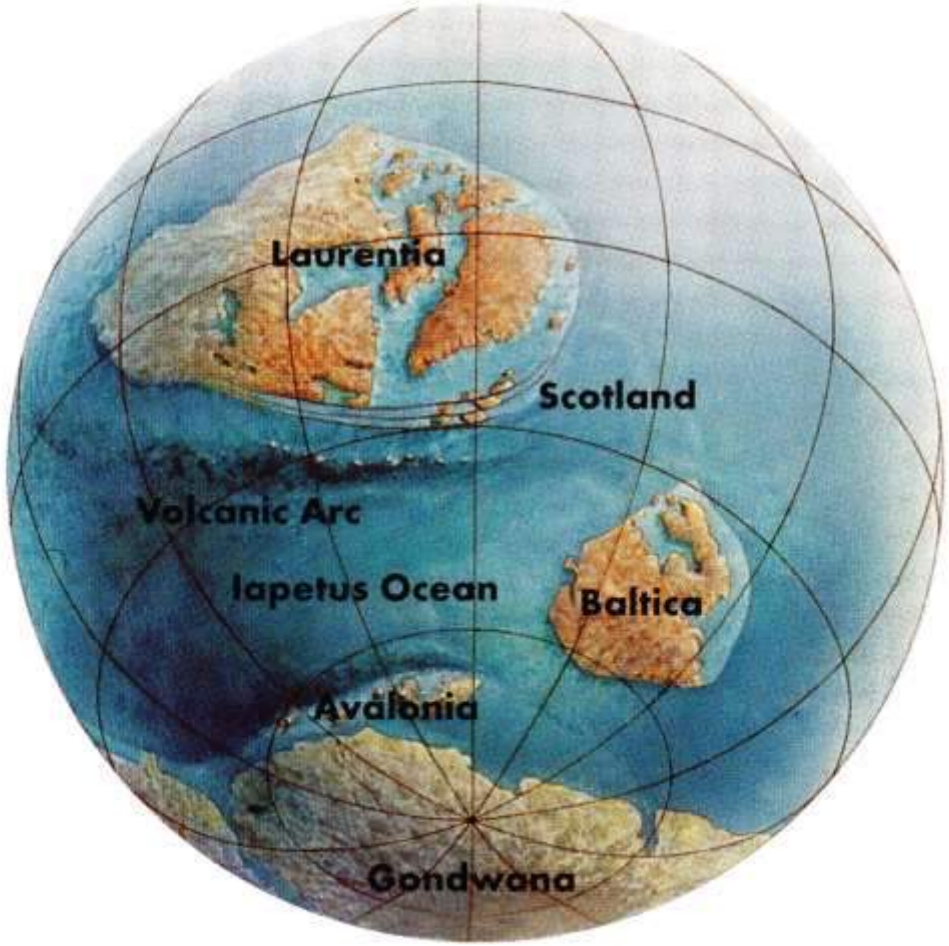


600 Million Years

A supercontinent situated around the South Pole starts to break up into individual plates. Scotland lies at the edge of Laurentia, a continental plate that also includes North America and Greenland.

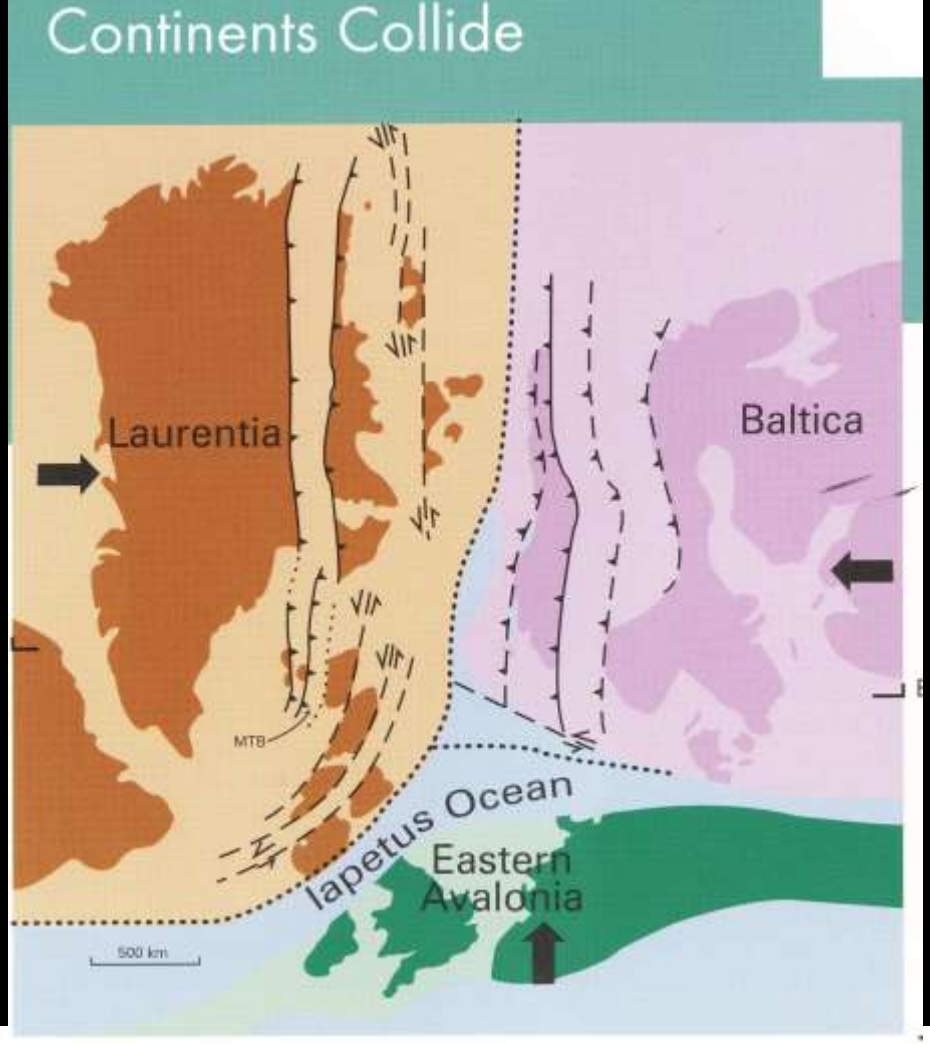
500 Million Years

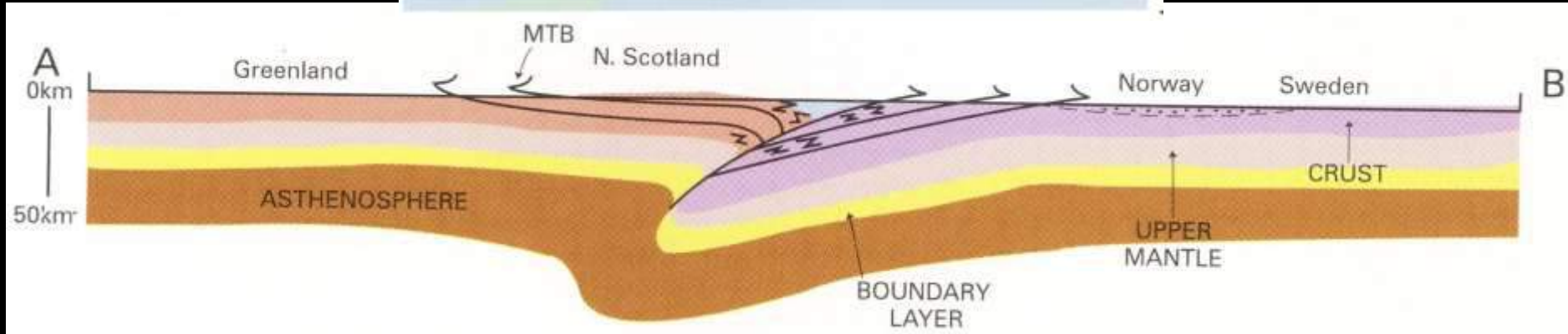
Laurentia has drifted northwards to tropical latitudes as the Iapetus Ocean opened. Volcanic arcs develop above subduction zones and subsequently collide with Laurentia. Avalonia (England and Wales) begins its rapid journey north, and Baltica (Norway and Sweden) spins slowly northwards.



400 Million Years

Final closure of the Iapetus Ocean complete. The continents collide like 'ghostly ships in the fog' Baltica collides head-on with Laurentia, whereas Avalonia 'docks' gently to the south.


Continents Collide
Laurentia
Baltica
MTB
Iapetus Ocean
Eastern
Avalonia
500 km


A
0km
50km
Greenland
MTB
N. Scotland
Norway
Sweden
B
CRUST
ASTHENOSPHERE
UPPER
MANTLE
BOUNDARY
LAYER

The Early Crust

A typical 'Lewisian' landscape - Loch Laxford

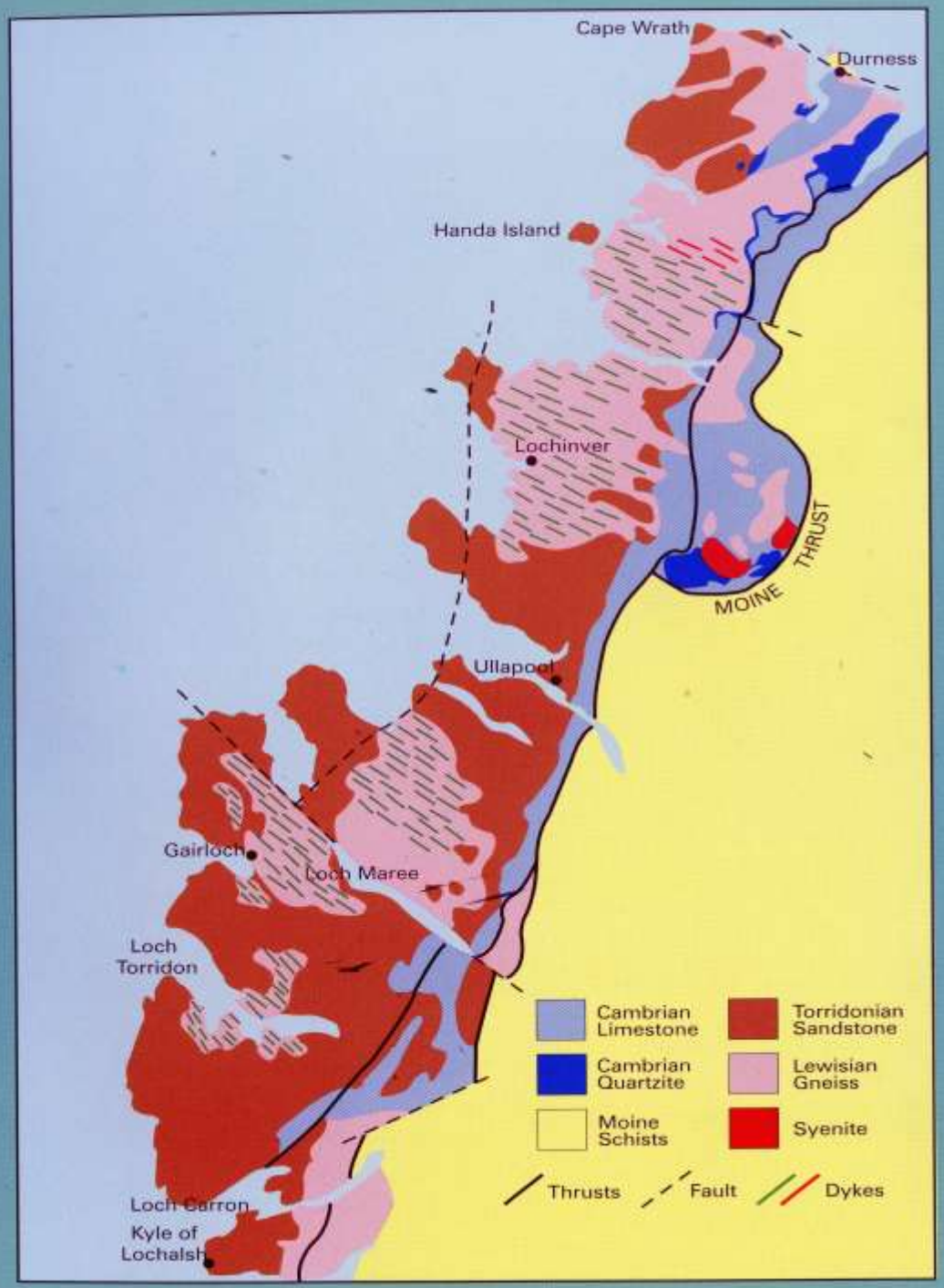
Lewisian gneiss, Scotland, 2012

Gneiss, south coast Newfoundland, 1987

Rivers of Sand

Glen Torridon - tiered hills of Torridonian Sandstone beds

Geological Map of the Northwest Highlands



Early Geologic Concepts

Three Ages of Rocks

- Primary
- Secondary
- Tertiary

Older Rock Is Always Under Younger Rock

Thrust Faults Not Recognized

Why Study Northern Scotland?

- 3 Billion years of rocks
- No ground cover
- Everything is visible

Birthplace of Modern Geology

- The Scottish highlands have been extensively studied for over 200 years and have been the birth place for key elements of modern geological understanding
- James Hutton in 1795 proposed that earth's geology evolved slowly over vast time periods and not by a series of catastrophes over thousands of years and is regarded as the founder of modern geology and he viewed "the present is the key to the past"

- In 1830 this was popularized and named the "Principle of Uniformitarianism" by Charles Lyell in his book "The Theory of Geology"
- Lyell's work strongly influenced Charles Darwin who viewed evolution as biological uniformitarianism which occurred imperceptibly over many generations
- Charles Lapworth in 1881 showed that folding could replicate the same beds many times
- Ben Peach and John Horne in 1907 were the first to demonstrate thrust faulting
- The Highlands have also been the source of a 60 year bitter debate from 1840 to 1905 in the highest geological circles of Great Briton called the "Highlands Controversy"

Main Rock Types in the Northern Highlands

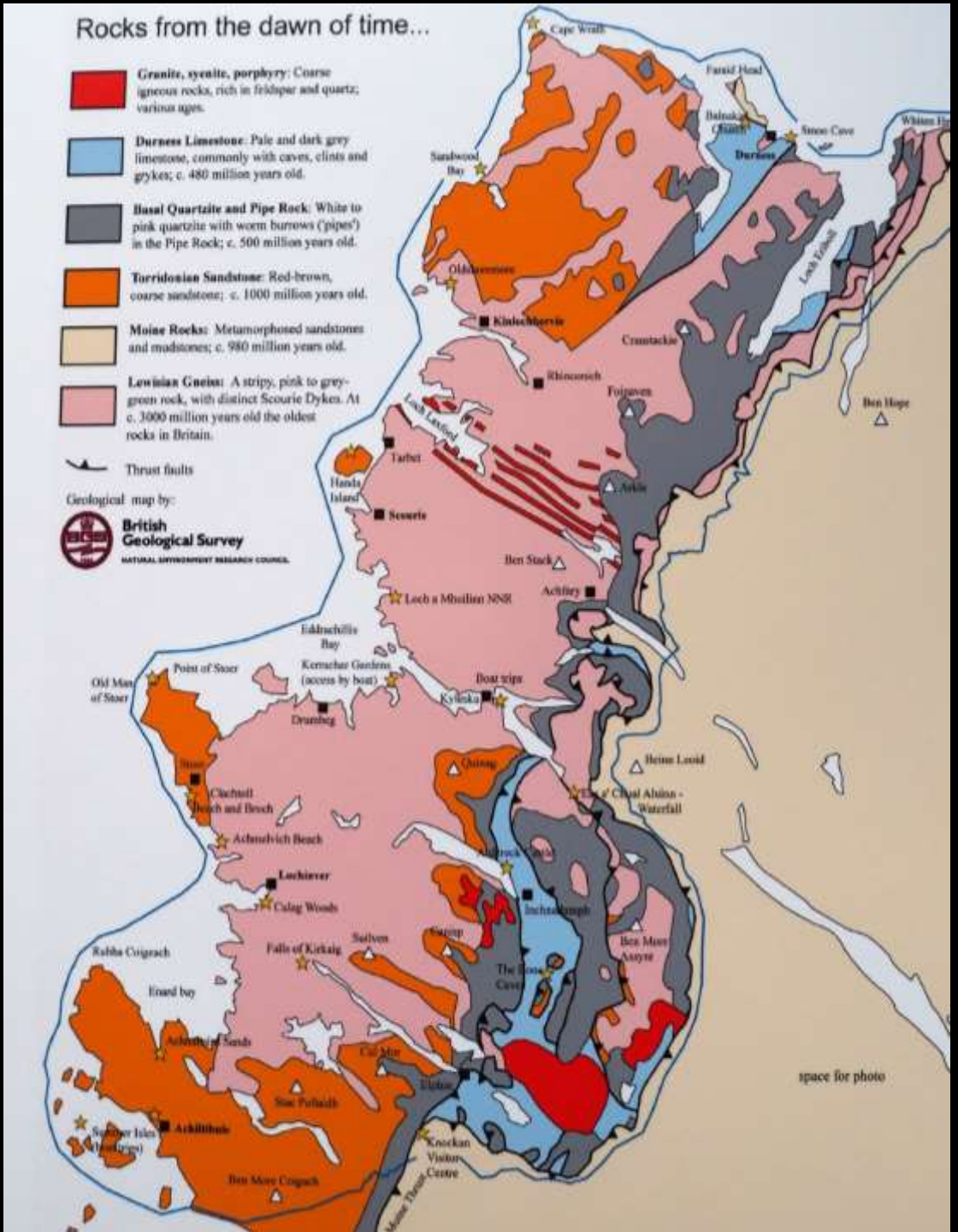
- Lewisian Gneiss
  - Precambrian(no fossils) high grade metamorphic rock made from mudstone and shale (high grade meaning subject to the highest temperatures, pressures for the longest times forming large crystals)
  - Types depend on the content of specific minerals and is often banded with layers of different mineral content
  - It named after the outer Hebridean island of Lewis which is completely covered by the gneiss
  - It is 3 Billion years old making it some of the oldest rock on earth
- Torridonian Sandstone
  - Coarse grain sedimentary sandstone containing a conglomerate mix of other rock types
  - Precambrian(1 Billion years in age & no fossils) and is not metamorphosed
  - Is deposited unconformally (2000Myr) on denuded rolling gneiss with small hills and valleys
  - This unconformity is one of the most striking features of the North West Highlands

Main Rock Types in Northern Highlands

- Moine Schist
  - Precambrian medium grade metamorphic rock formed from mudstone and shales
  - Has medium grained mica flakes in a preferred sheet like orientation called schistocity
  - Has a preponderance of lamellar (flat, planar) minerals such as micas, chlorite, talc, and graphite also containing quartz
  - Its name Moine came from A'Mhoine on the north coast which is a region of peat bogs
  - At the thrust zone the schist can be metamorphosed by the shearing action from the thrust and are then referred to as Moine mylonites

Sedimentary Cambrian Rocks

- Durness Limestone named after the town of Durness at the northwest corner of Scotland is fairly pure calcium carbonate with fossils present(less than 500 Myr)
- Salterella grits are a band of quartzite and grit at base changing to carbonate dolomite with worm pipes up to an inch in diameter ,forming an escarpment between fucoid beds and limestone above
- Fucoid beds vary in composition with some containing carbonates and others more shale like with a rusty color
- Quartzite 500’ in thickness ,at bottom layered coarse quartz and feldspar and at top “pipe rock”,fine grained quartz containing vertical worm holes



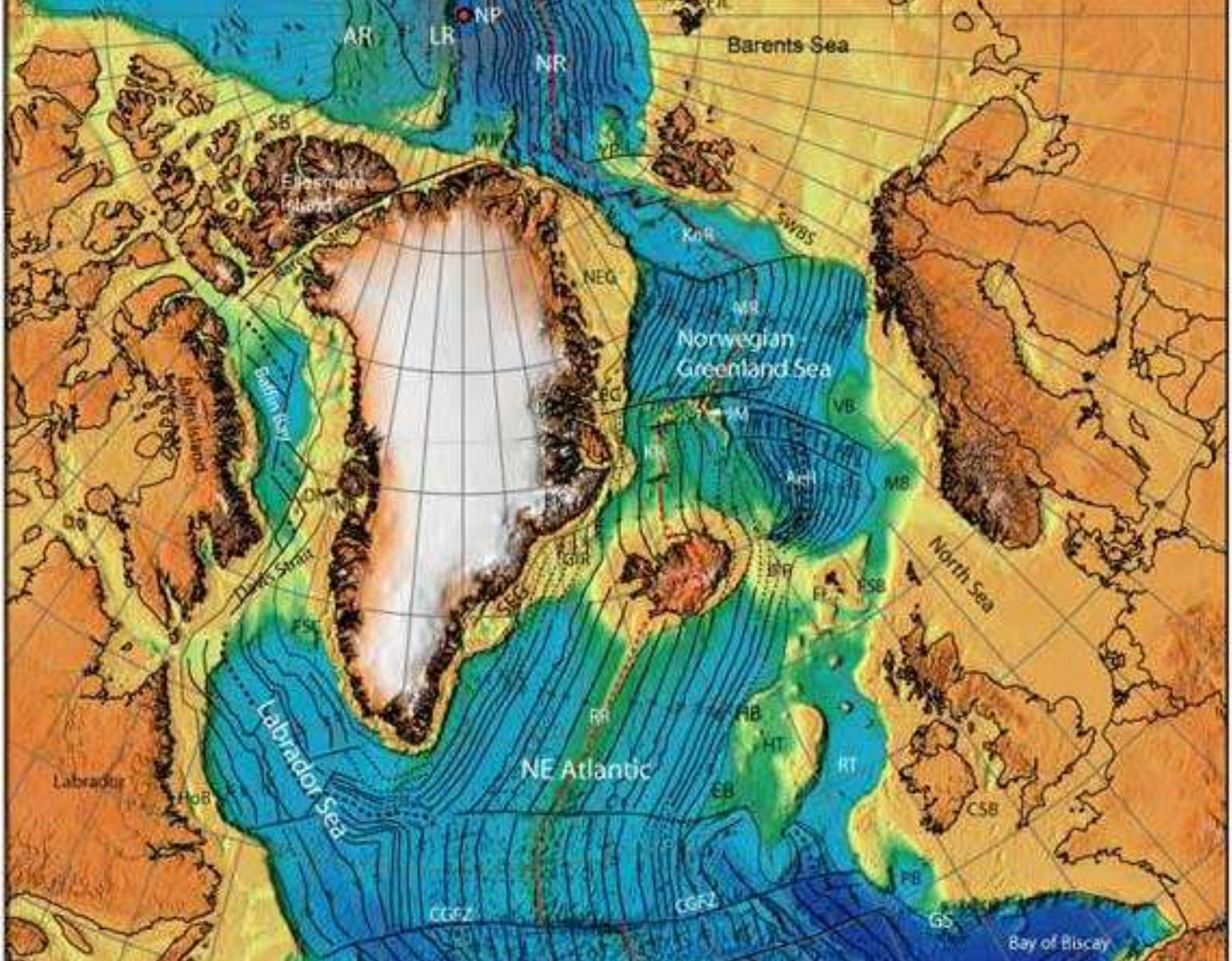
Moine Thrust

- The Moine Thrust occurred during the Caledonian Orogeny in the late Ordovician to early Silurian (455-430 Ma) after the continents collided and the Iapetus ocean closed at 420Ma
- The Moine was lifted and thrust over the ancient Lewisian Gneiss on the Laurentian Plate as the European plate moved westwards
- The thrust moved about 50 miles from east to west over a period of several million years and has a 10-20 degree dip to the east
- The thrust zone is 120 miles long running from the north coast to the Island of Skye and has a maximum width of 6 miles

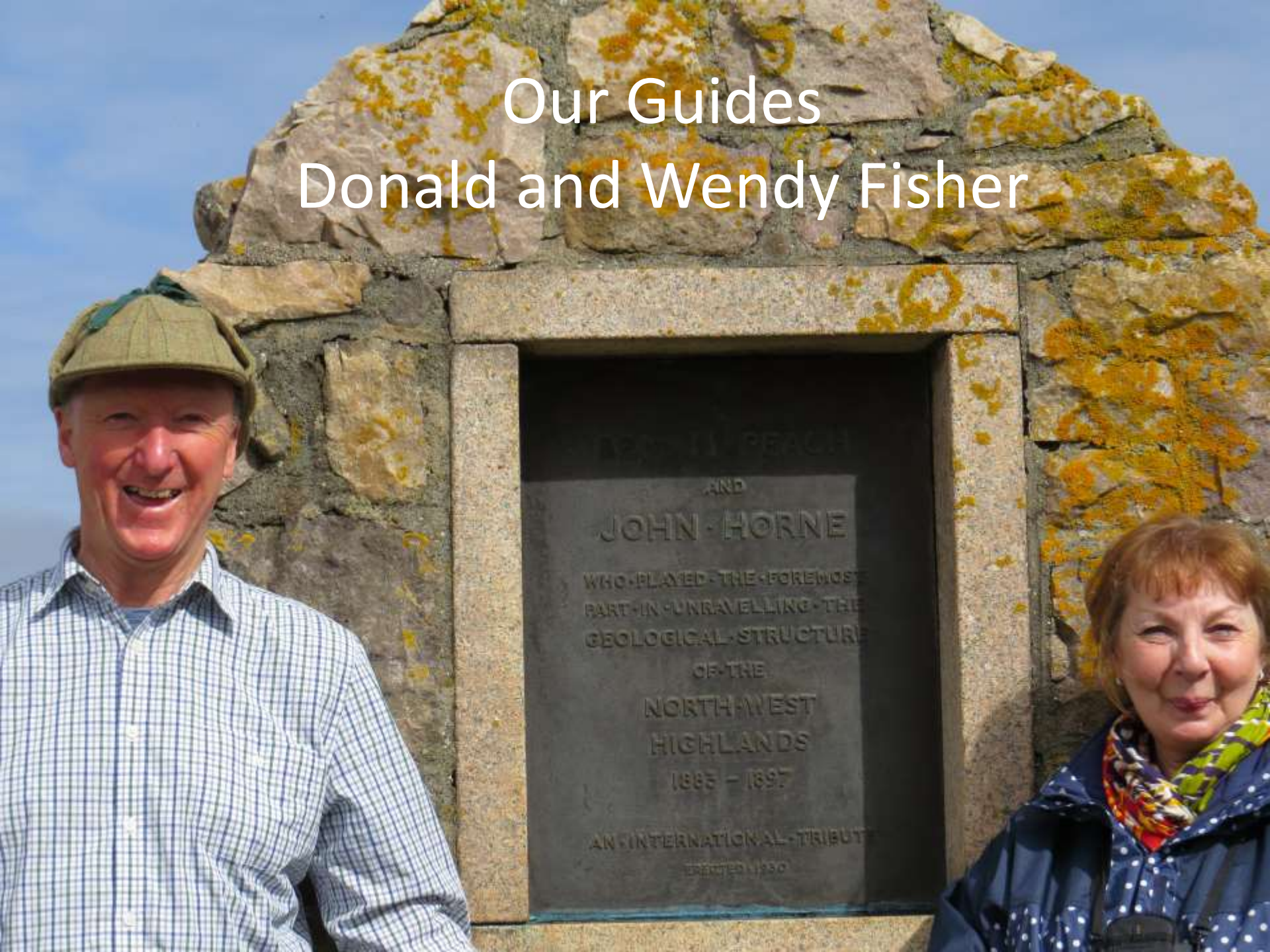
40 Million Years

The North Atlantic Ocean opens 80 million years ago and at 65 million years, Greenland splits off from Europe. North America and Europe continue to drift apart to this day.


ATLANTIC OCEAN FLOOR
EUROPE
AFRICA
SOUTH AMERICA


NP
AR
LR
NR
Barents Sea
SB
MIP
YP
Ellesmere Island
KnR
SWBS
NEG
MR
Norwegian
Greenland Sea
EG
VB
KR
AsH
MB
Baffin Bay
Baffin Island
DS
Davis Strait
GSR
ESR
FI
FSB
North Sea
FSR
Labrador Sea
RR
FB
HT
RT
NE Atlantic
Labrador
HgB
EB
CSB
FB
CGFZ
CGFZ
GS
Bay of Biscay
50 E
40 E
30 E
20 E
50 N
10 E
0 E

Our Guides
Donald and Wendy Fisher




First Evening Social


GEOLOGISTS
OF
JACKSON HOLE
PSV GLASS
LAMINATED
SAFETY GLASS

LOCATIONS IN NORTH SCOTLAND

- Loch Glencoul
- Smoo Cave
- Traigh Allt Chailgeag Beach
- Ben Arnabol Thrust Fault
- Scourie Dikes
- Cambrian Pipe Rock

The Glencoul Thrust, Loch Glencoul

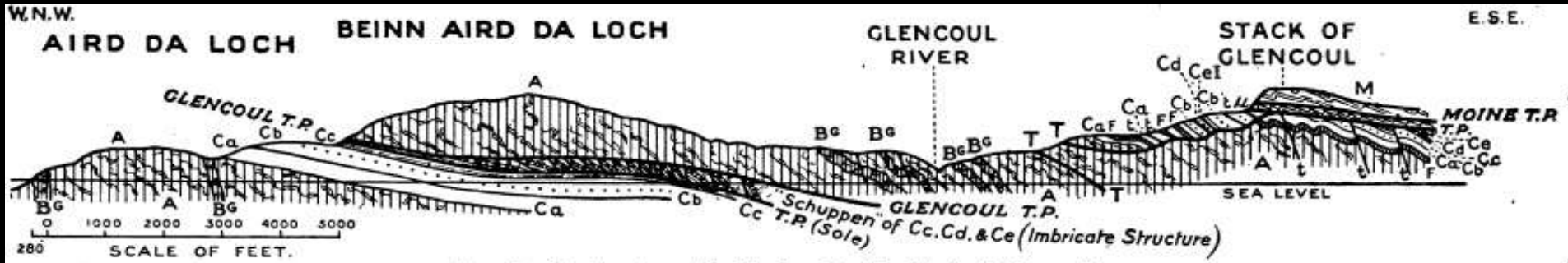


FIG. 5.—Section from Aird da Loch to the Stack of Glencoul.

A. Lewisian Gneiss. Bg. Basic Dykes. Ca. Basal Quartzites (Cambrian). Cb. Pipe-rock. Cc. Fucoid-beds. Cd. Serpulite-grit.
Ce I. Dolomite (Ghrudaidh group). μ. Mylonites. M. Eastern Schists. F. Intrusive Igneous Rocks. T. and T.P. Thrust-planes.


3 BYA Gneiss
550 MYA Quartzite
880 MYA Schist

Peach & Horne Memorial, Loch Assynt

Dedicated to Ben Peach and John Horne who played the foremost part in unraveling the geological structure of the Northwest Highlands, 1883-1897, placed 1930

DATE	NAME	ADDRESS
Sep 12-18	Ben N. Peach	72 Grange Road Edinburgh
Sep 12-18th	John Horne	Edinburgh.
" "	T. J. Jehu	St Andrews.
"	Chas. Barrois	Lille (France)
	A. Strahan	28 Jermyn St. London S.W.
	C. K. Leith	Madison, Wis., U.S.A.
	S. H. Reynolds	" Bristol
	W. F. P. McLintock	Edinburgh, Royal Scottish Museum
	Jr. Richey	33 George Square Edinburgh
	W. S. Boulton	University College, Cardiff
	Dr. Alb. Heim	Zürich Switzerland
	Albert Gilligan	University Leeds
	Paul M. Lugeon	Lausanne Switzerland
	Prof. Emile Haug	Sorbonne Paris
	Dr. E. Jérémine	St. Petersburgh, Russia

CLASSIC NORMAL FAULT


SMOO CAVE

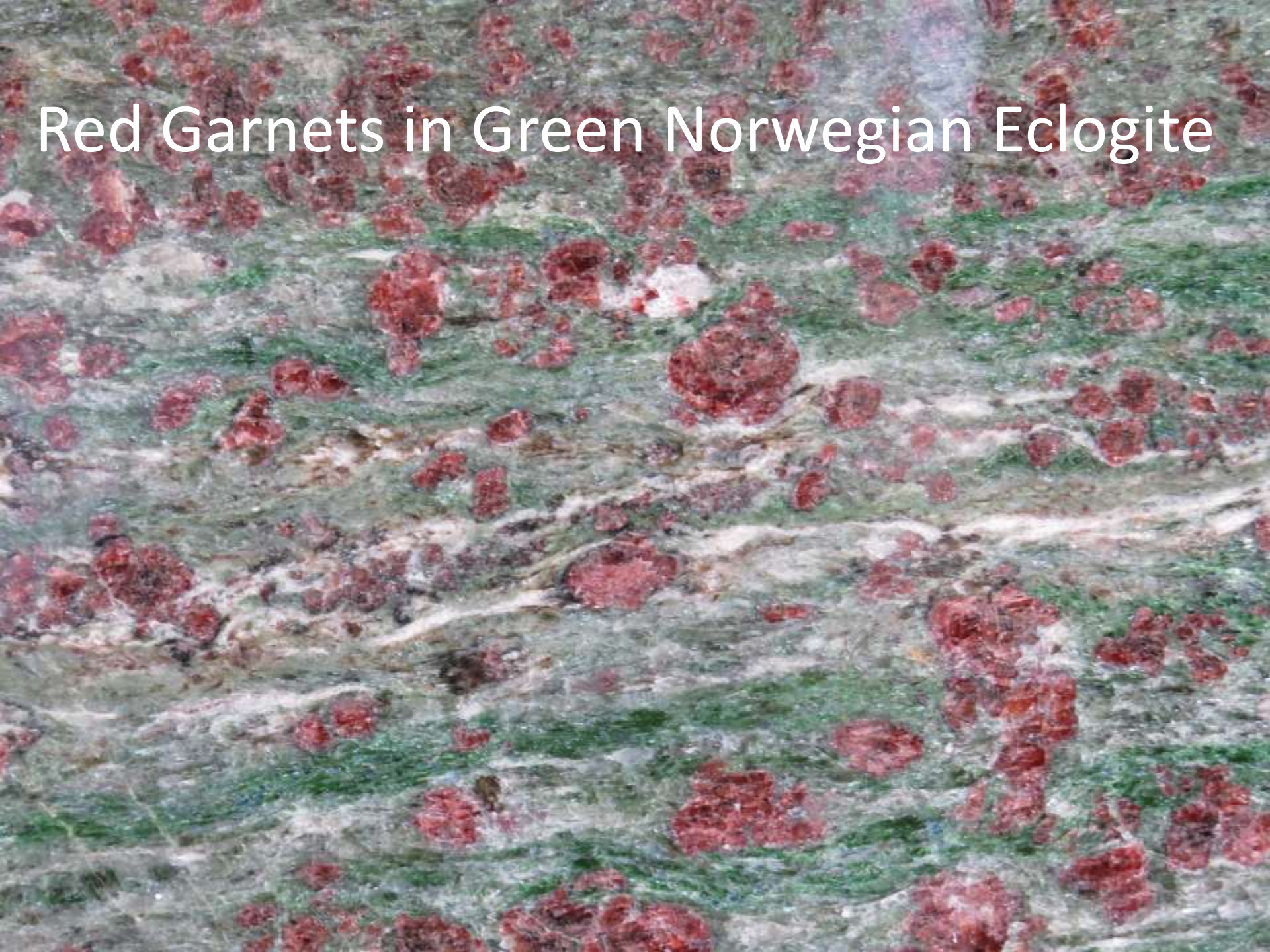

Traigh Allt Chailgeag Beach

Traigh Allt Chailgeag Beach

Ben Arnabol Thrust Fault


Dunrobin Castle

Geology Museum


Red Garnets in Green Norwegian Eclogite

Scourie Dike

Cambrian Pipe Rock

LOCATIONS IN NORTH SCOTLAND

- Loch Glencoul
- Smoo Cave
- Traigh Allt Chailgeag Beach
- Ben Arnabol Thrust Fault
- Scourie Dikes
- Cambrian Pipe Rock

- Knockan Crag
- Strath Dionard
- Stac Pollaidh
- Clatchtoll – Split Rock
- Achmelvich
- Old Man of Steor
- Bone Caves
- Inverewe Gardens
- Mt Slioch

Knockan Crag, Northwest Highlands Geo Park

The story of Peach and Horne's 14 year study of the Highland's geology is well told at Knockan Crag

John Horne and Ben Peach outside the Inchnadamph Hotel on Loch Assynt

Knockan Crag Geological Park which shows the various post Cambrian rock layers including the over riding Moine Schists

Donald explaining the wonders of Knockan Crag

Knockan Crag, Northwest Highlands Geo Park

View of cliff side at Knockan Crag(~400’ high) showing 5 sedimentary layers covered with Moine Schist(quartzite, pipe rock, fuccoid beds, salterella grit, limestone)

Cambrian pipe rock, quartzite with vertical worm holes

Fucoid Beds, sandstone & siltstone & vegetable matter cemented by carbonate

Limestone over Fucoid Bed & Salterella Grit, sandstone, shell casts & carbonate

Contact between the limestone and the schist

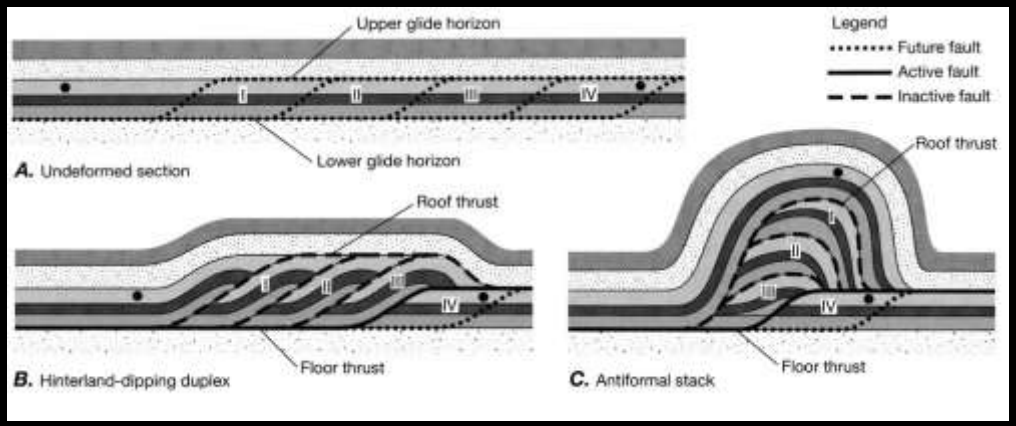
Moine Schist over Durness Limestone, Knockan Crag


Chirstine Marechal’s arms across 500 million years of time
Feel 500 million years of time

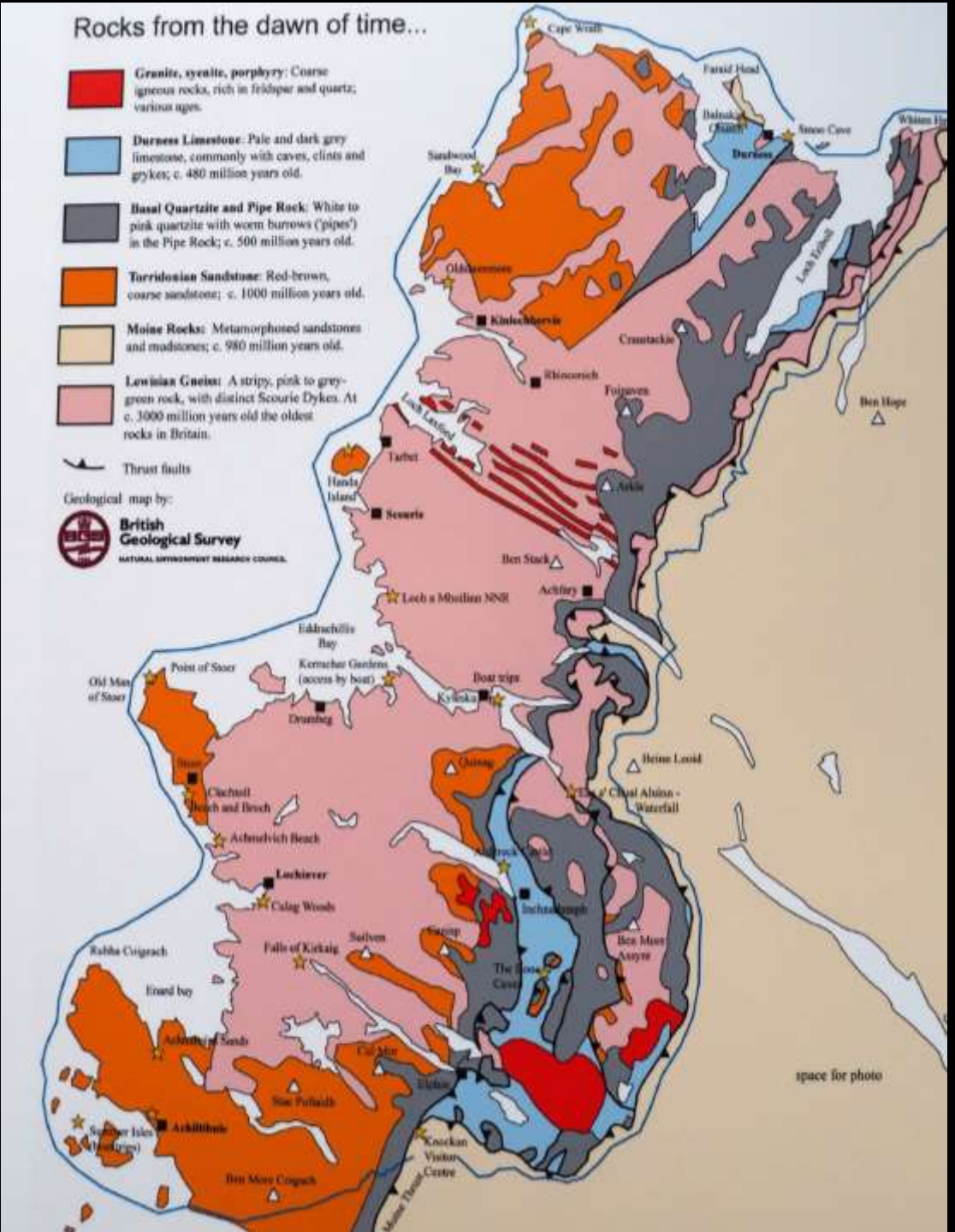
Mylonized Schist, Knockan Crag

Top of Knockan Crag with Cul Beag(2538’) and Stac Pollaidh(2039) behind

Imbricate Structure Strath Dionard



- After a long 11 mile hike the peak Foinaven is seen which is formed by multiple thrusts of the same quartzite layer forming an imbrication
- These thrusts are driven by the main Moine thrust to the west
- The folding on the back side of the imbrication is very evident



Assynt Geology

- All of the rocks are old with most being precambrian and the youngest being the Silurean igneous intrusions (430 Ma)
- The Assynt topography is intimately related to its geology
- The Lewisean gneiss forms an undulating rocky plateau, varying from 500’ to 1000’ high and are dotted with lochs
- The Torridonian sandstone forms detached mountains upon the plateau
- The Cambrian quartzite are mountain builders since they are resistant to erosion and protect the rock underneath
- The Moine schist to the east forms a large plateau but that is less rocky than the gneiss plateau to the west

- Suilven (2400’) and Cul Mor(2800’) from Stac Pollaidh(2000’) showing 1400’ and 2000’ of Torridon sandstone over Lewisean Gneiss
- At 800 million years ago the mountains were at their highest and it was estimated there was 17000’ of sandstone covering the gneiss
- They have eroded back to their current heights leaving much of the area with only the original gneiss with isolated island mountains of sandstone

View from Stac Pollaidh, 2013


Betty Elliot, Jennifer Truman, Brent Schaffer, Bud Elliott, Bonnie Voorhees, Virginia Adler


Cross Bedding Torridon Sandstone, Stac Pollaidh

Looking North, Stac Pollaidh

Achnahaird,Hebridean Goat

Split Rock, Clachtoll, 1Bya sandstone over 3Bya gneiss, strike N-S

Clachtoll,unconformity between Lewisean Gneiss and Torridon Sandstone, Strike E-W indicating an ancient canyon

Precambrian stromatolites on Clachtoll beach

Clachtoll – Lazy Beds,2000Ya

Clachtoll, 1 billion year fossilized waves in sandstone

Clachtoll, Iron age Broch, 100yr BC to 100yr AD

Stac Fada cross bedding in sandstone and deformation and darkening due to a meteorite impact. Thought until recently to be due to a lava intrusion


Darker Material Ejecta From Meteorite Impact

Gneiss Country, Achmelvich, Assynt

Gneiss shore, Achmelvich

Highly folded Lewisian Gneiss where the orange color is due to minerals containing iron and manganese

Achmelvich, contorted banding in gneiss

Achmelvich, Scourie dyke, dolerite intrusion into the gneiss

Canisp(2790’) and Suilven(2450’) looking east over the Lewisean gneiss from Achmelvich


Steor Head Lighthouse

Old Man of Steor,sixty meter(60m) column of Torridonian Sandstone


Cutting Beds in Torridonian
Sandstone
(1 Billion Years Old)


Smoo Cave
Ben Arnabol
Twenty Five Miles
Cape Wrath
Strathy Point
Traigh Allt Chailgeag Beach
Strath-Dionard
Kinlochbervie
Point of Steor
Clachtoll
Bay of Steor
Achmelvich
Stac Pollaidh
Knockan Crag
Loch Stack
Loch Glencoul
Skiag Bridge & Loch Assynt
Bone Caves
Slioch
Bettyhill
Tongue
Kyle of Tongue
North-west Sutherland
Scourie
Altnaharra
Lochinver
Inchnadamph
Ledmore
Assynt-Coigach
Laxg
Oykel Bridge
Ullapool
Bonar Bridge
Dornoch
Dornoch Firth
Tain
Poolewe
Gairloch
Loch Maree
Wester Ross
Kinlochewe
Achnasheen
Alness
Invergordon
Cromarty Firth
Dingwall
Fortrose
Nairn
Muir of Ord
Inverness

Trail to Bone Caves

The Bone Caves were formed before the last ice age over 10,000 years ago by water eroding the limestone. Many bone remnants have been found including a walrus bone pin 2000 years old indicating people live in the area at that time

Bone Caves


Pierre Marechal, Mary Springer, Bonnie Voorhees, Donald Fisher, Christine Marechal
Mike Adler, Mike Scher, Nancy Ayers

An Artesian spring


Inverewe Gardens


Jack Hales (the weatherman), Susan Hales

Mt Slioch, Loch Maree

Unconformity of Torridonian sandstone over Lewisian gneiss and to the right quartzite over the sandstone

Double-Decker Delight

Two-Faced

Look closely at Slioch, the remarkable mountain (980m/3215ft) opposite. You can see it consists of two parts. The lower section is made of gneiss (sounds like 'nice'), the silvery-grey rock that once formed gentle hills and glens hereabouts. Above it lies a rusty-brown sandstone, which great rivers created when they swept across this area and dumped sand over 5km (3miles) deep. All this happened many millions of years ago, when life had barely begun on Earth.

Going to Pieces

Slioch is now less than 1km high, so where did the other 4km of sandstone go?

The answer is that heavy rains, powerful rivers and rock shattering frosts gradually wore it away. Huge glaciers supplied the finishing touches when they scoured and scraped their way across this landscape. Given time, the constant wear of water and weather will turn these mountains back to sand.

Gneiss Sand Easy

These two rocks began life very differently.

TOPPING SANDSTONE

The sandstone was left by vast rivers. *Feel the sand under your hand.*

GNEISS BOTTOM

By contrast, huge forces deep in the Earth created the gneiss. *Touch the folds where rock buckled under pressure and heat.*

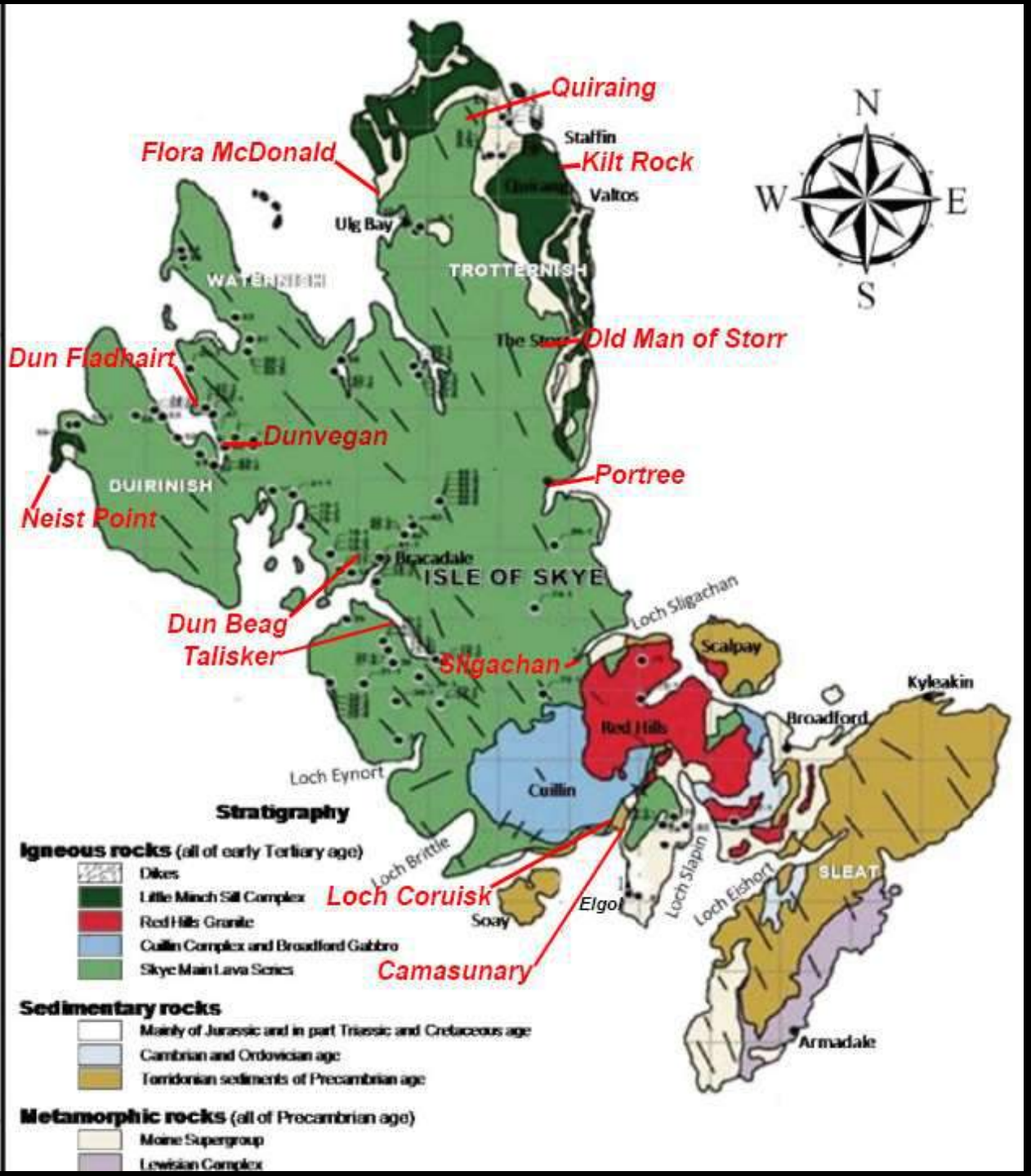
SCOTTISH NATURAL HERITAGE

This is typical of the Geo Park signs. It notes that the sandstone was deposited on the gneiss 1 Billion years ago and Slioch reached it maximum height of 17000' 800 million years ago and reached its current height of 3215' after the last ice age 10,000 years ago

- Corrieshalloch Gorge, Moine Rock, 100m drop
- Ice age raised beach, Gairloch

Applecross on the way to Skye

Skye Geology



- Skye is 50 miles long and 25 miles wide
- Except for the southeast the majority of Skye is volcanic
- The Cuillins are the only real mountain ranges in Great Britain and they are the remnants of magma chambers
- The black Cuillins are gabbro forming ridges with fine features
- The red Cuillins are granite which weathers more and so are very rounded domes
- Northern and mid Skye are mostly basalt from as many as 24 separate lava flows

Approaching Portree

Portree, Morning

Going north out of Portree to the Trotternish Peninsula with the Old Man of Storr in the distance - all Tertiary Lava Flows

- The Old Man of Storr in northern Skye is an isolated pinnacle of 60 million year lava, 160’ high and 40’ in diameter which stands in front of the main escarpment at Storr
- The escarpment itself exposes a sequence of 24 lava flows

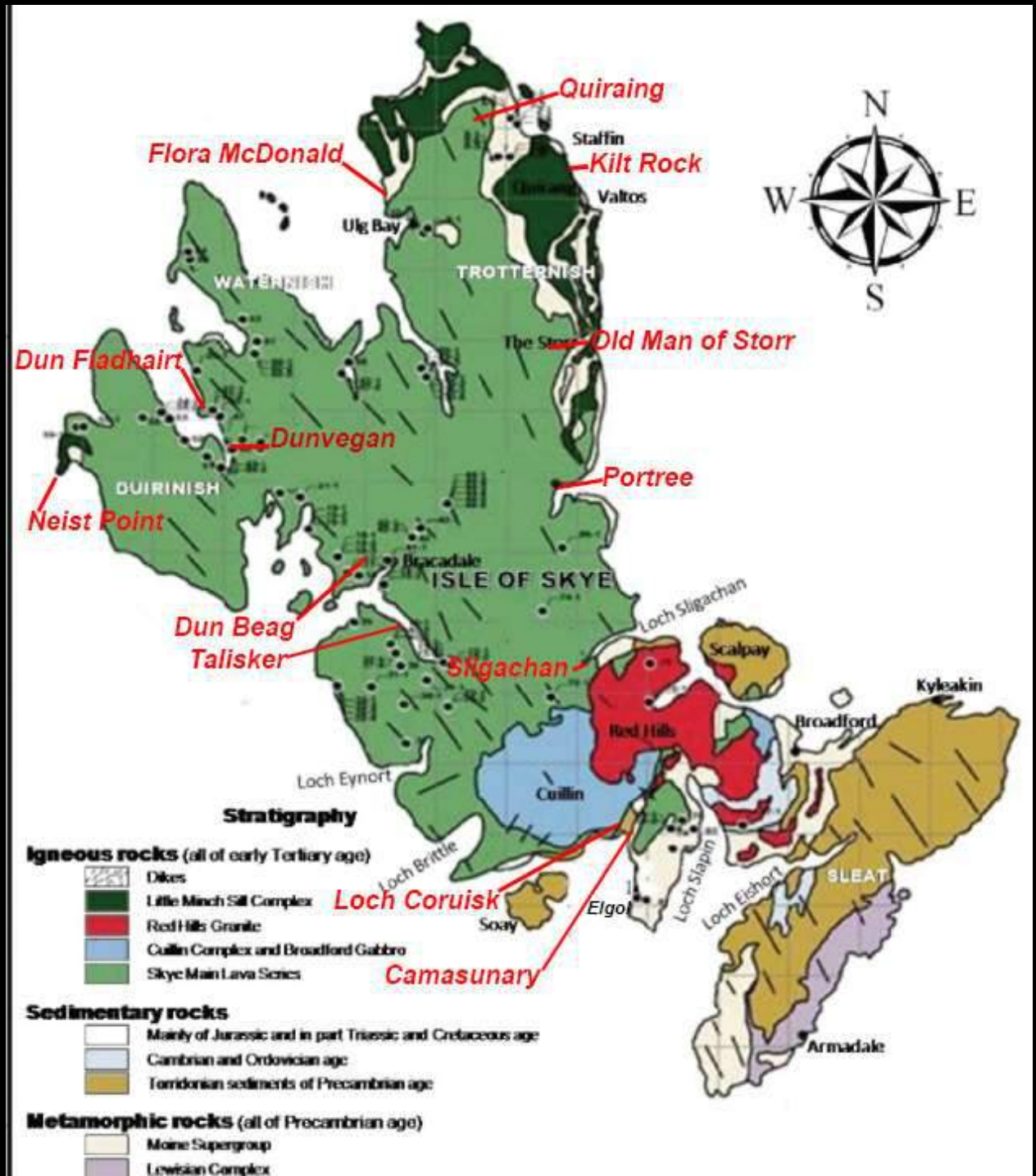
The Quiraing in the very north of Skye, showing landslips that expose wedges of 60 Myr lava and isolated pinnacles

Kilt Rock, Staffin, Skye

- Tertiary (60 million years) basalt columns were formed as the lava slowly cools and contracts with the hexagonal patterns having the lowest energy(pleats in the kilt)
- Below, dolerite was forced between layers of Jurassic(150 mya) sandstone forming horizontal sills(tartan pattern in the kilt)


Dick Schwind, Lillian McMath


Flora MacDonald House


Quiraing
Flora McDonald
Kilt Rock
Staffin
Valtos
Uig Bay
TROTTERNISH
WATERNISH
Old Man of Storr
Dun Fladhairt
Dunvegan
Portree
DUIRINISH
Neist Point
Bracadale
ISLE OF SKYE
Loch Sligachan
Dun Beag
Talisker
Sligachan
Scalpay
Kyleakin
Broadford
Red Hills
Loch Eynort
Cuillin
Stratigraphy
Igneous rocks (all of early Tertiary age)
Dikes
Little Minch Sill Complex
Red Hills Granite
Cuillin Complex and Broadford Gabbro
Skye Main Lava Series
Loch Brittle
Loch Coruisk
Soay
Elgol
Loch Slapin
Loch Eishort
SLEAT
Camasunary
Armadale
Sedimentary rocks
Mainly of Jurassic and in part Triassic and Cretaceous age
Cambrian and Ordovician age
Torridonian sediments of Precambrian age
Metamorphic rocks (all of Precambrian age)
Moine Supergroup
Lewisian Complex
N
W
E
S


Talisker Distillery

Dun Beag Broch, a 2000 year old double walled structure that was housing but also formed defense from attacks

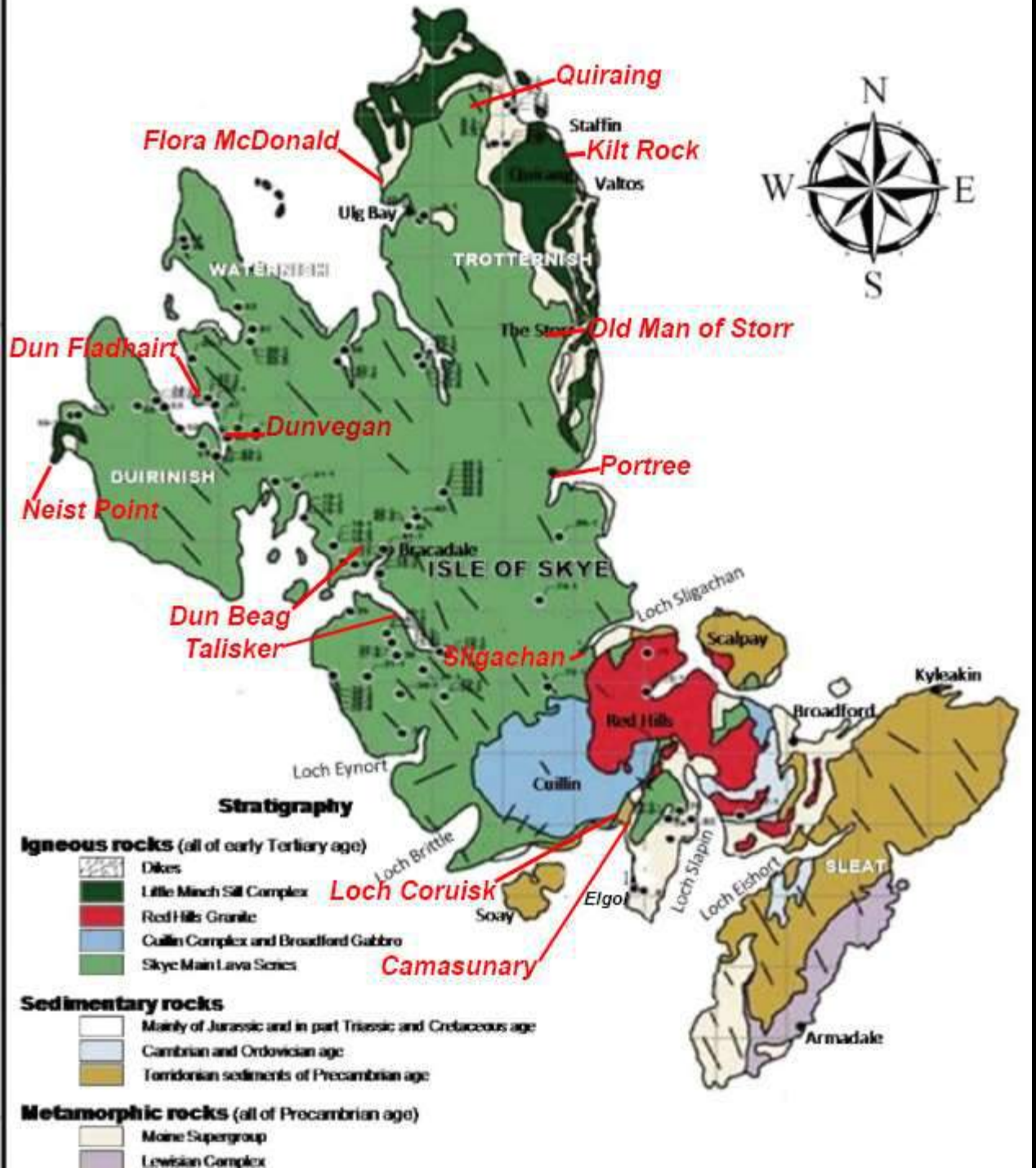

FÀILTE GU
DÙN BEAG
Welcome to
Dun Beag

Dunvegan is the oldest continuously inhabited castle in Scotland
and has been the ancestral home of the Chiefs of Clan MacLeod for 800 years.
Queen Elizabeth spent part of World War II here.

Neist Point is the most westerly point in Scotland. The geology is tertiary basaltic lavas but it has been intruded as was the case in the Troternish Peninsula

Elizabeth Kingwill,

Mike & Virginia Adler


Quiraing
Flora McDonald
Kilt Rock
Staffin
Valtos
Uig Bay
TROTTERNISH
WATERNISH
The Storr
Old Man of Storr
Dun Fladhairt
Dunvegan
Portree
DUIRINISH
Neist Point
Bracadale
ISLE OF SKYE
Dun Beag
Talisker
Sligachan
Loch Sligachan
Scalpay
Kyleakin
Broadford
Red Hills
Loch Eynort
Cuillin
Loch Brittle
Loch Coruisk
Soay
Elgol
Loch Slapin
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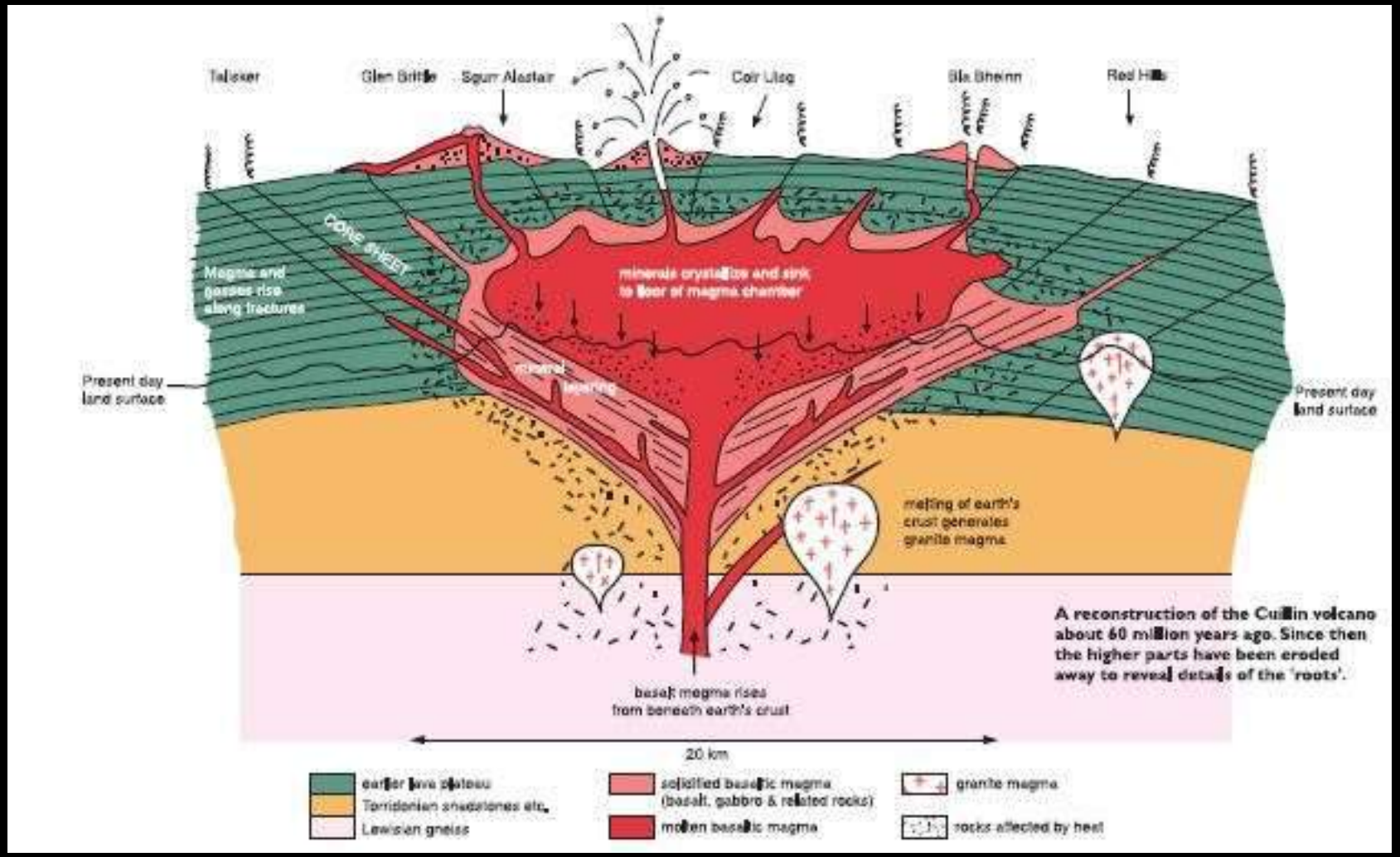
Cambrian and Ordovician age
Torridonian sediments of Precambrian age
Metamorphic rocks (all of Precambrian age)
Moine Supergroup
Lewisian Complex

Blaven -Black Cuillin



- The Cuillin mountains are the remnants of Tertiary volcanos(60 Mya) where the upper lava flow are mostly eroded and what is left are the magma chambers
- The black Cuilins are gabbro, the intrusive version of basalt and form jagged mountain summits
- The red Cuillins are from granite the intrusive version of rhyrolite which form rounded summits

Summit of Blaven Showing Black & Red Cuilins-Donald Fisher

- Camasunary Trail in the SW of Skye

Jennifer Truman, Bud Elliott, Mike & Virginia Adler, Betty Elliott

Black Cuilin, Sgurr na Banachdich,3150’ with Loch Coruisk below with Camasunary beyond


Highlands Cow


THE END