
Still two billion years
more in the
Hebridean Terrane!

Kenorland - hypothesised to have formed c.2.72 Ga.

N. V. Lubnina and A. I. Slabunov; 2017

Formed by the accretion of two or more earlier cratons that later formed Laurentia, Baltica, Western Australia and Kalahari.

The core of Kenorland, the Baltic/Fennoscandian shield, traces its origins back to over 3.1 Ga. Much evidence from the Yilgarn craton greenstone belts.

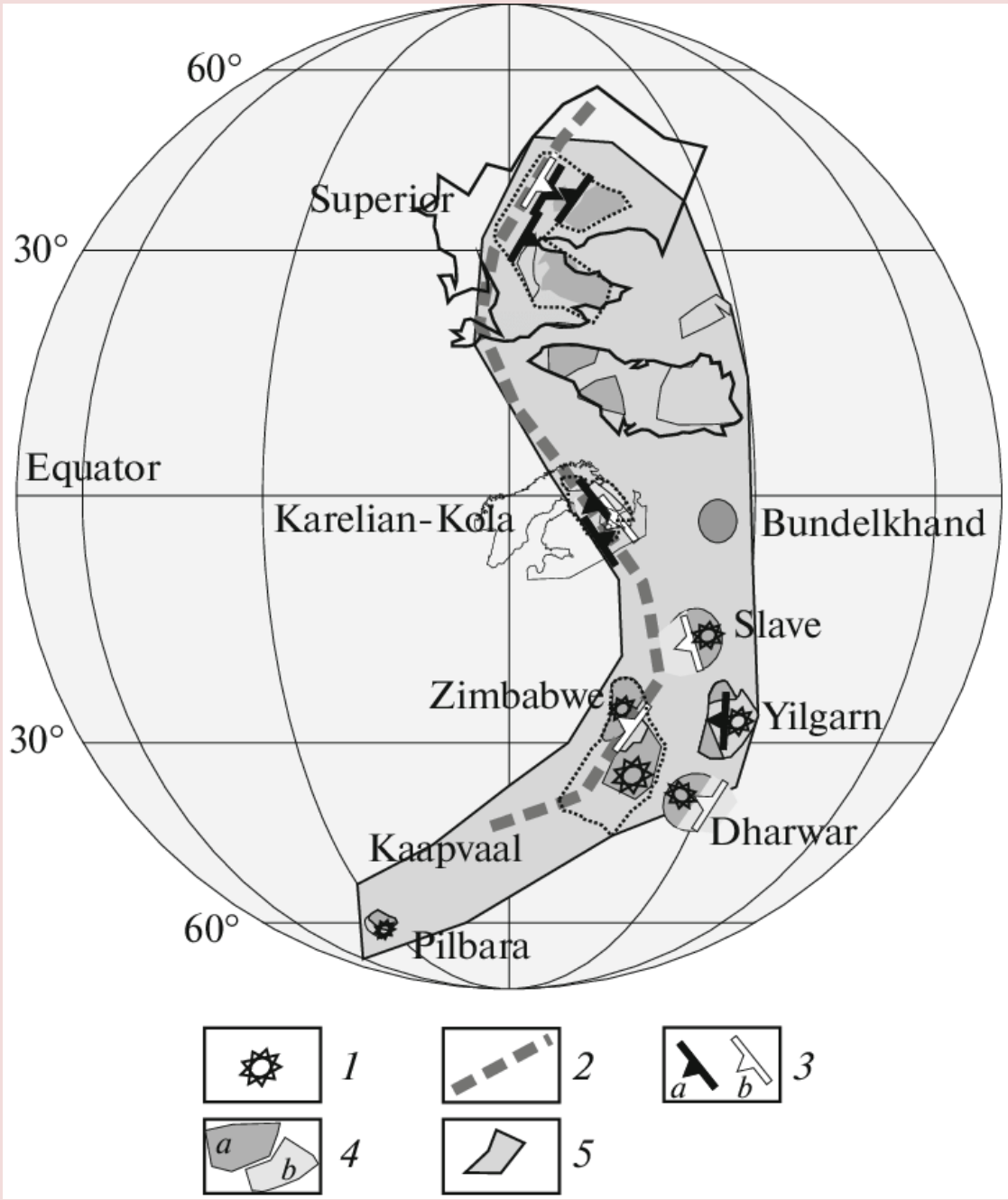
So formed from the accretion of several smaller terranes, including the Hebridean. Began rifting 2.48-2.45 Ga, protracted through to 2.10 Ga, leaving intruded mafic dykes and sedimentary rift basins on many continents.

Break-up contemporary with the Huronian glaciation (60 My duration), the deposition of extensive banded iron formations (BIFs) and rise in oxygen levels. Rainfall, weathering and erosion increased, greenhouse gases decreased, all leading to a Snowball Earth period.

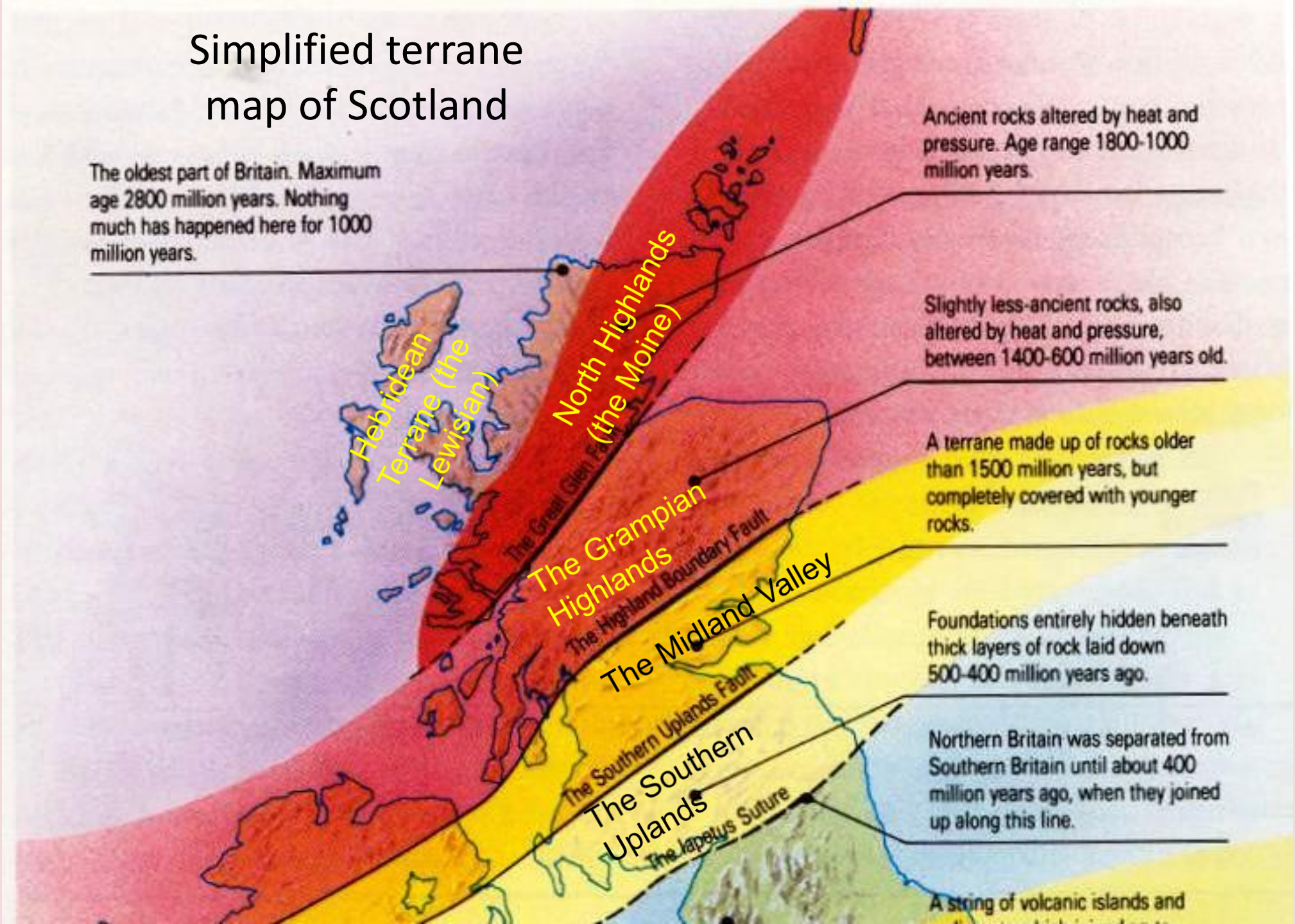
Cause of rifting likely to have been a deep mantle plume.

And the base of the Scottish Lewisian would have been part of Laurentia. But where's Laurentia?

However let's not jump to conclusions. Not everything fits, and there are alternatives being proposed.

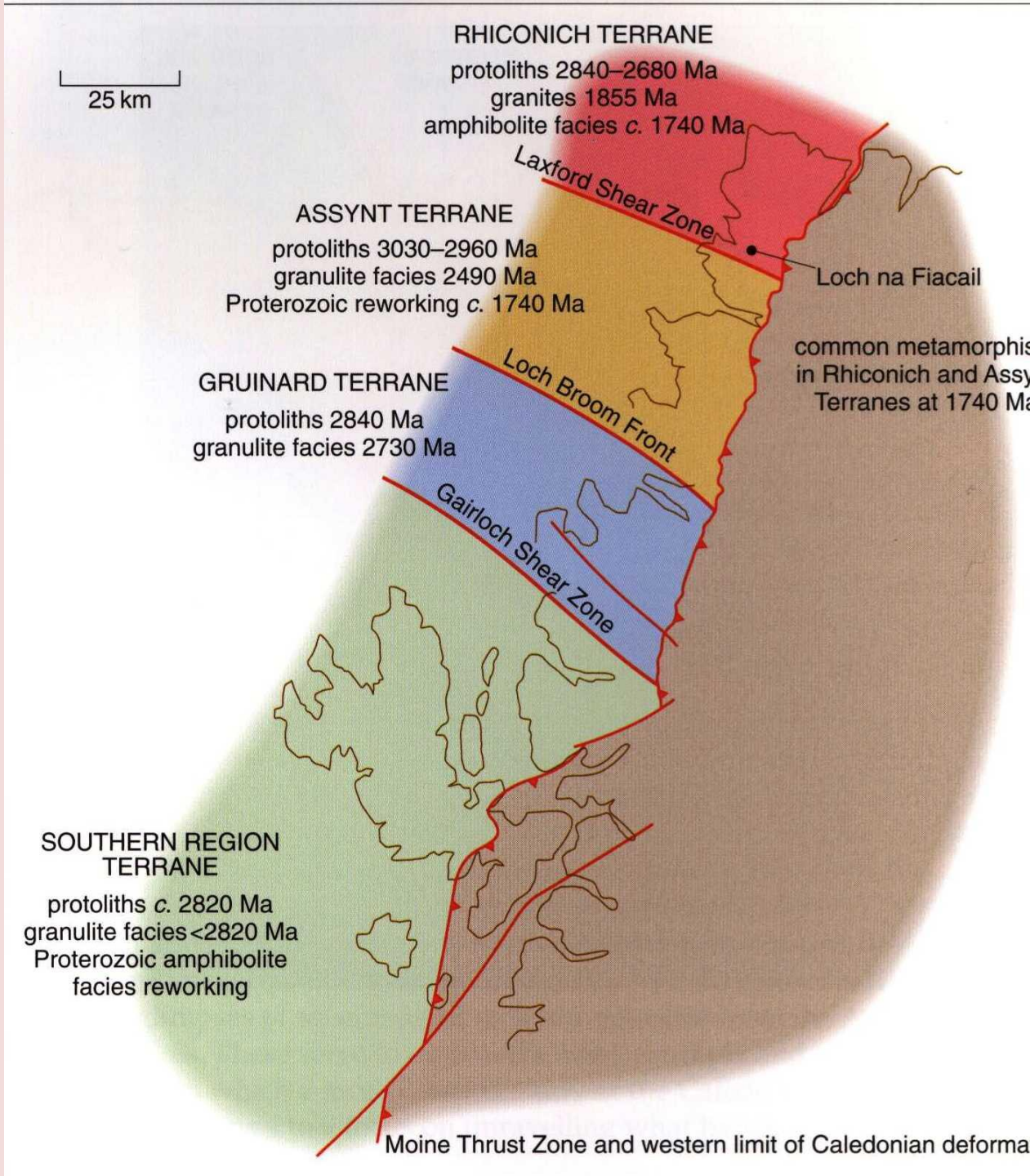


Simplified terrane map of Scotland



Smaller terranes composing the larger Hebridean Terrane!

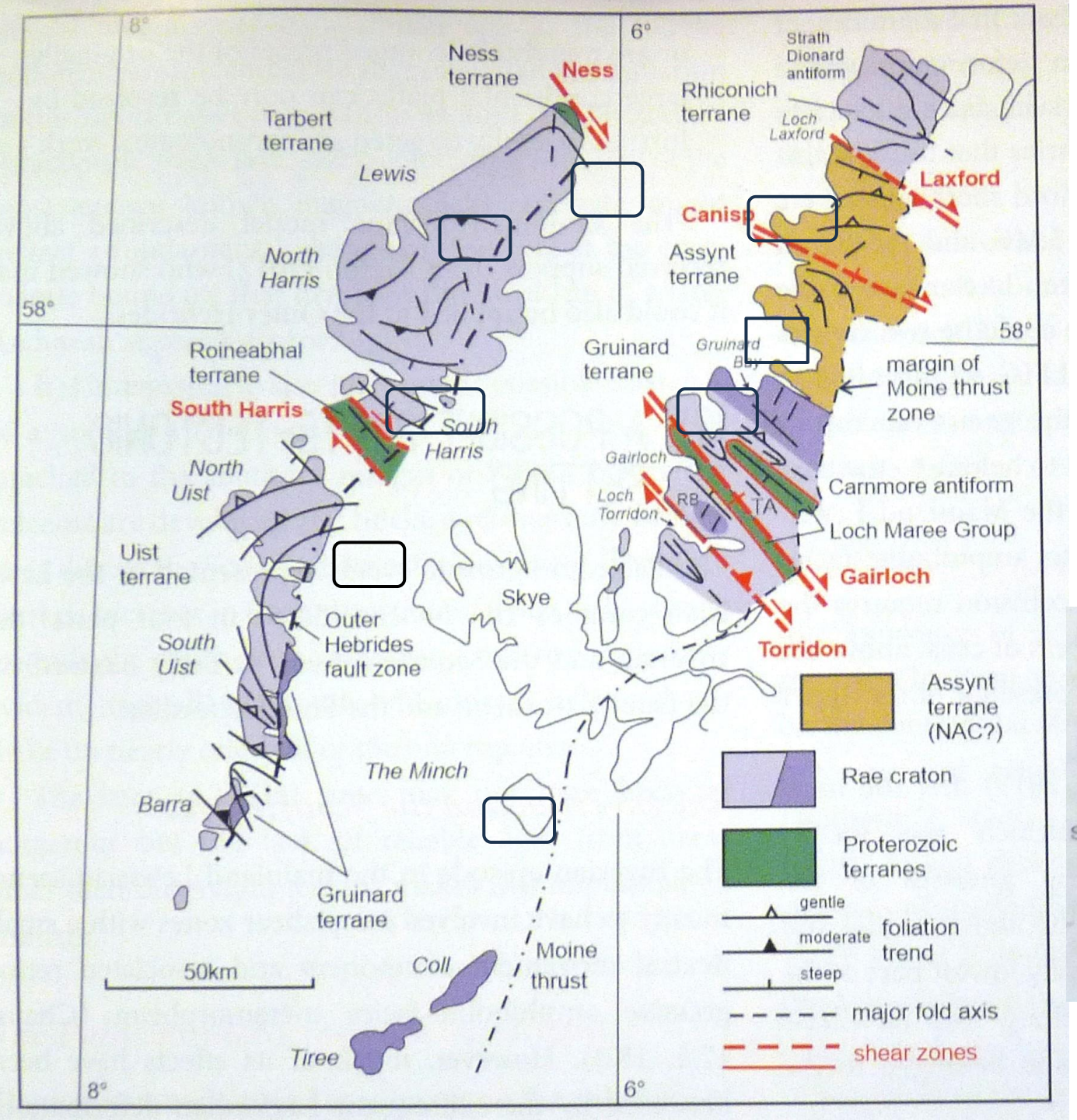
All fragments of Kenorland?

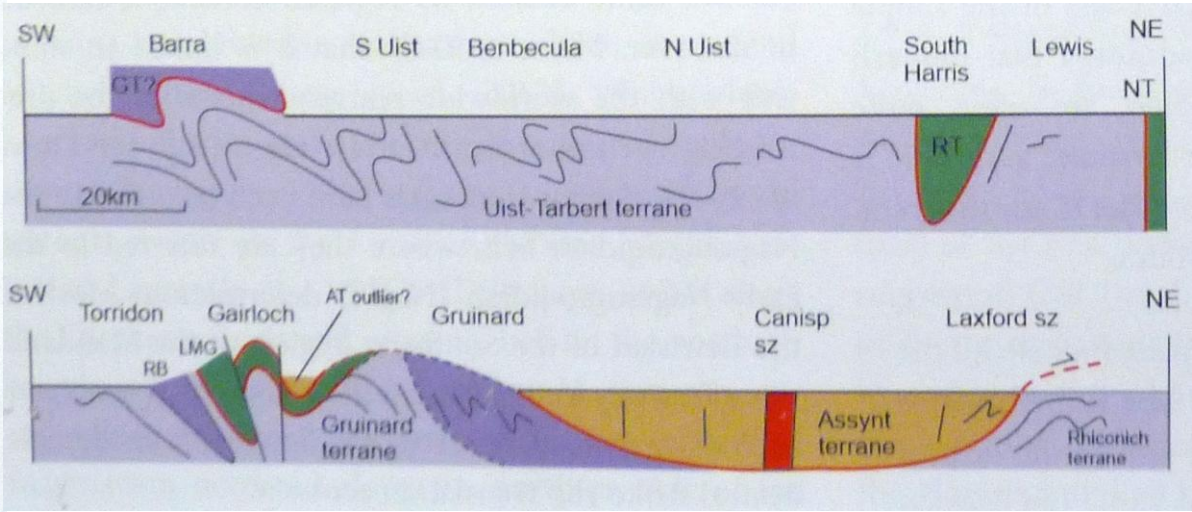


Hebridean Terrane

Simplified map and section across the Hebridean terrane. (Park, 2005)

Rae Craton in purple
North Atlantic Craton (NAC) in light brown
Later Proterozoic terranes in green





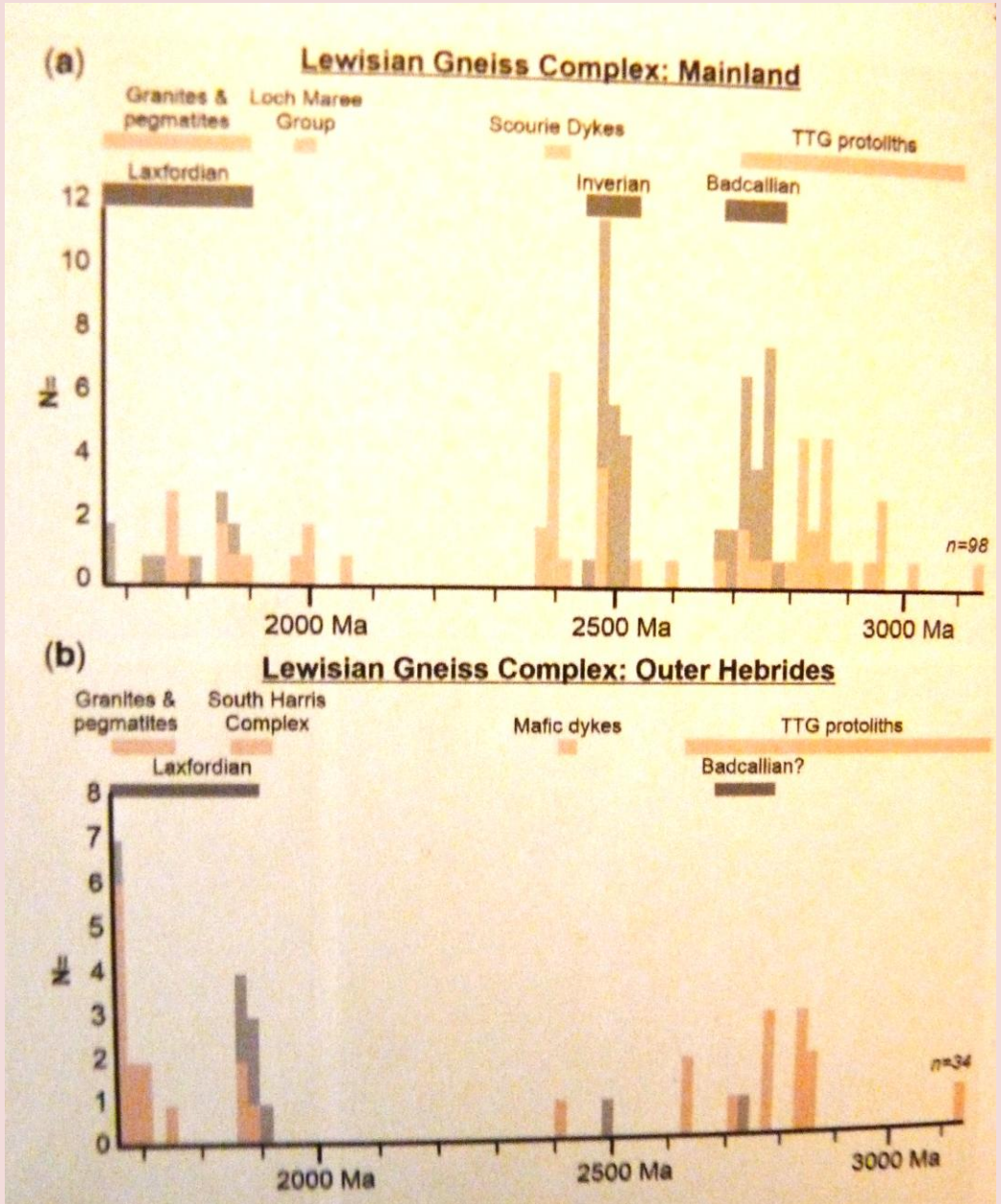
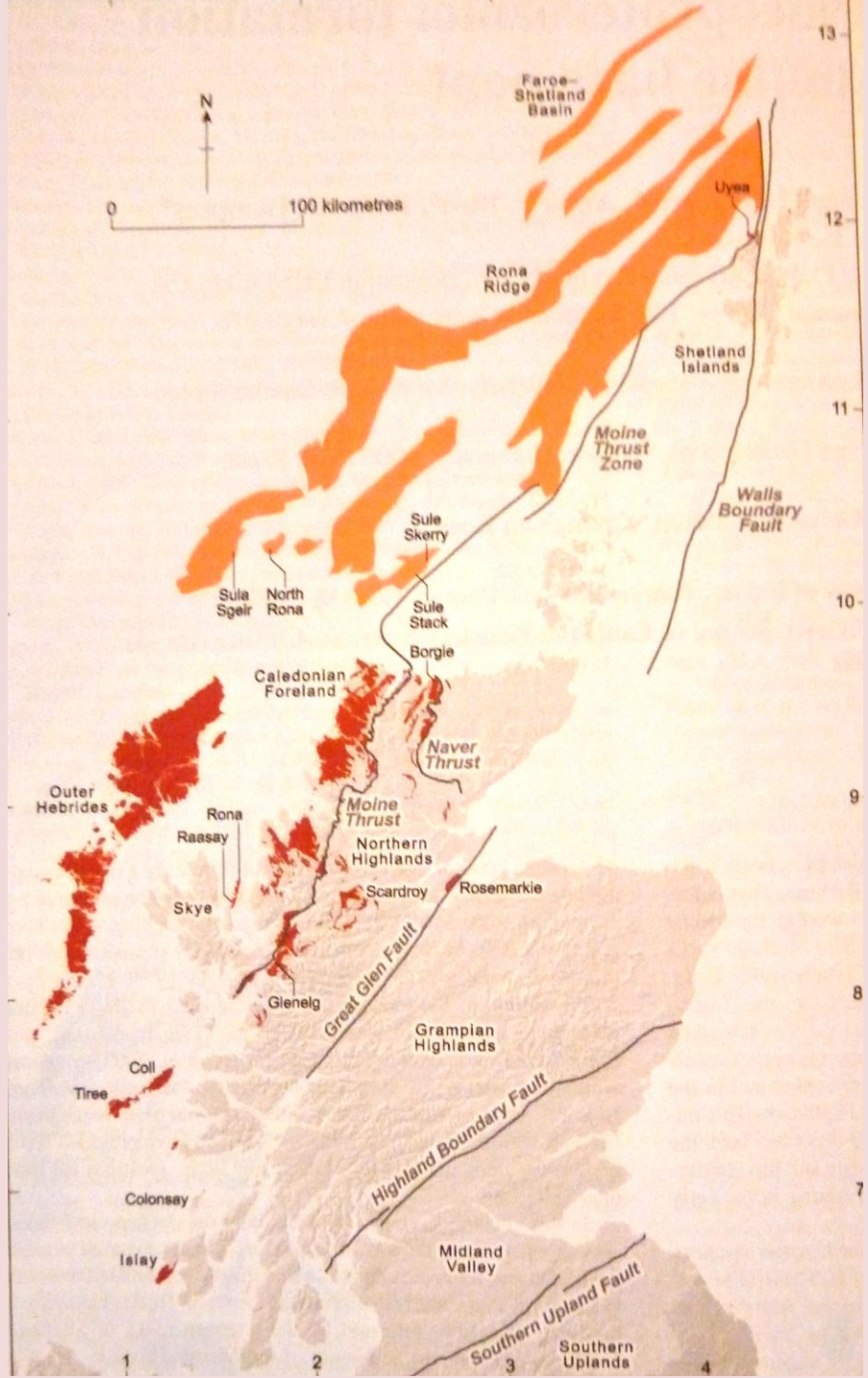
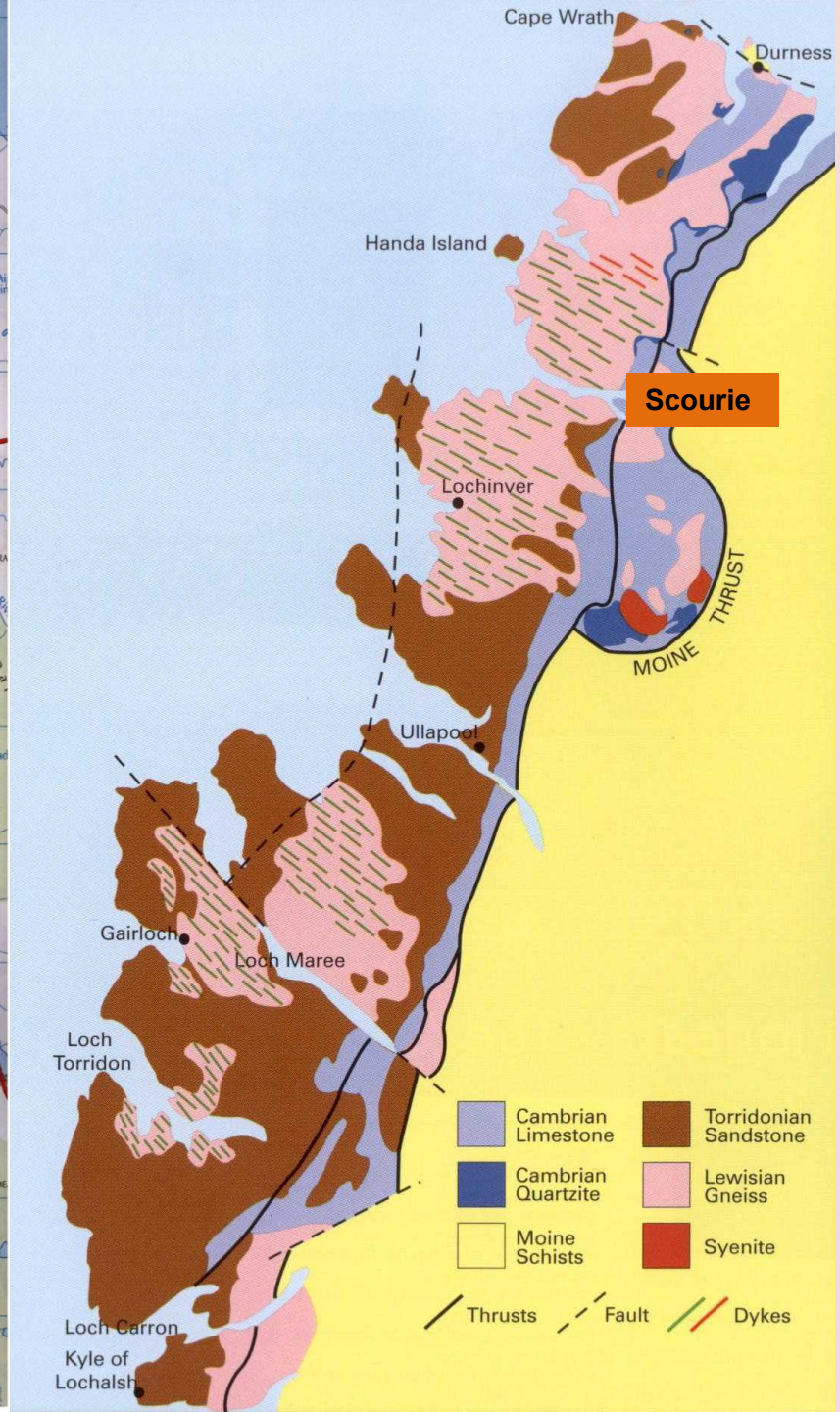


Fig. 3.5. Histogram compilation detailing the U–Pb zircon age data from samples from (**a**) the mainland and (**b**) the Outer Hebridean portions of the Lewisian Gneiss Complex. Pink indicates protolith ages, and grey indicates metamorphic ages. Interpreted ages are those of the





Lewisian rocks

The Lewisian rocks are covered in places by later Torridonian (c.1 Ga) and Cambrian (c.0.54 Ga) rocks.

They are also cut through by thousands of igneous dykes, all on a NW-SE trend.

The dykes and the folding tell of later events, in particular, of **three episodes**:

Scourian complex,3.0-2.5 Ga involving the Badcallian and Late Scourian events

Inverian episode, 2.5-1.9 Ga

Laxfordian complex, 1.9-1.0 Ga

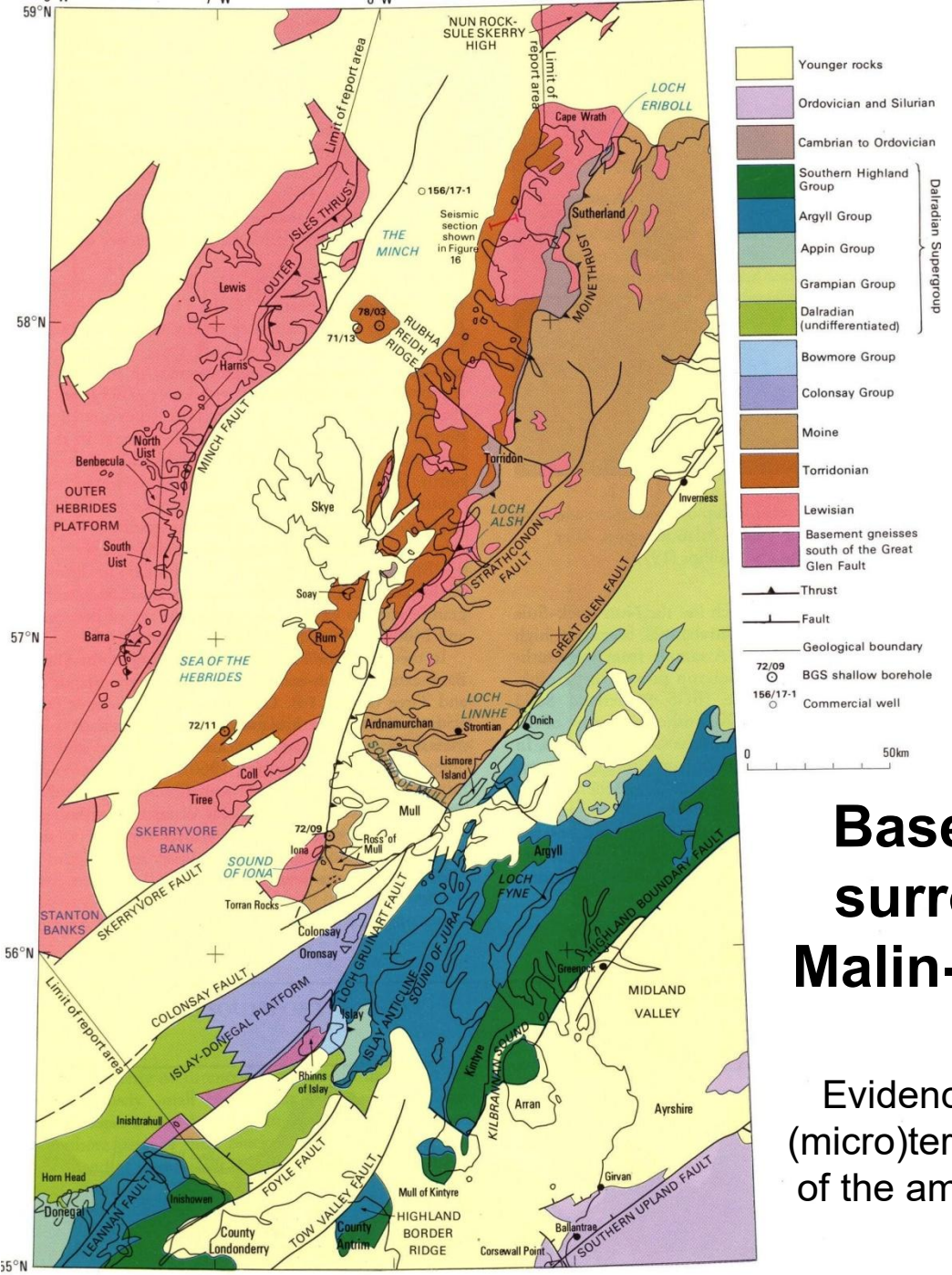


Figure 14 Distribution of basement rocks.

Basement rocks surrounding the Malin-Hebrides sea area

Evidence for many separate (micro)terranes, most being part of the amalgamated Hebridean Terrane.

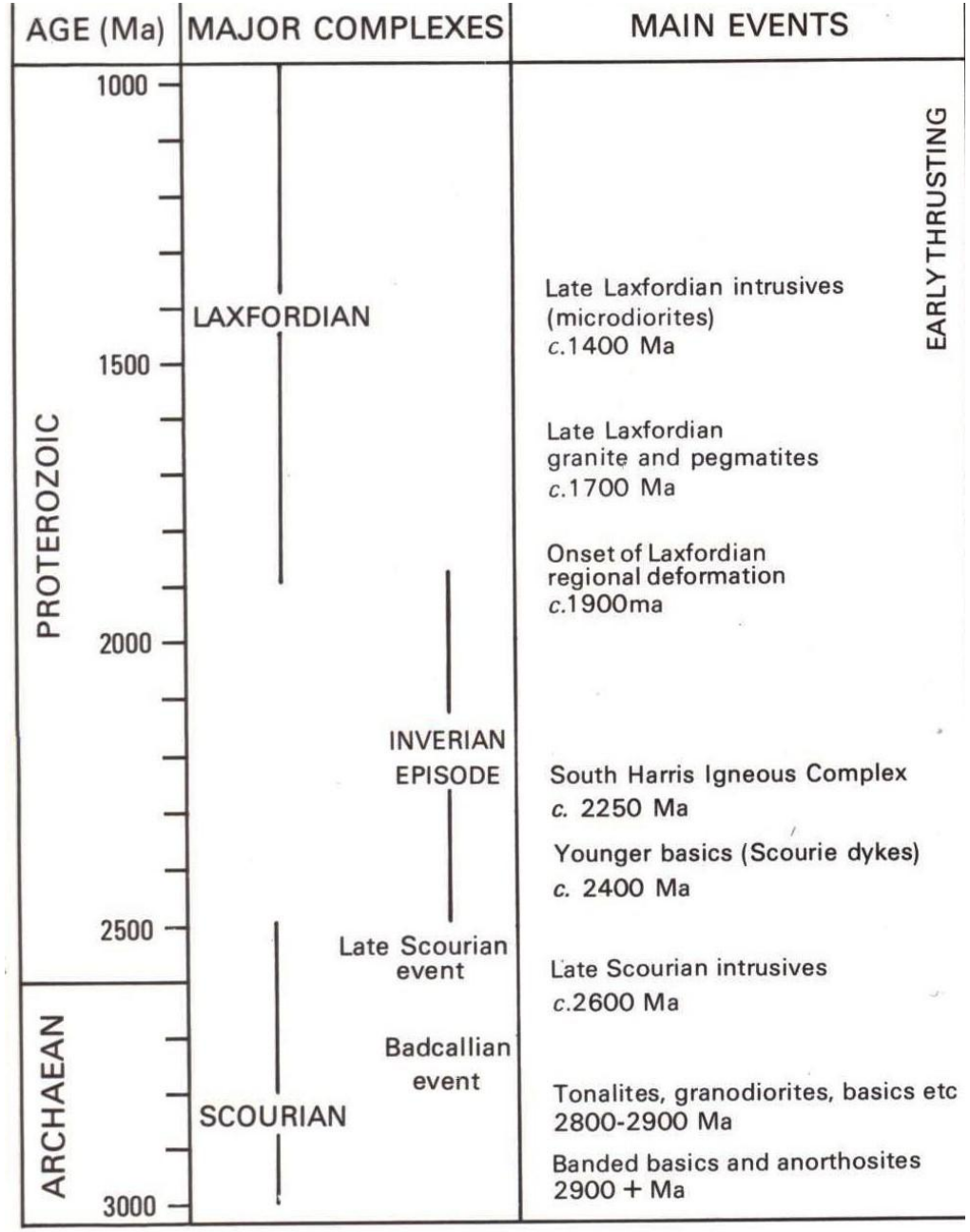
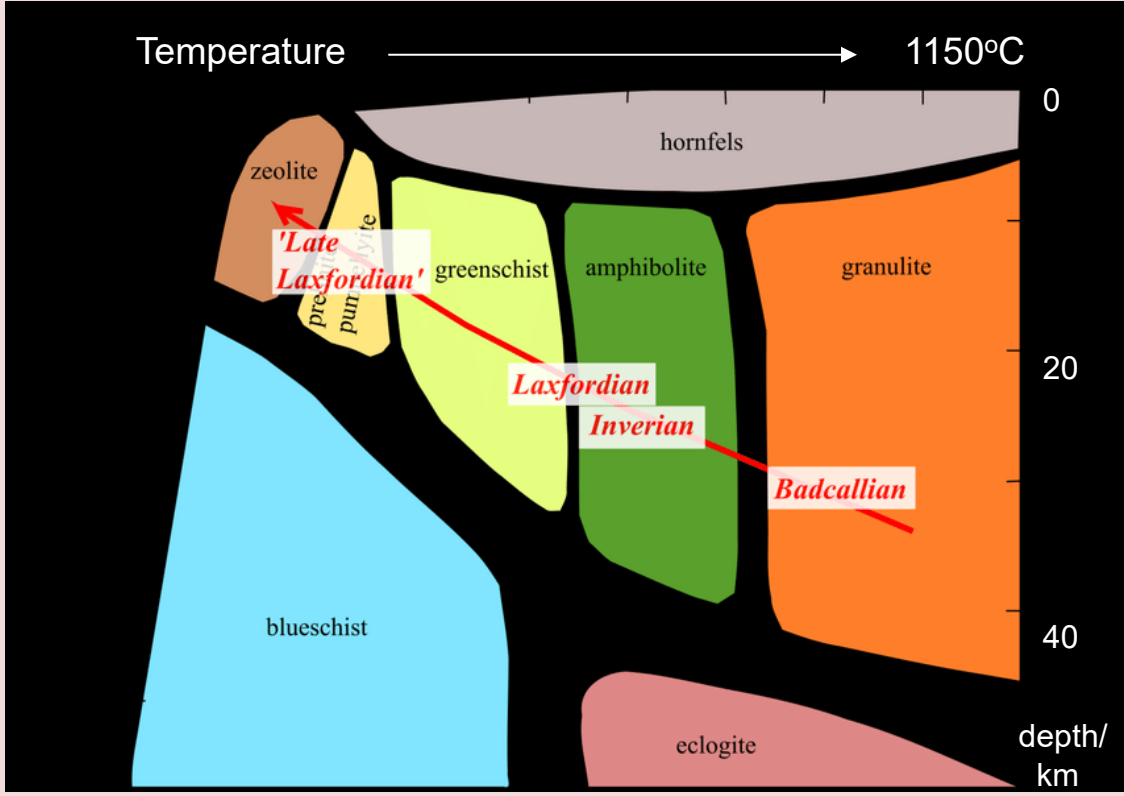
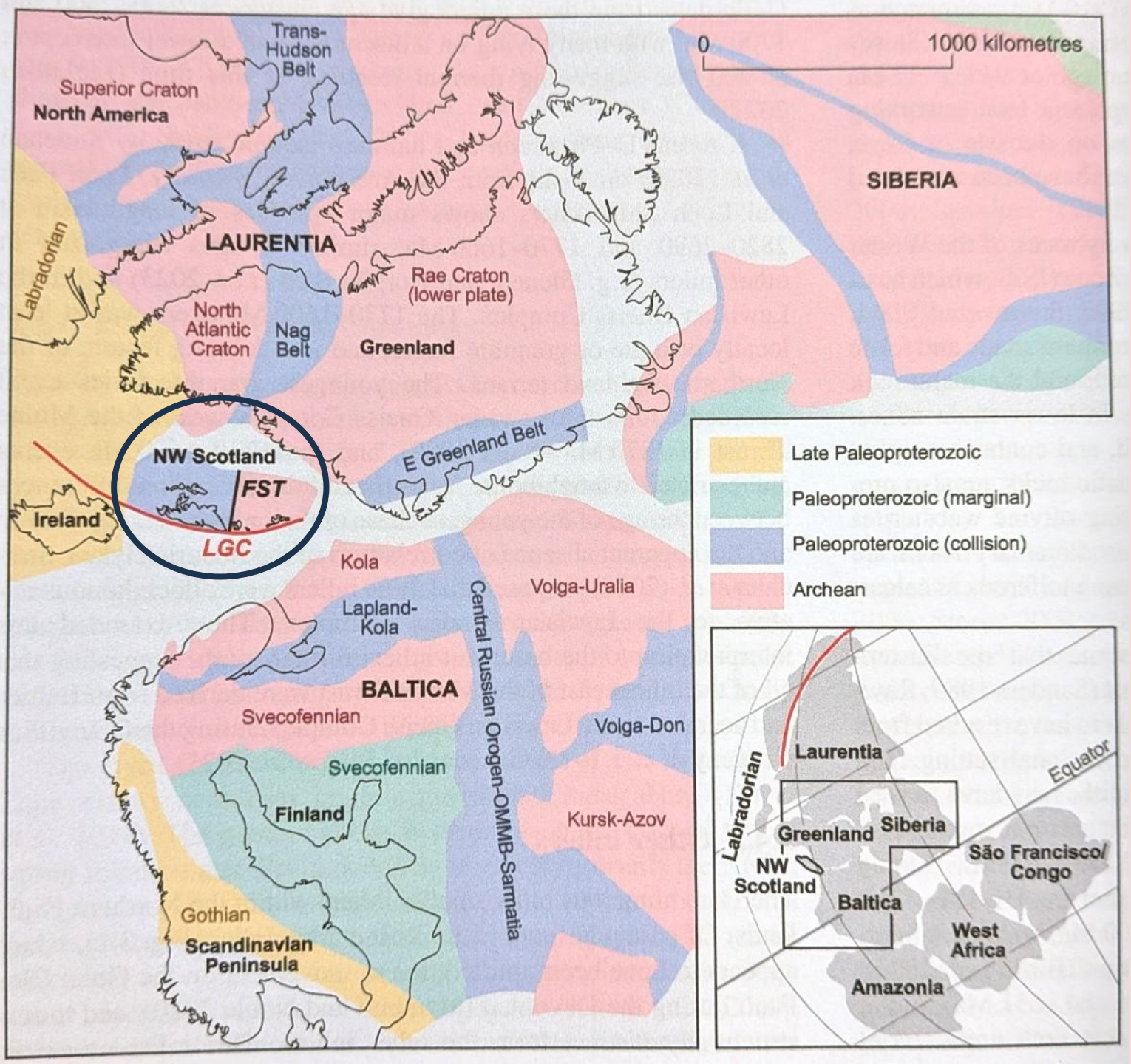


Figure 17 The main events in the development of the Lewisian Complex. After Fettes and Mendum (1987).

The Scourian Complex

- 2.9 – 2.5 Ga: deposition of sedimentary and intrusion of igneous rocks within a continental plate.
- 2.5 Ga: plate subduction event > Scourian Orogeny
  - **Badcallian** subduction event, collision of Rae craton and NAC?.
  - high grade metamorphism - creation of Scourian Complex
- 2.4 - 2.0 Ga: intrusion of the Scourie dyke swarm
- Rock compositions correspond with the compositions of many other high grade Archaean terranes elsewhere in the world.
- Mostly banded acid-gneisses of probably plutonic (intruded at depth) igneous origin.
- Probably derived from pre-existing basic rocks, not from the mantle, in an island arc as ocean crust subducted > plate tectonics at work.
- A few rare metasediments.
- All much altered by further events in the following 1000 million years.




Trans-
Hudson
Belt
Superior Craton
North America
0
1000 kilometres
SIBERIA
LAURENTIA
Labradorian
Rae Craton
(lower plate)
North
Atlantic
Craton
Nag
Belt
Greenland
NW Scotland
FST
Ireland
LGC
E Greenland Belt
Kola
Volga-Uralia
Lapland-
Kola
Central Russian Orogen-OMMB-Sarmatia
BALTICA
Svecofennian
Volga-Don
Svecofennian
Finland
Kursk-Azov
Gothian
Scandinavian
Peninsula
Late Paleoproterozoic
Paleoproterozoic (marginal)
Paleoproterozoic (collision)
Archean
Laurentia
Labradorian
Equator
Greenland
Siberia
NW
Scotland
São Francisco/
Congo
Baltica
West
Africa
Amazonia

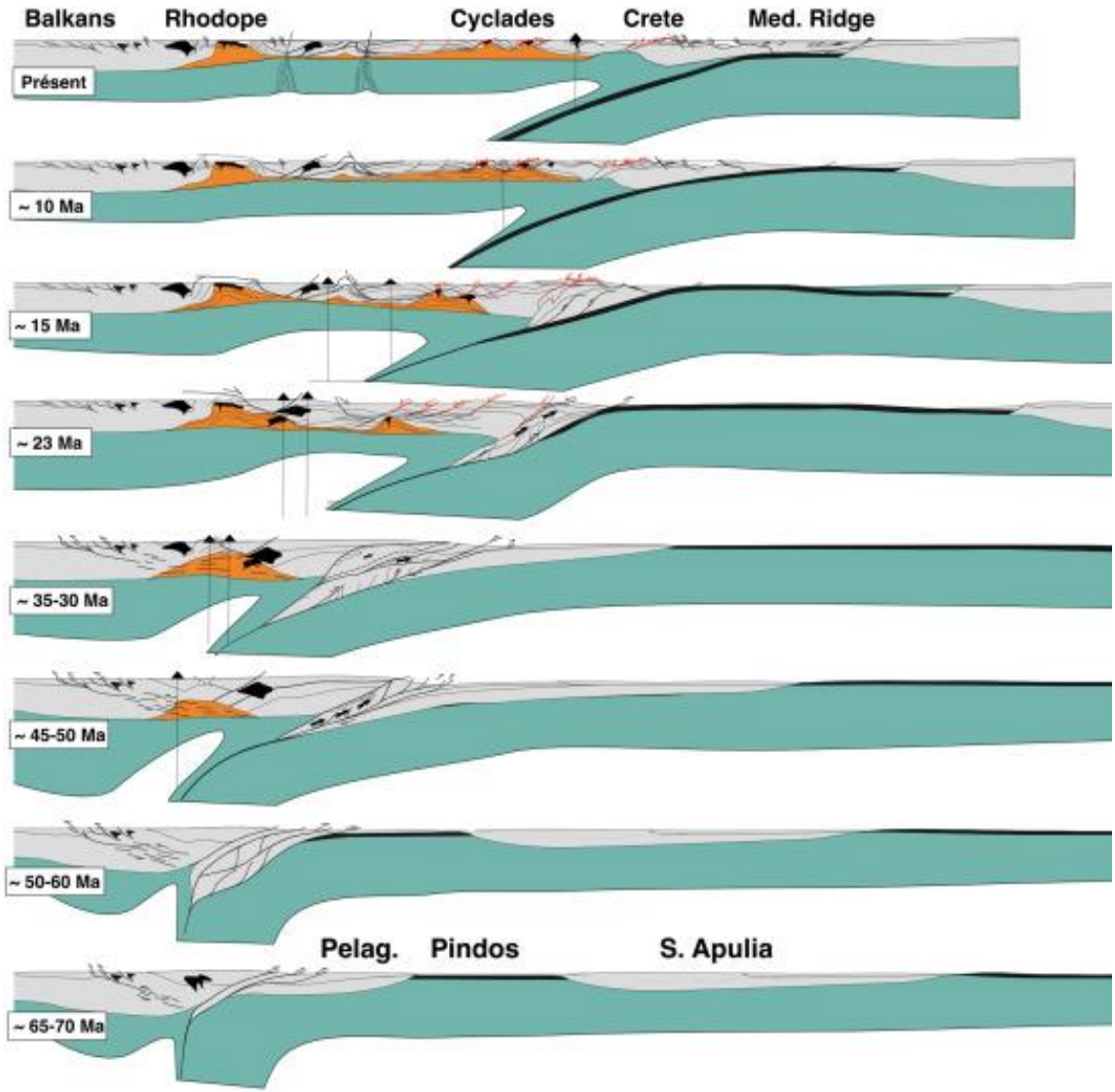
ical Scourian banded gneiss showing intrafolial folds refolded by NW–SE-trending Inverian folds. NG 815 705, near Lo
Gairloch, NW Highlands. Photo R.G. Park (Ch. 3).

The Scourian Complex

Subduction zone event – 2.9 to 2.5 Ga

The Scourie dyke swarm 2.4 Ga

- very numerous,over a large area (at least 120 x 250km)
- generally trending SE-NW or E-W.
- probably intruded at a time of great **crustal extension** as a result of the subduction.
- most abundant rock type of the dykes is quartz-dolerite.
- occurred over some 400 Ma, into the following Laxfordian



Scourie dyke, South Uist

The Scourian Complex

Badcallian subduction zone event – 2.9 to 2.5 Ga

At this stage we leave the Archaean and enter the Proterozoic – life is now a major player.

The Great Oxygenation Event!

2.4 – 2.0 billion years ago

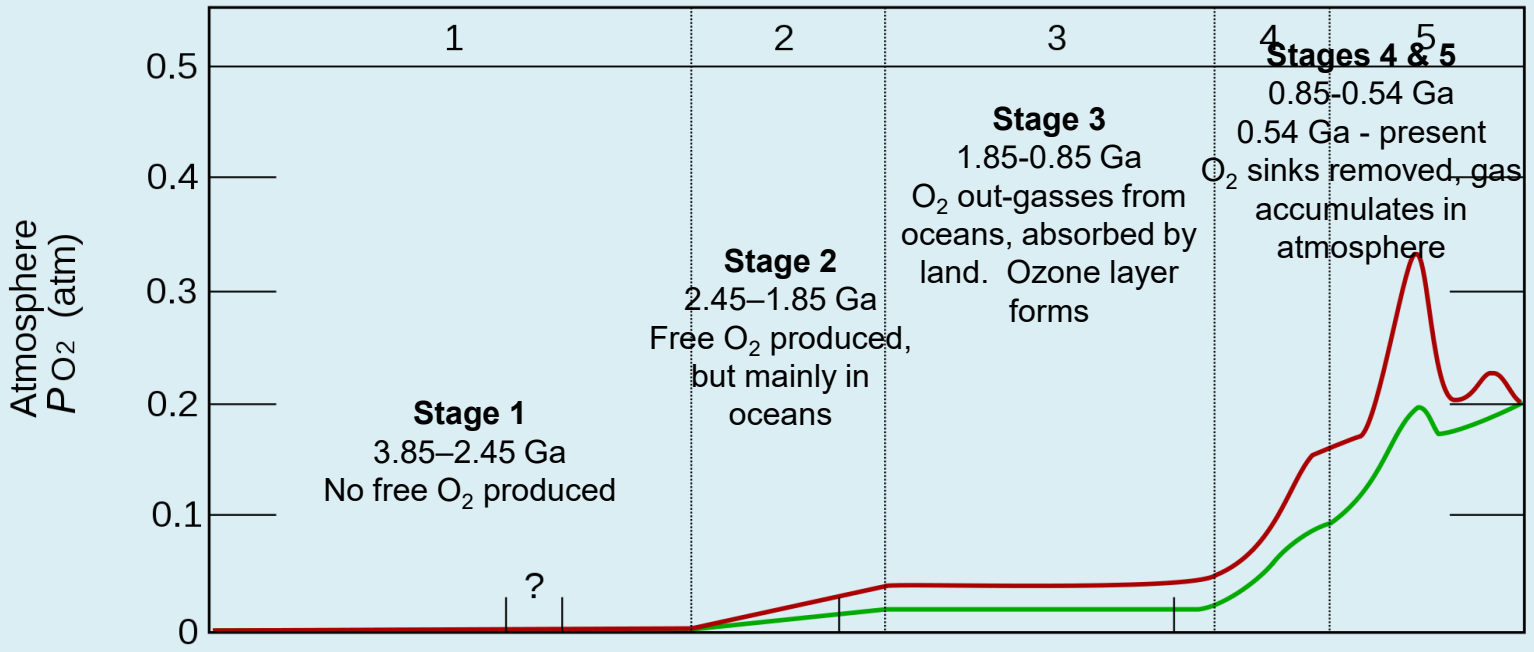
- the time when excess free oxygen started to accumulate in the atmosphere and oceans.
- the time by when all the accessible iron minerals had been oxidised from Fe(II) to Fe(III)

The Great Oxygenation Event! 2.4 – 2.0 Ga

BUT!

- a disaster for the anaerobic life (cyanobacteria) that had produced the oxygen by photosynthesis!
- creating probably the largest extinction event in Earth's history.
- also removed atmospheric methane, triggering the Huronian glaciation, possibly the longest Snowball Earth episode ever

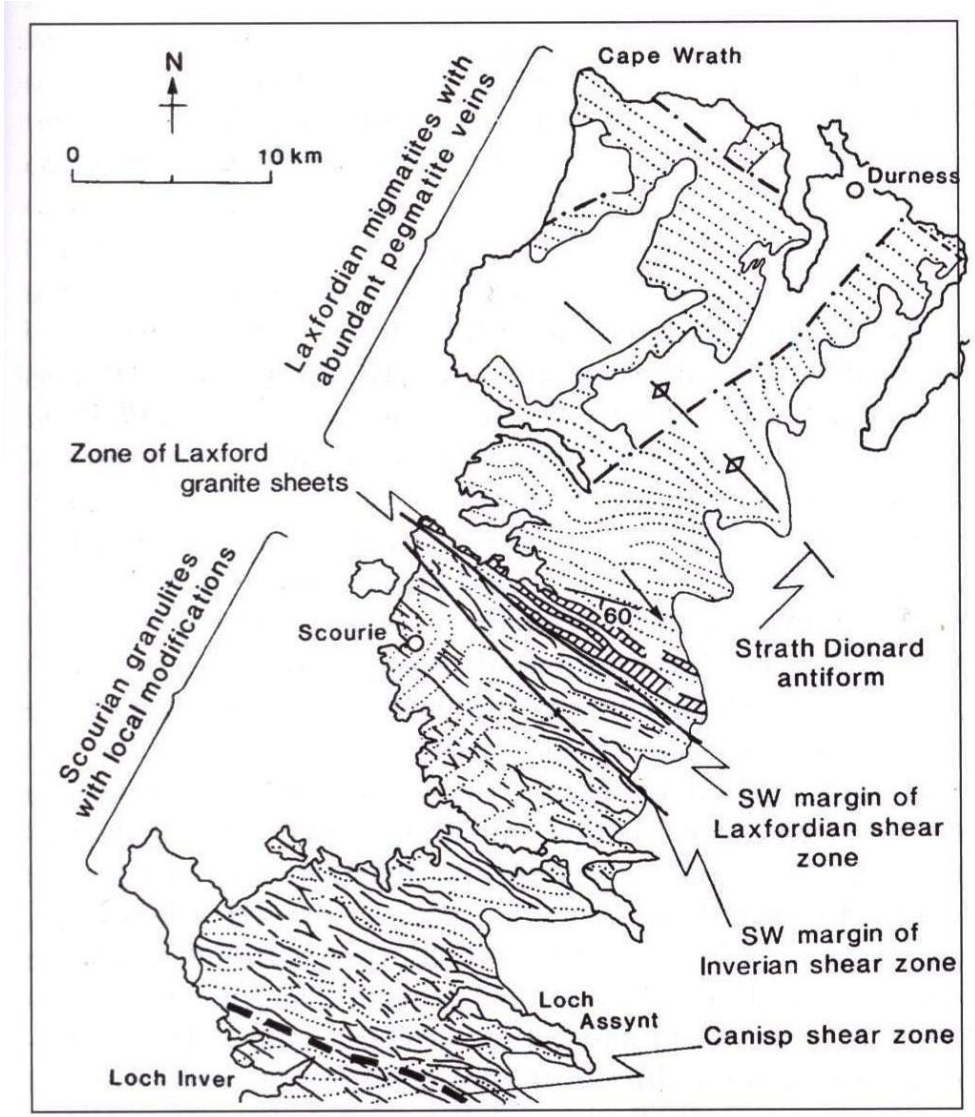
Stages



Oxygen build-up in the Earth's atmosphere

Red (upper) and green (lower) lines represent the range of the estimates.

Fig. 3.7. Simplified map of the Northern Region and the transitional zone in the northern part of the Central Region, showing the principal structures and the boundaries of the major Inverian and Laxfordian shear zones. Dotted lines represent trend of banding; Scourie dykes in black; Laxford granite sheets hachured. Note generalized dip of planar fabric and plunge of linear fabric in the Laxfordian shear zone. After Watson (1983).



The Inverian metamorphic event 2.48-2.42 Ga

Even while the Scourie dykes were still being emplaced, new forces were at work, stretching, shearing, bending – the Inverian event, which left a new fabric in the gneiss and other rocks.

The metamorphism was retrograde, meaning less high-grade metamorphic amphibolite rocks were created.

Intense deformation with new folds and steep shear zones – may be two terranes colliding and sliding sideways.

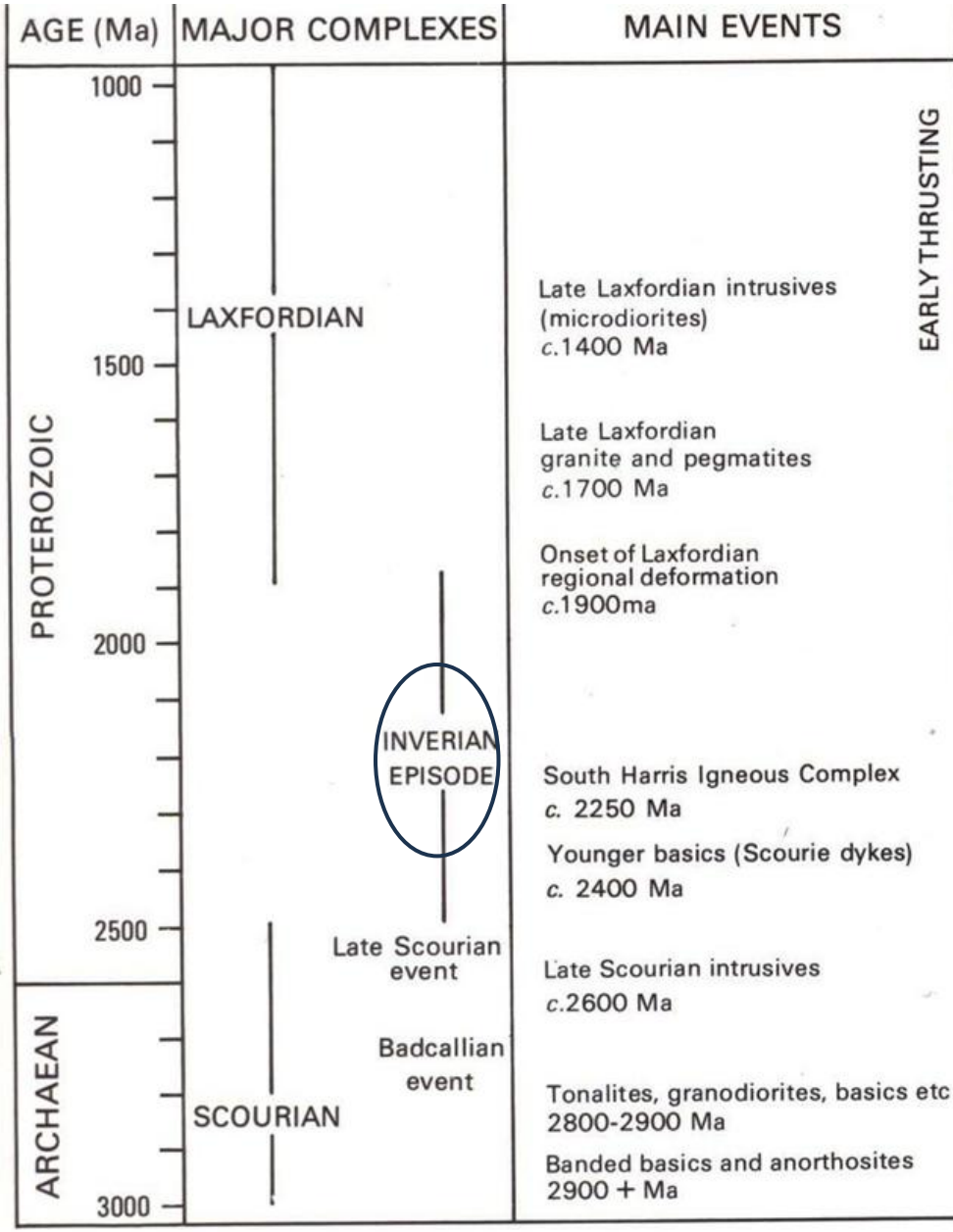
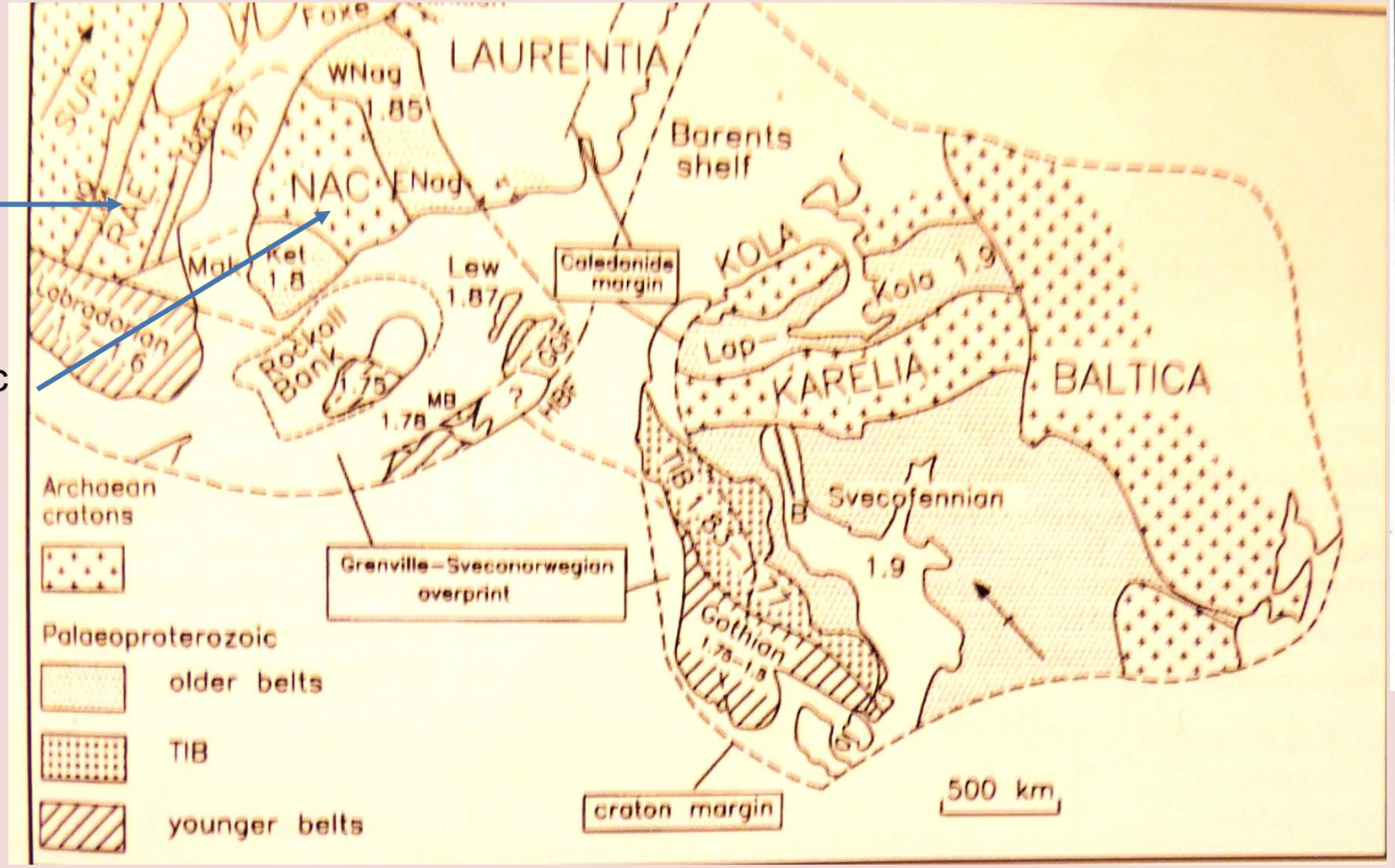


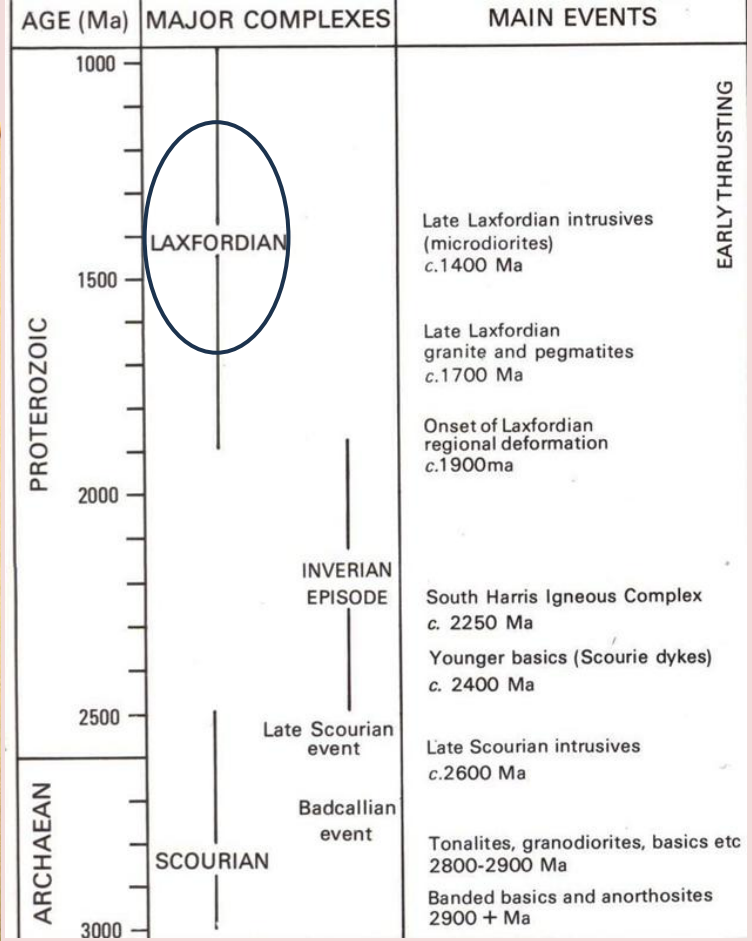
Figure 17 The main events in the development of the Lewisian Complex. After Fettes and Mendum (1987).

The Laxfordian Orogeny – 1.9-1.0 Ga

Rae craton

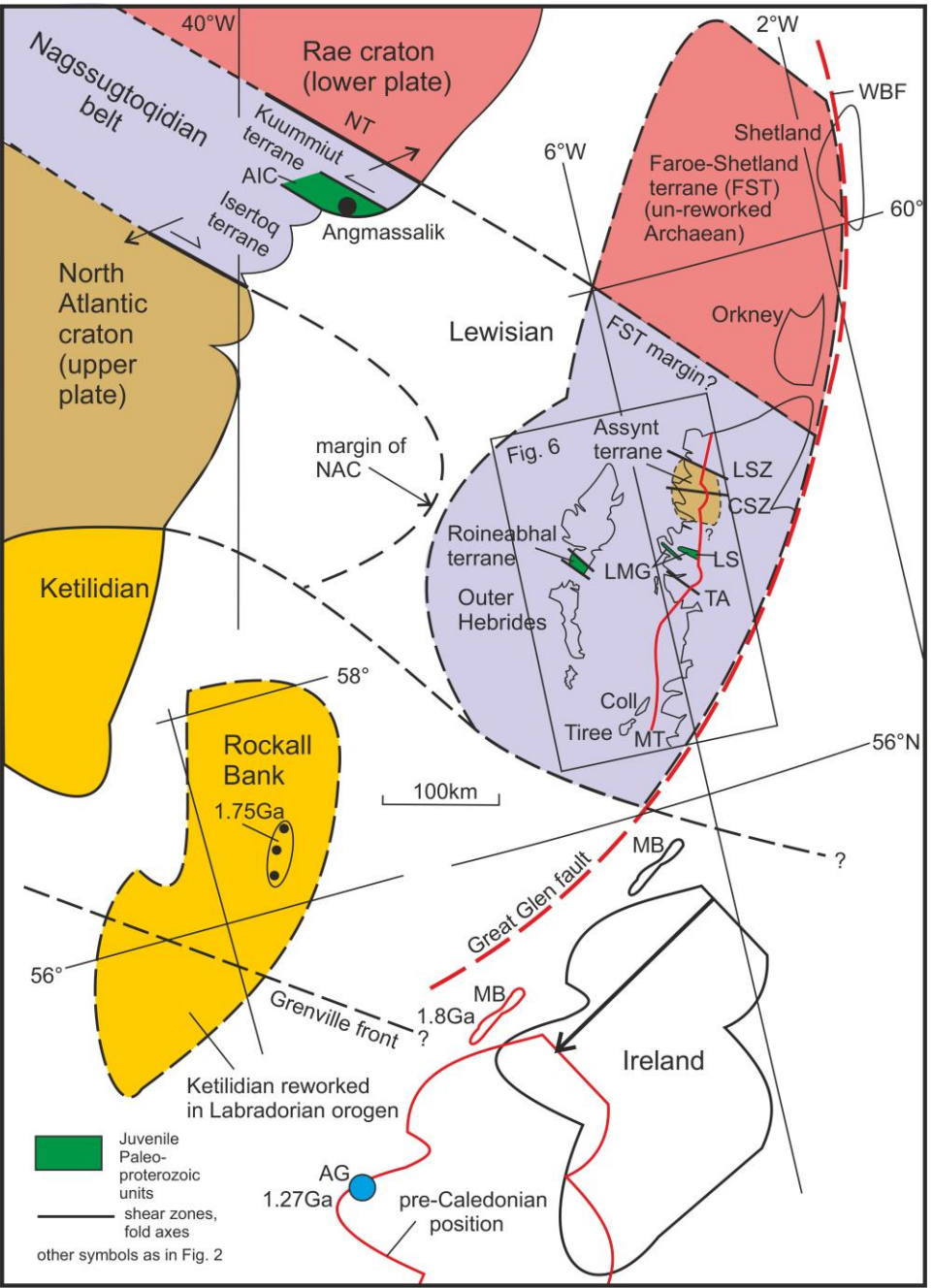
North Atlantic Craton





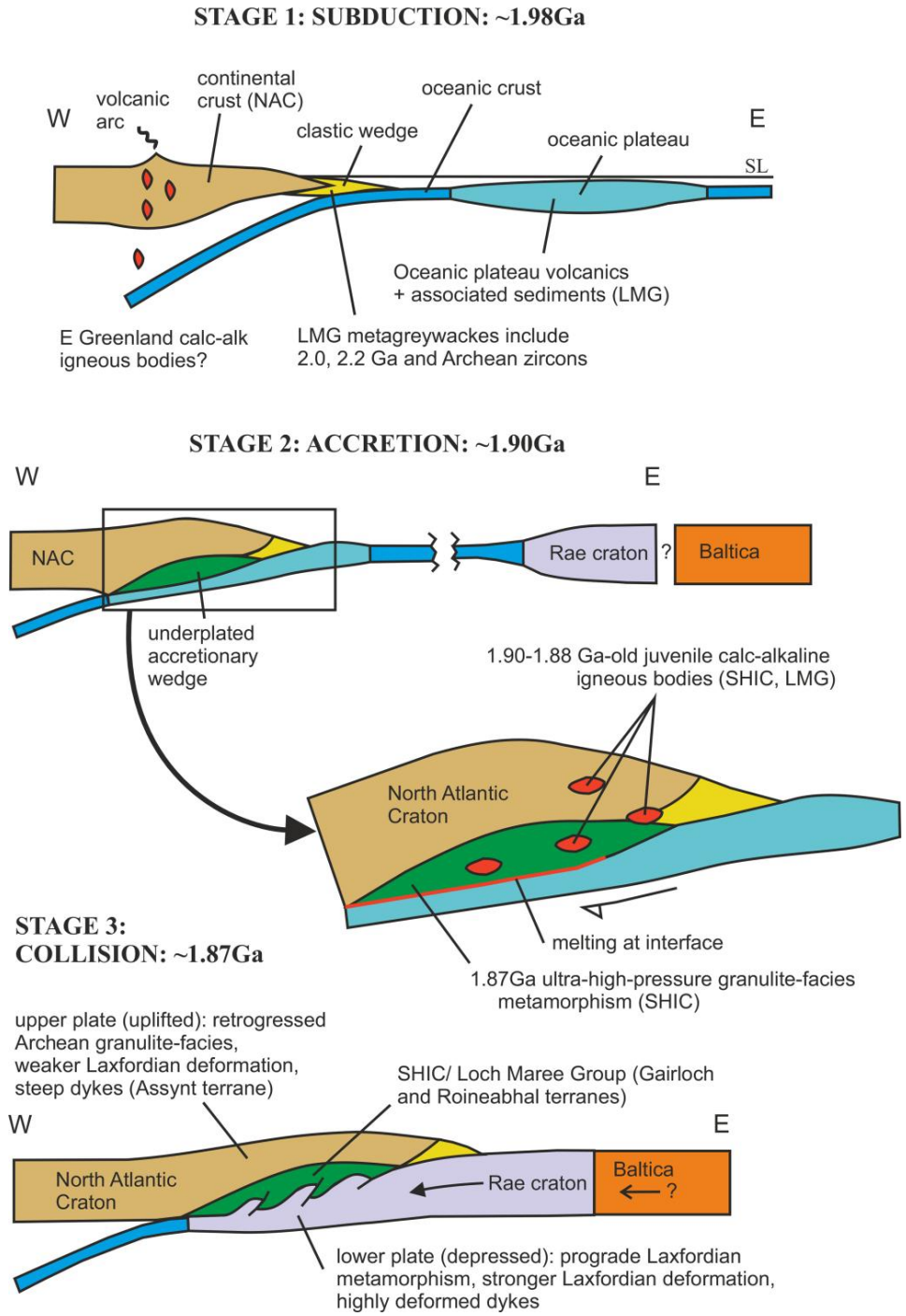
High-grade metamorphism and deformation, forming migmatite (a mix of older rock with added new molten material). Also emplacing granite, all crushed in the last stages of the orogeny. Scourie dykes in places are sheared and altered to amphibolites about 1.7 Ga.

The Laxfordian Orogeny – 1.9-1.0 Ga



Related to the contemporary orogeny in the Nagssugtoqidian belt in Greenland, as the North Atlantic Craton collided with the Rae craton.

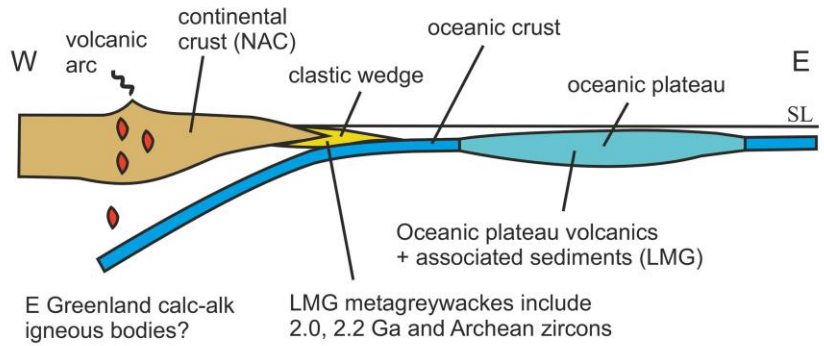
In the early Laxfordian, sediments were deposited in the Loch Maree area, intruded by dykes and sills, now much altered.



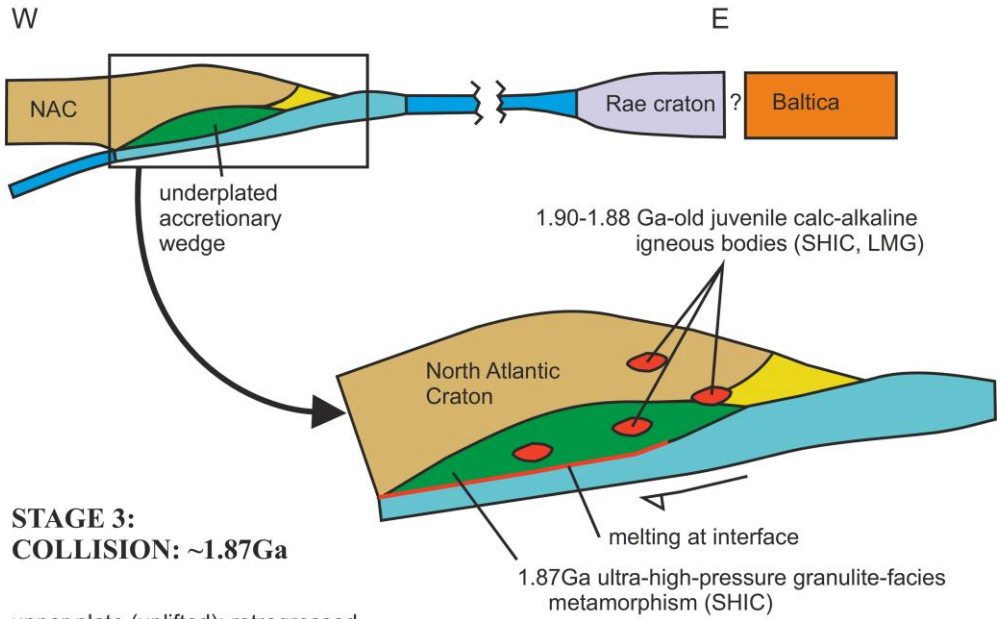
The ultimate Laxfordian exposure!

Grey, striped = Badcallian gneiss, cut by…
…black = foliated amphibolite Scourie dykes…
… then later cut by pink = granite veins…
…and all deformed by Laxfordian orogeny

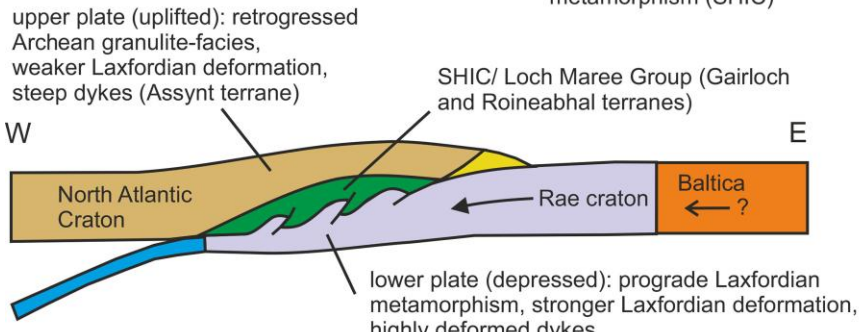
STAGE 1: SUBDUCTION: ~1.98Ga

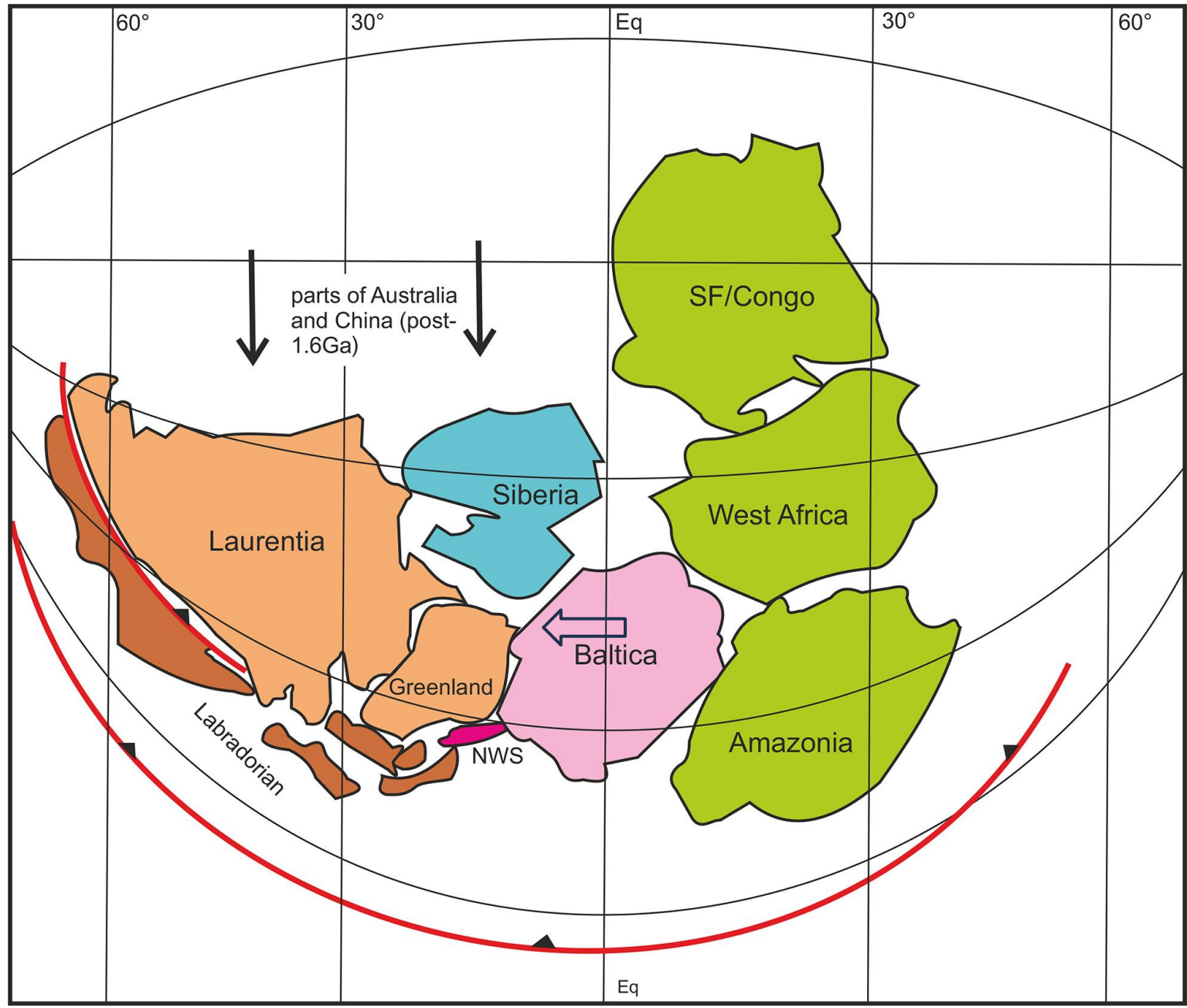


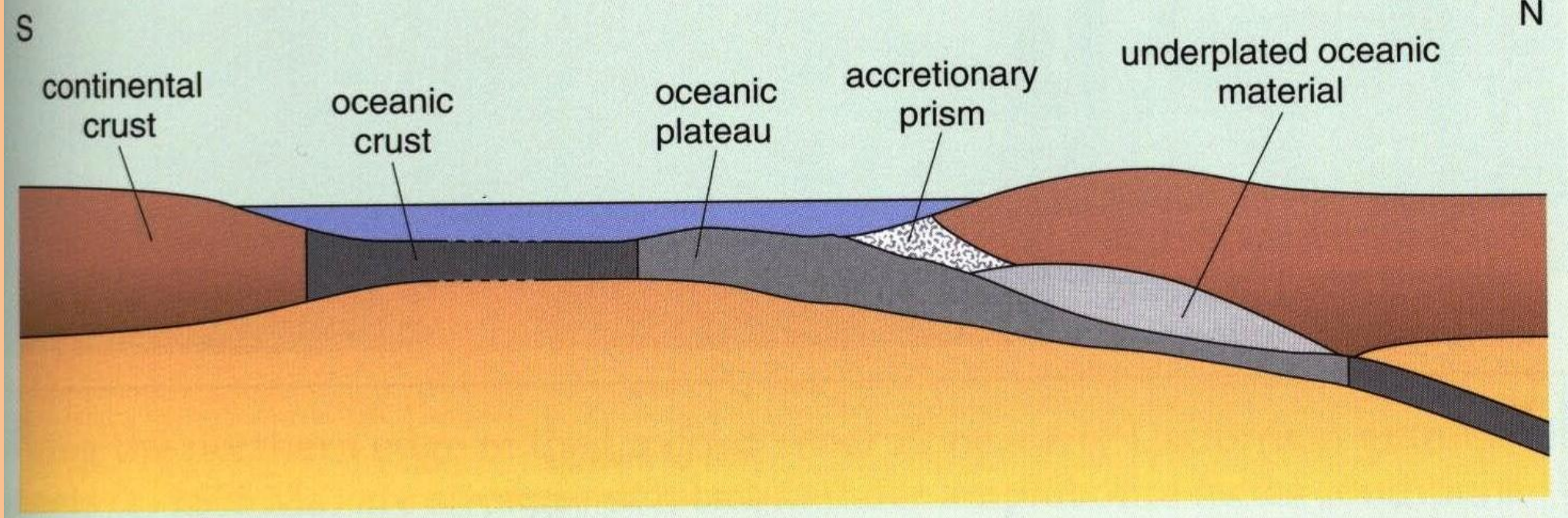
STAGE 2: ACCRETION: ~1.90Ga



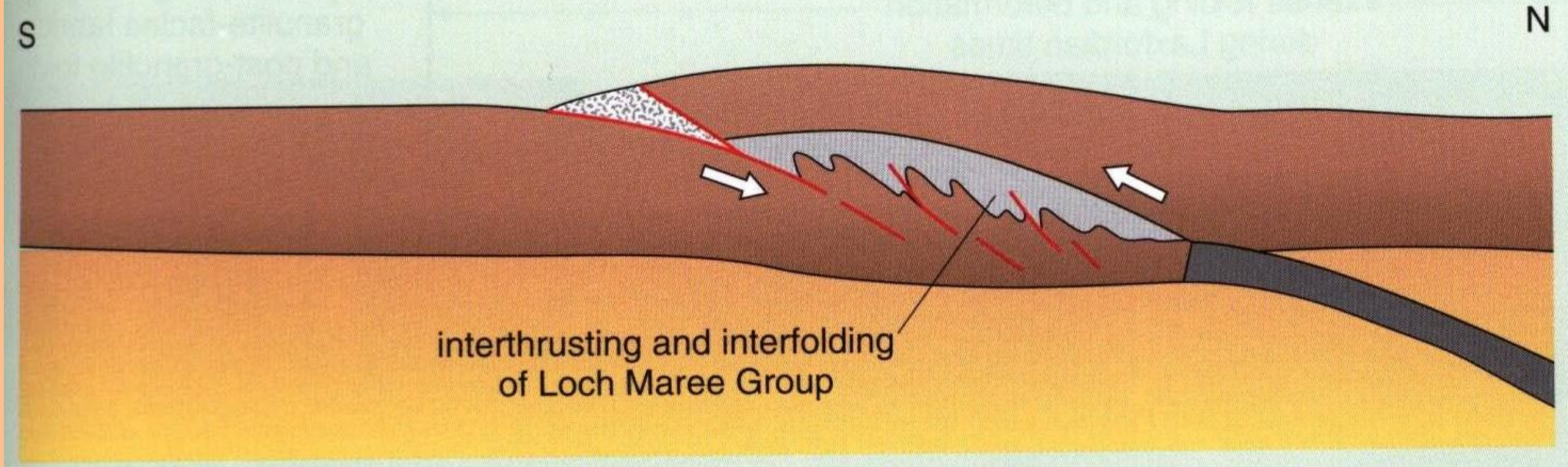
STAGE 3: COLLISION: ~1.87Ga







(a) *c.* 1900 Ma



(b) *c.* 1870 Ma

Loch Maree Group

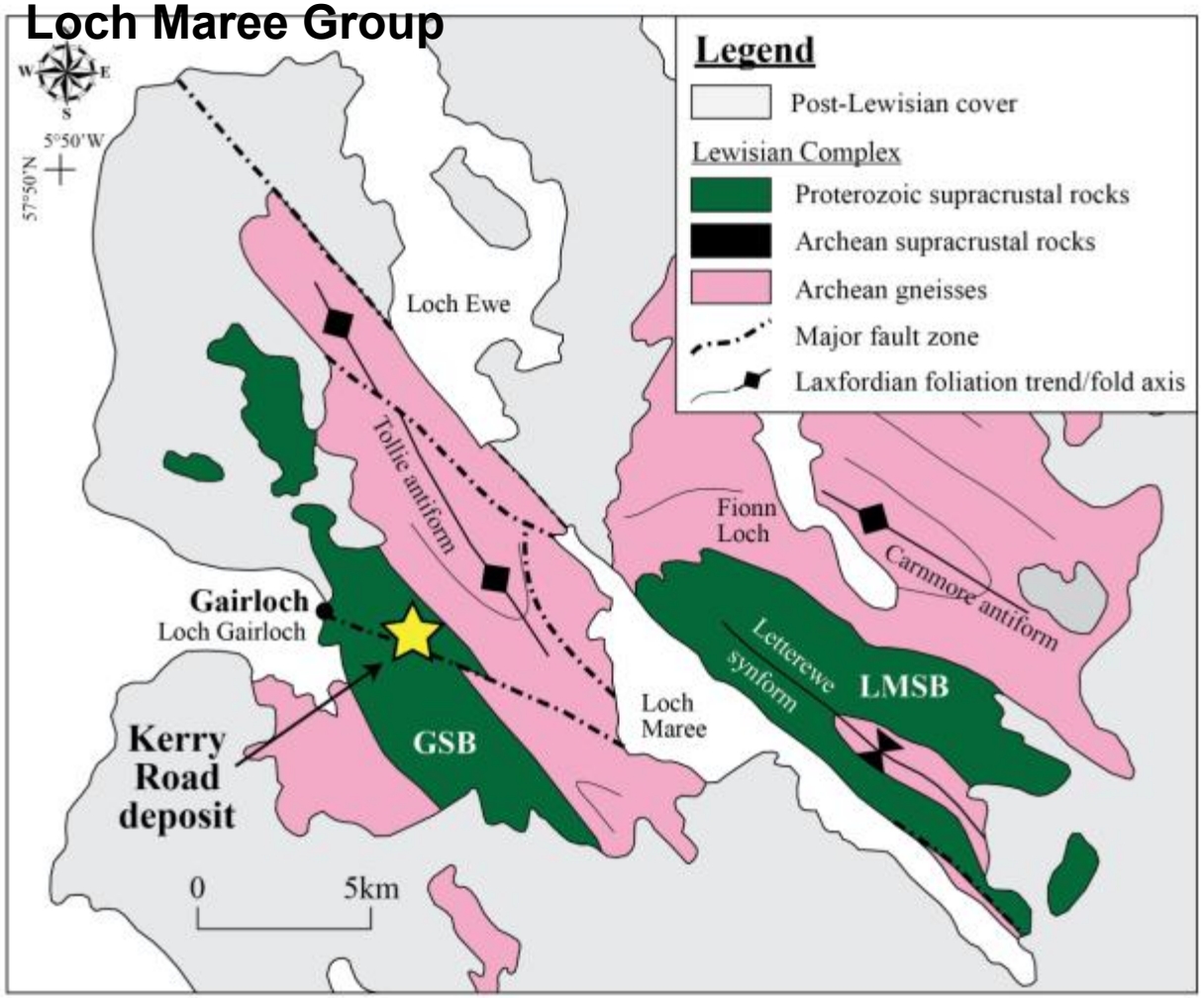


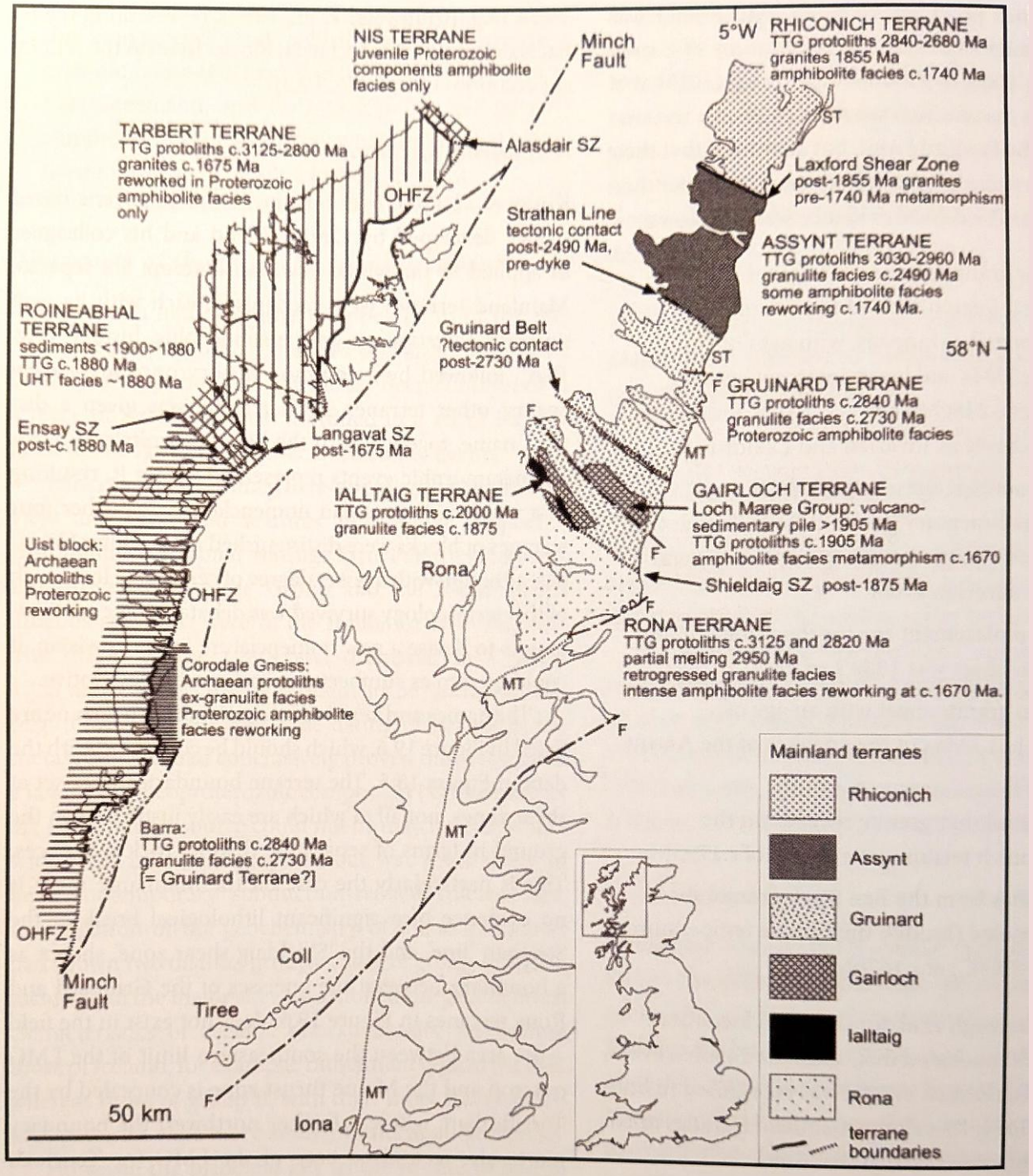
Figure 2. Simplified geological map of the Gairloch region (modified from Park et al., 1987, 2001). Also shown is the position of the Kerry Road deposit (star). GSB: Gairloch Schist Belt; LMSB: Loch Maree Schist Belt.

33% ocean floor sediments, semipelites, mainly mudstones and silts (greywackes) to rare carbonates, metamorphosed to schists and marble,

interbanded with

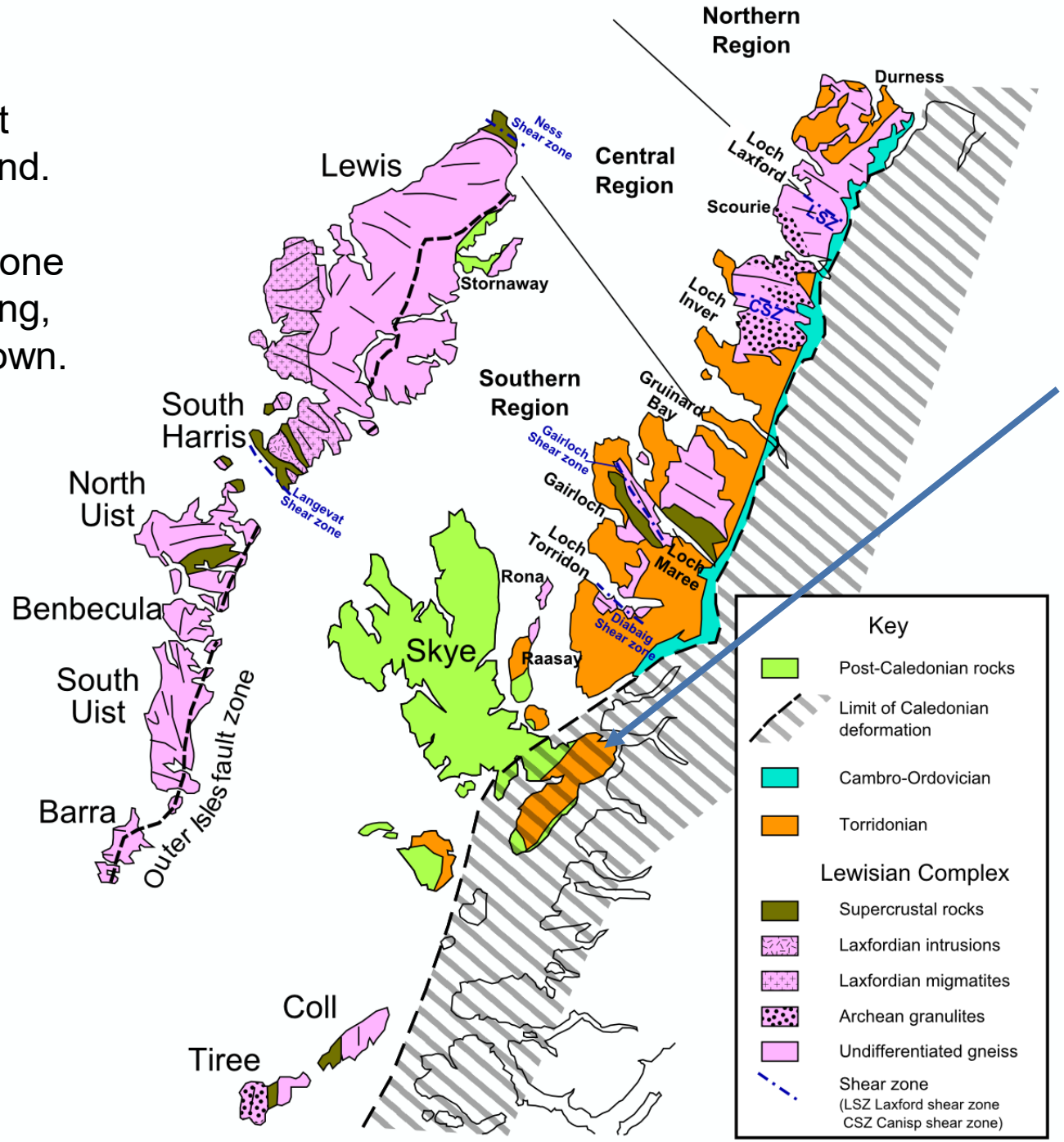
67% amphibolites derived from ocean floor basalts and altered Scourie dykes (emplaced as sills later).

Figure 17.1 Extract from the geological map of the Gairloch area. Loch Maree Group: *Ap*, amphibolite; *Ab*, biotite amphibolite; *S*, quartz-biotite schist; *Sc* quartz-chlorite schist; *Q*, quartzite, magnetite-quartzite, garnet-grunerite schist; *L*, metacarbonate; *Sg*, graphitic schist. Palaeoproterozoic intrusions: *Gp*, Ard gneiss; *P*, granitic pegmatite; *Ad*, amphibolite (metadolerite); *Ud*, ultramafic amphibolite (meta-picrite). Archaean gneiss: *Ga*, biotite gneiss; *Gb*, hornblende gneiss. *Gi*, lalltaig gneiss*. T, Torridonian. my/cb, mylonites/cataclasites. Adapted from Park (2002). *Originally mapped as Archaean but probably Palaeoproterozoic.


NIS TERRANE
juvenile Proterozoic components amphibolite facies only
Minch Fault
5°W
RHICONICH TERRANE
TTG protoliths 2840-2680 Ma
granites 1855 Ma
amphibolite facies c.1740 Ma
ST
Laxford Shear Zone
post-1855 Ma granites
pre-1740 Ma metamorphism
TARBERT TERRANE
TTG protoliths c.3125-2800 Ma
granites c.1675 Ma
reworked in Proterozoic amphibolite facies only
Alasdair SZ
OHFZ
Strathan Line
tectonic contact
post-2490 Ma, pre-dyke
ASSYNT TERRANE
TTG protoliths 3030-2960 Ma
granulite facies c.2490 Ma
some amphibolite facies reworking c.1740 Ma.
58°N
ROINEABHAL TERRANE
sediments <1900>1880
TTG c.1880 Ma
UHT facies ~1880 Ma
Gruinard Belt
?tectonic contact
post-2730 Ma
ST
F
GRUINARD TERRANE
TTG protoliths c.2840 Ma
granulite facies c.2730 Ma
Proterozoic amphibolite facies
Ensay SZ
post-c.1880 Ma
Langavat SZ
post-1675 Ma
MT
IALLTAIG TERRANE
TTG protoliths c.2000 Ma
granulite facies c.1875
GAIRLOCH TERRANE
Loch Maree Group: volcano-sedimentary pile >1905 Ma
TTG protoliths c.1905 Ma
amphibolite facies metamorphism c.1670
Shieldaig SZ post-1875 Ma
Rona
Uist block:
Archaean protoliths
Proterozoic reworking
OHFZ
RONA TERRANE
TTG protoliths c.3125 and 2820 Ma
partial melting 2950 Ma
retrogressed granulite facies
intense amphibolite facies reworking at c.1670 Ma.
Corodale Gneiss:
Archaean protoliths
ex-granulite facies
Proterozoic amphibolite facies reworking
Barra:
TTG protoliths c.2840 Ma
granulite facies c.2730 Ma
[= Gruinard Terrane?]
OHFZ
Minch Fault
Coll
Tiree
50 km
Iona
Mainland terranes
Rhiconich
Assynt
Gruinard
Gairloch
Ialltaig
Rona
terrane boundaries

Outer Hebrides has a parallel history, but not identical to the mainland.

Separated by a fault zone 200 km long, with a long, complex history of ts own.



This is telling us that the metamorphic history of the Lewisian basement has ended before the deposition of the Torridonian sediments.

Summary of the very bottom!

Big Bang and star formation

Forming chemical elements by nuclear synthesis

Stable nuclei and the common elements

Accretion of the planetary disc, formation of the Solar system

The infant Earth, collision, formation of the Moon, the Hadean Era

Differentiation – core and mantle, atmosphere, the separation of cratons from ‘basalt ocean’ – granitic composition from basaltic.

The late heavy bombardment

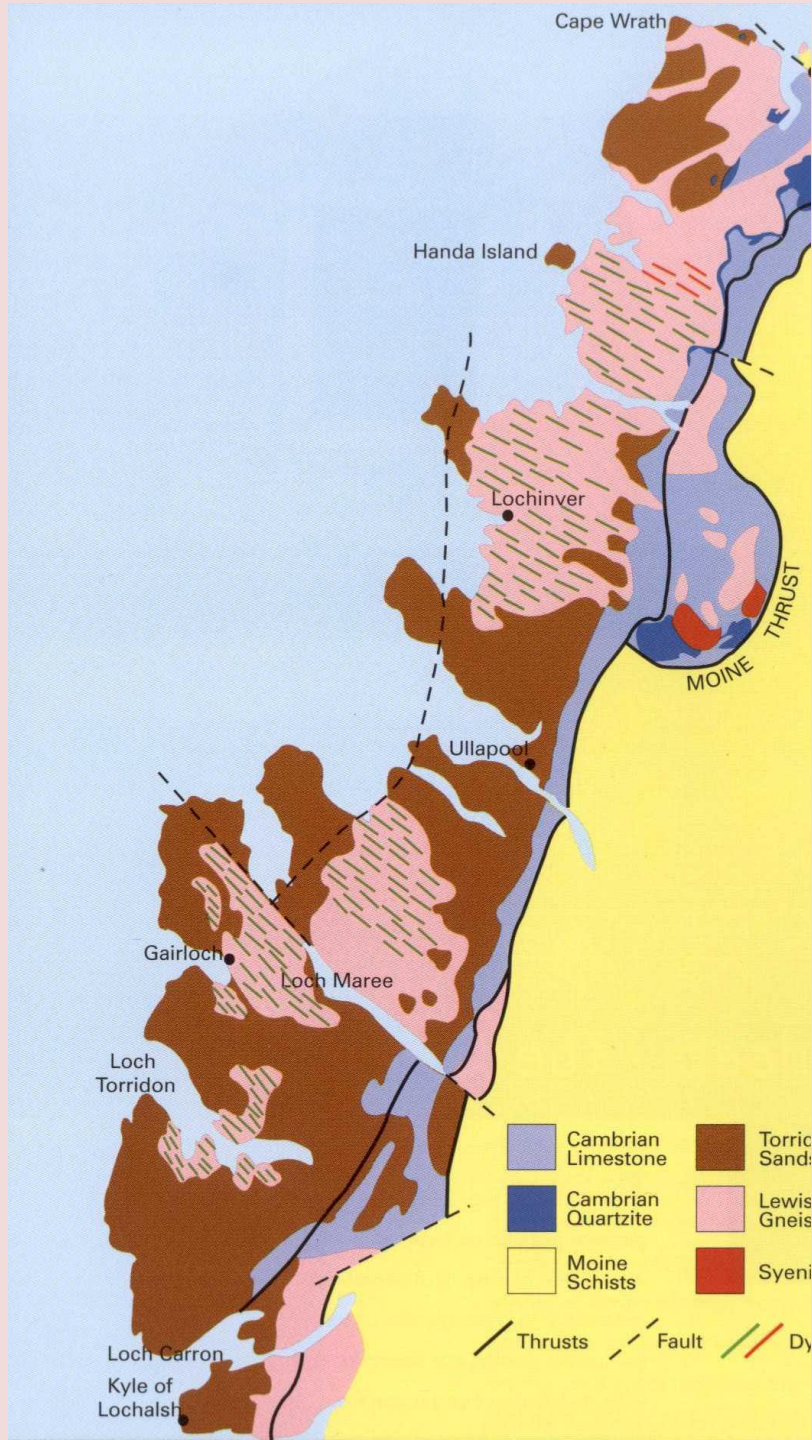
The development of a solid crust

Surface processes begin

The Archaean Era has begun, and Plate Tectonics too!

Hebridean Terrane of NW Scotland as a tiny slice of craton made of several earlier terranes

Nearly 2000 million years of the Lewisian and its suffering?



1500 million years of the Lewisian?

The Scourian Complex – 3.0 to 2.0 Ga

Badcallian subduction zone event – 2.9 to 2.5 Ga

The Great Oxygenation Event during this time

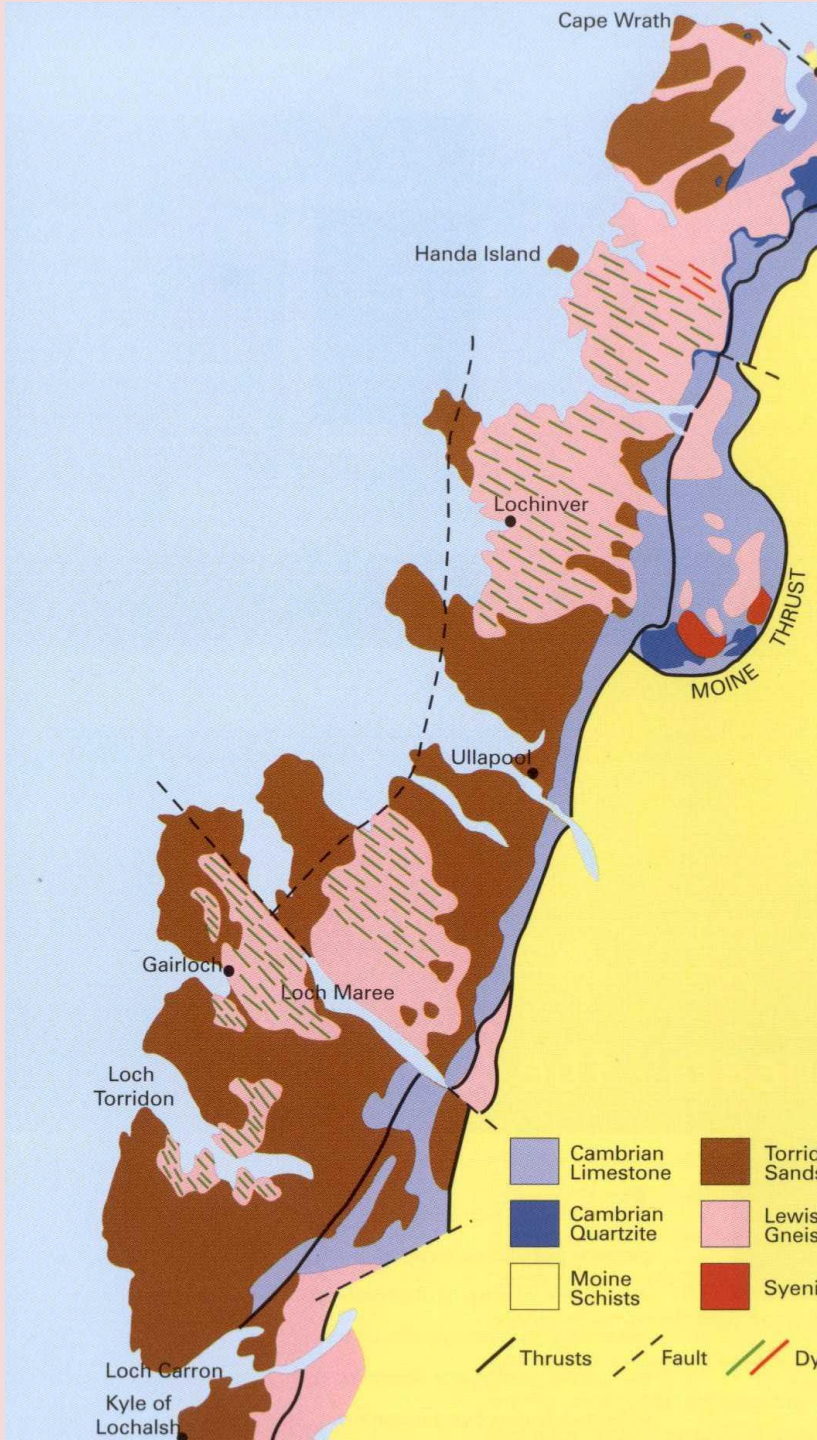
– the Archaean becomes the Proterozoic

The Inverian event – 2.4 Ga

Scourie dykes – 2.4 to 2.0 Ga

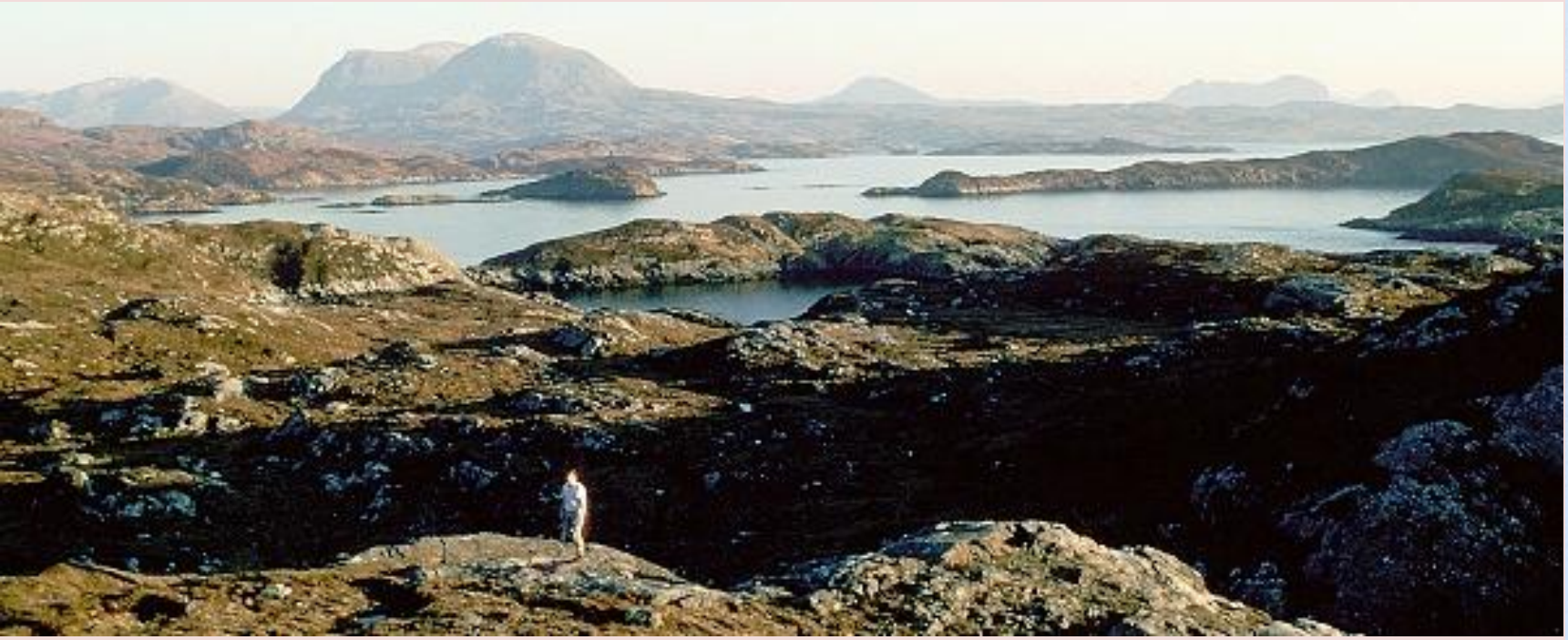
Loch Maree Group sediments & volcanism – 2.0 Ga

And in this time, did oceans come and go? It is thought that dry land covered only 5% of the Earth's surface at this time. The cratons were still a minor feature of the planet. Surely a lot of sediment was eroded, transported and deposited in this time – and the cycle repeated many times. Remnants of such sedimentarty rocks are rare – the Loch Maree Group is such a rare survival

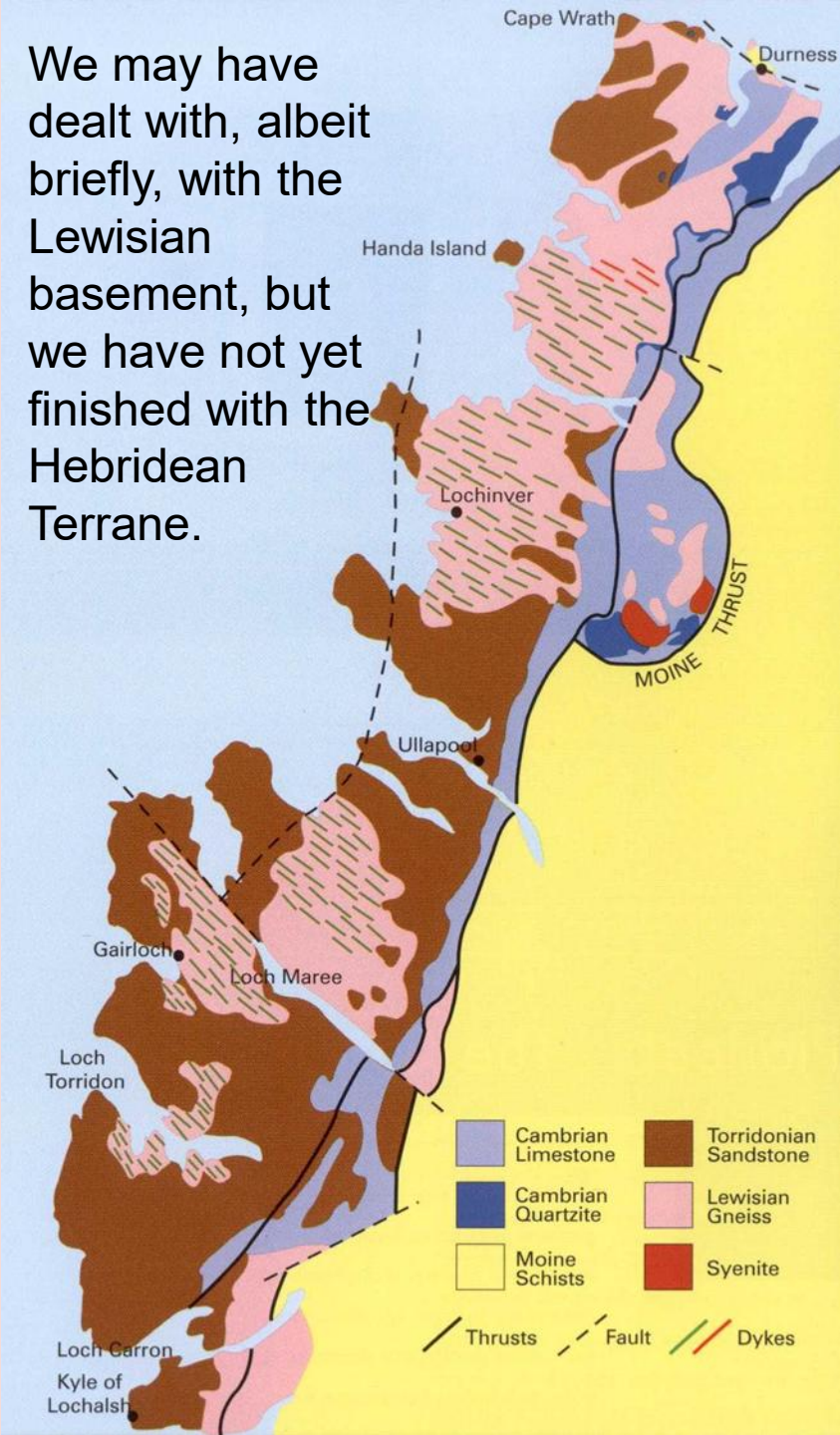


Many questions remain for the Lewisian, among them…

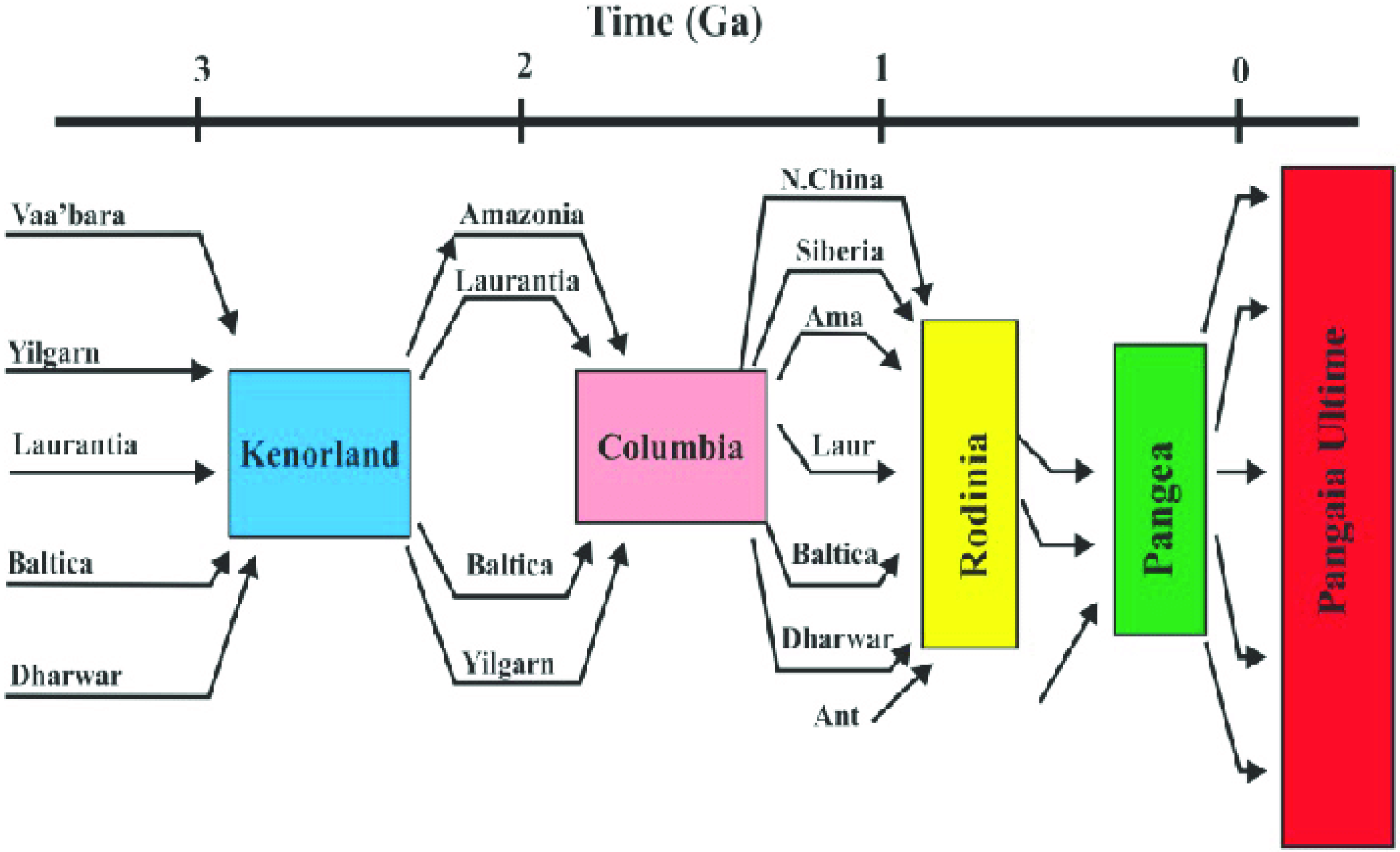
- 3 billion years and still at the surface? Surely there must have been sediments deposited on top? What happened to those sediments?
- What are those distant mountains?
- What is going on at the south-eastern edge, where the basement seems to disappear? Is it still there underneath what lies to the south-east?
- How has it managed to survive for 3 billion years?



We may have dealt with, albeit briefly, with the Lewisian basement, but we have not yet finished with the Hebridean Terrane.



It’s time to see how the global picture is changing – just an overview of the succession of supercontinents.



Nena and Columbia

- Both begin 2.0-1.8 Ga

Nena: a minor supercontinent

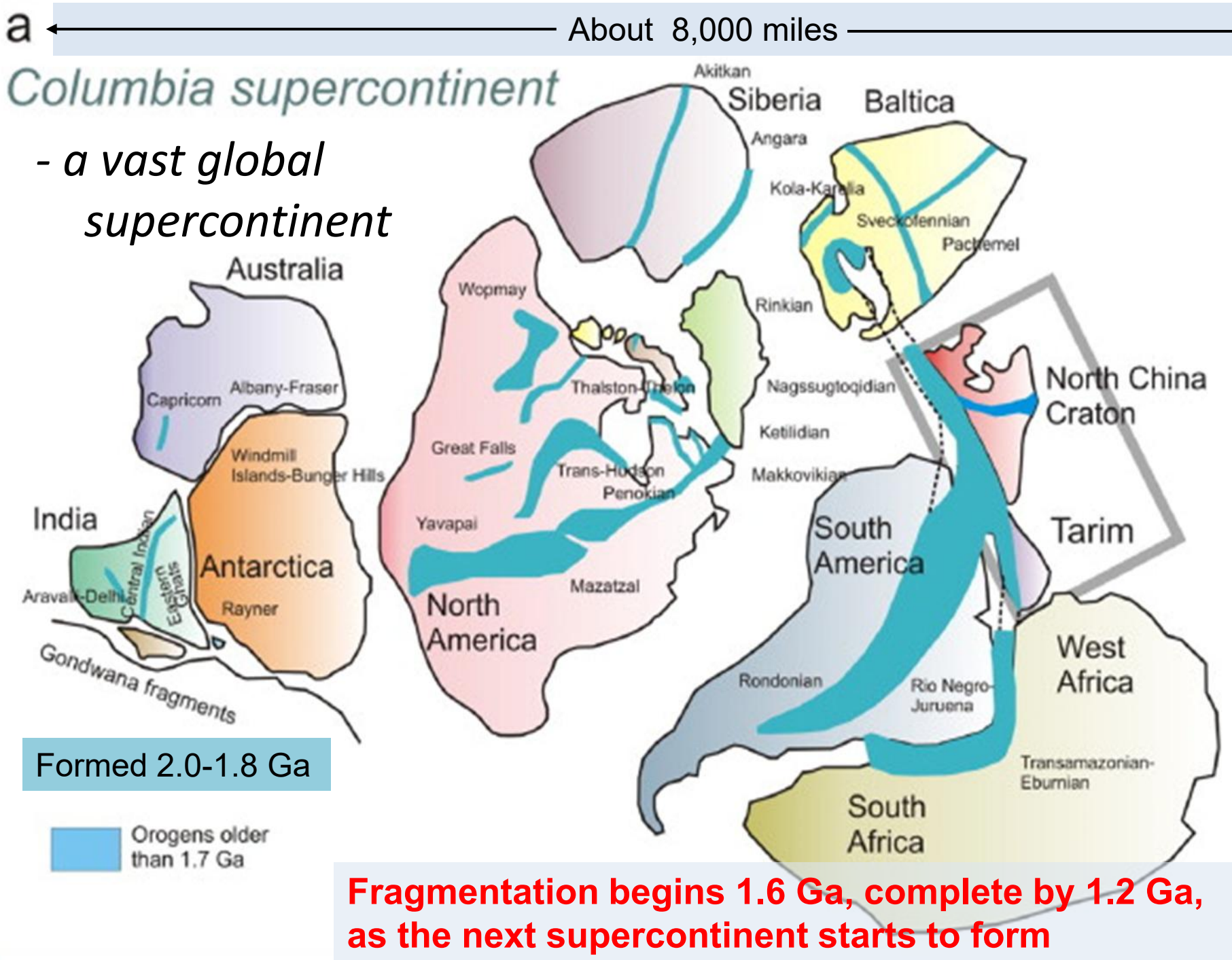
Columbia: a vast supercontinent

Nena and Columbia

Nena: a minor supercontinent

- Formed from Arctica, Baltica and East Antarctica
- Collided with and became part of **Columbia!**

- (Nena = North Eurasia + North America)



The east coast of India was attached to western North America

Southern Australia against western Canada.

Most of South America lay so that the western edge of modern-day Brazil lined up with eastern North America, forming a continental margin that extended into the southern edge of Scandinavia.

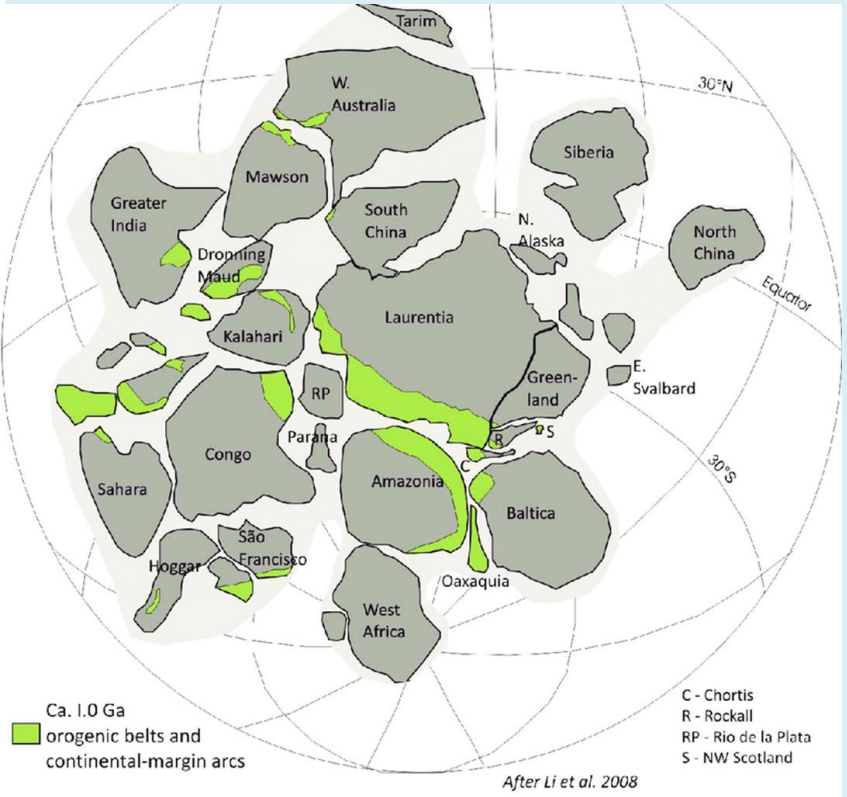
Map that!

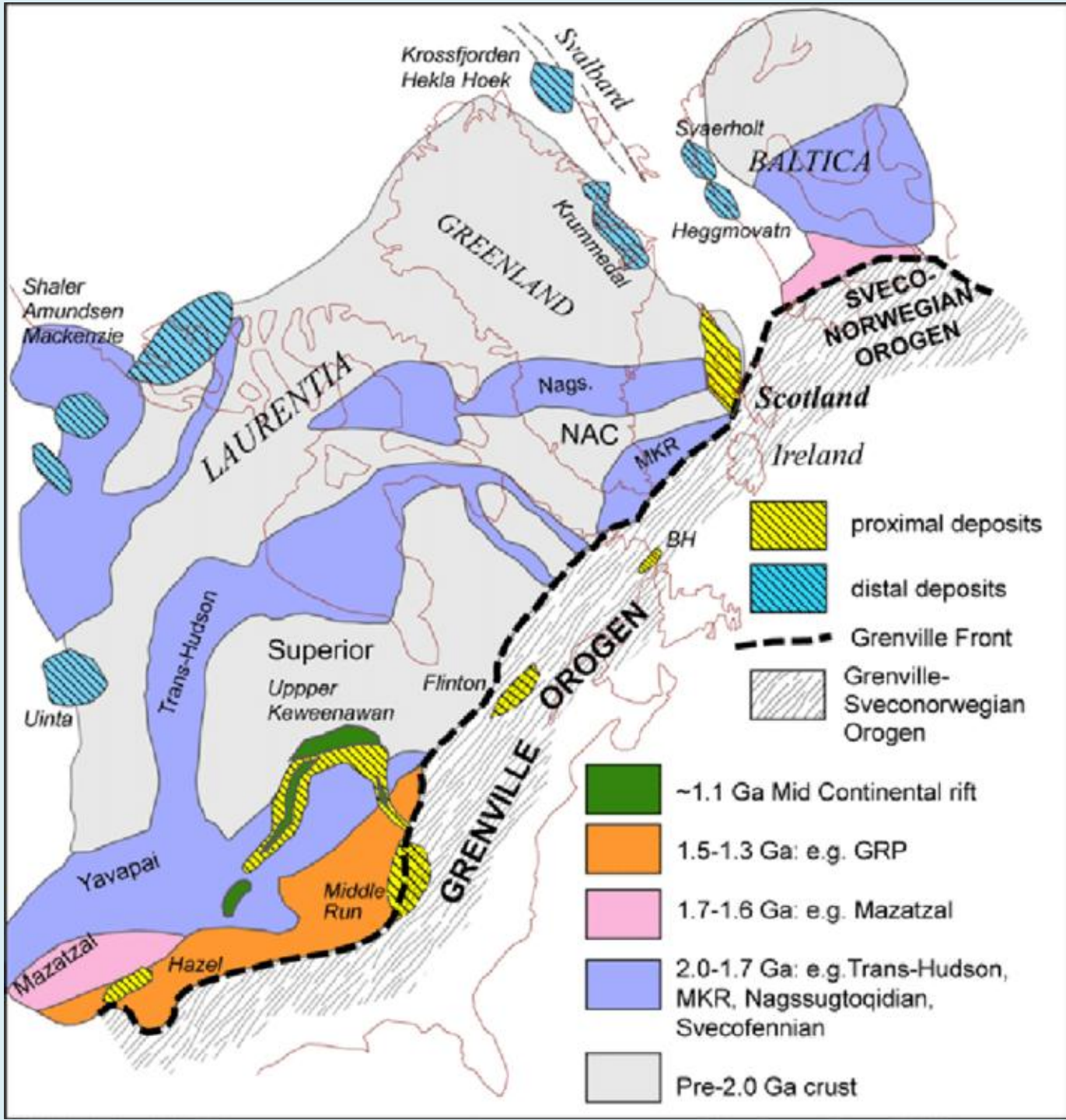
Now becoming part of… Rodinia!

The cratonic pieces of the jigsaw rearrange with significant plate collisions, involving subduction and orogeny.

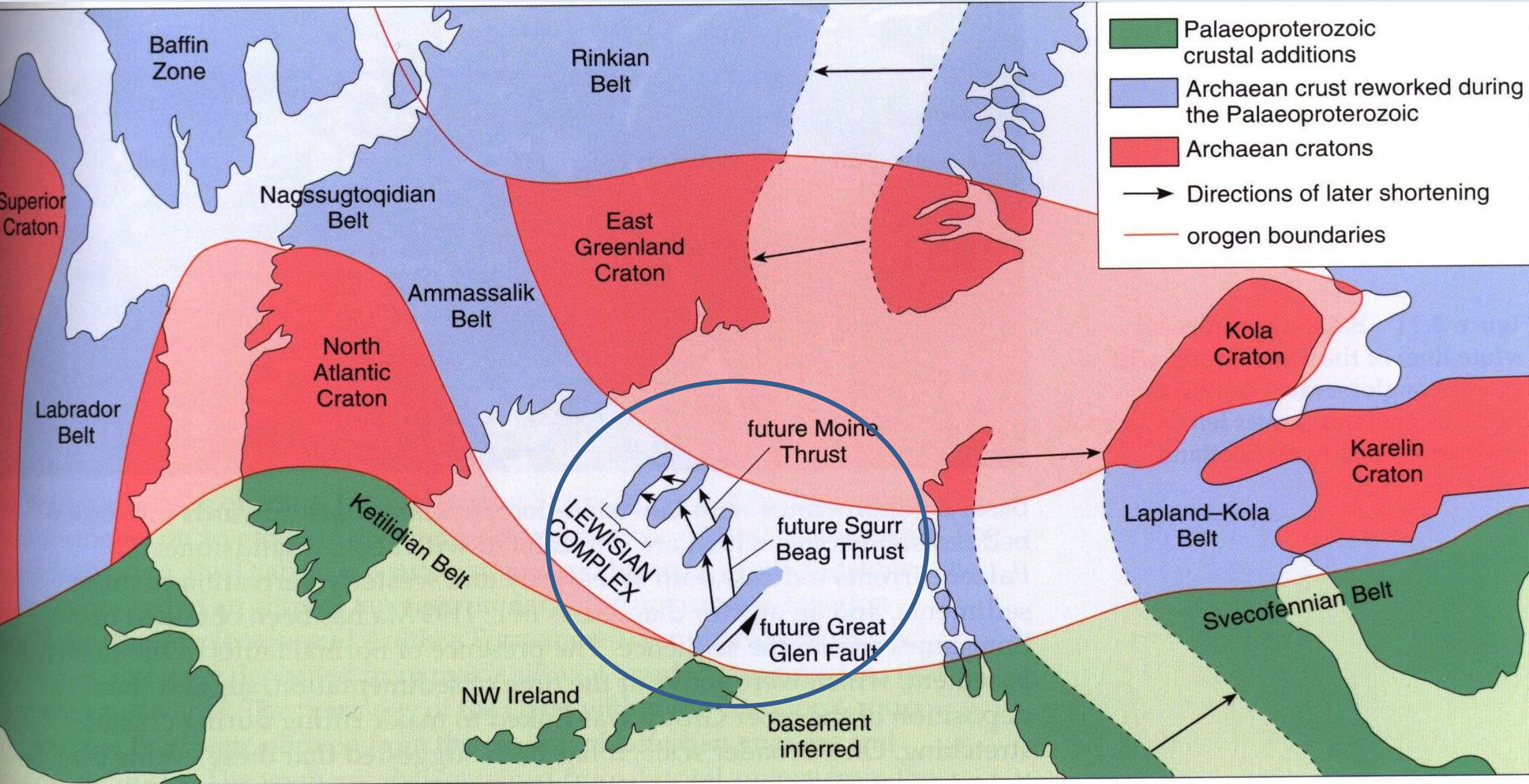
Patches of green represent the main part of the Grenvillian orogenic belt – mountains formed by plate collisions as Rodinia assembled, and whose remnants can still be identified across many of the present continents.

1.1 – 0.75 Ga



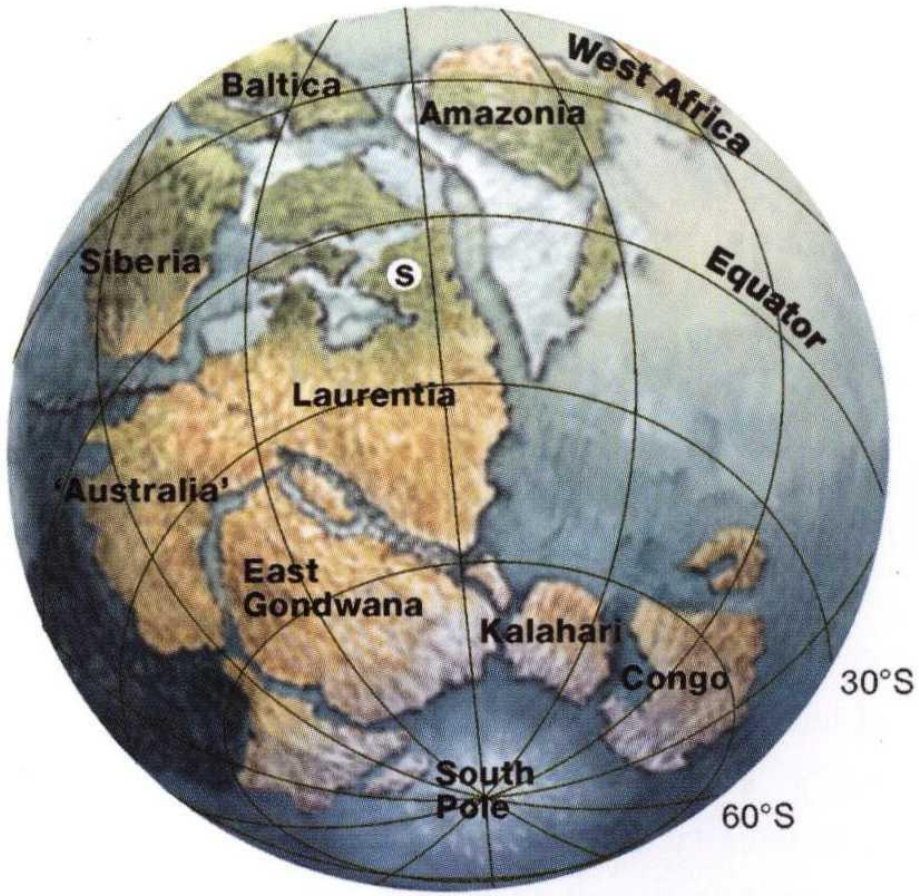


Scotland's progress within Rodinia's cratons



The Lewisian Comes to the Surface

- Laurentia drifts towards the collisions that will form Rodinia
- Intensive continental erosion removes vast quantities of the continent as sediments
- Sediments deposited around the edges of the continent
- The eroded surface is still there...



750 million years ago. The land that was to become Scotland was just south of the Equator. The 'S' on a white dot indicates the position of Scotland. At this time, Scotland's near neighbours were South America (Amazonia) and North America (Laurentia).

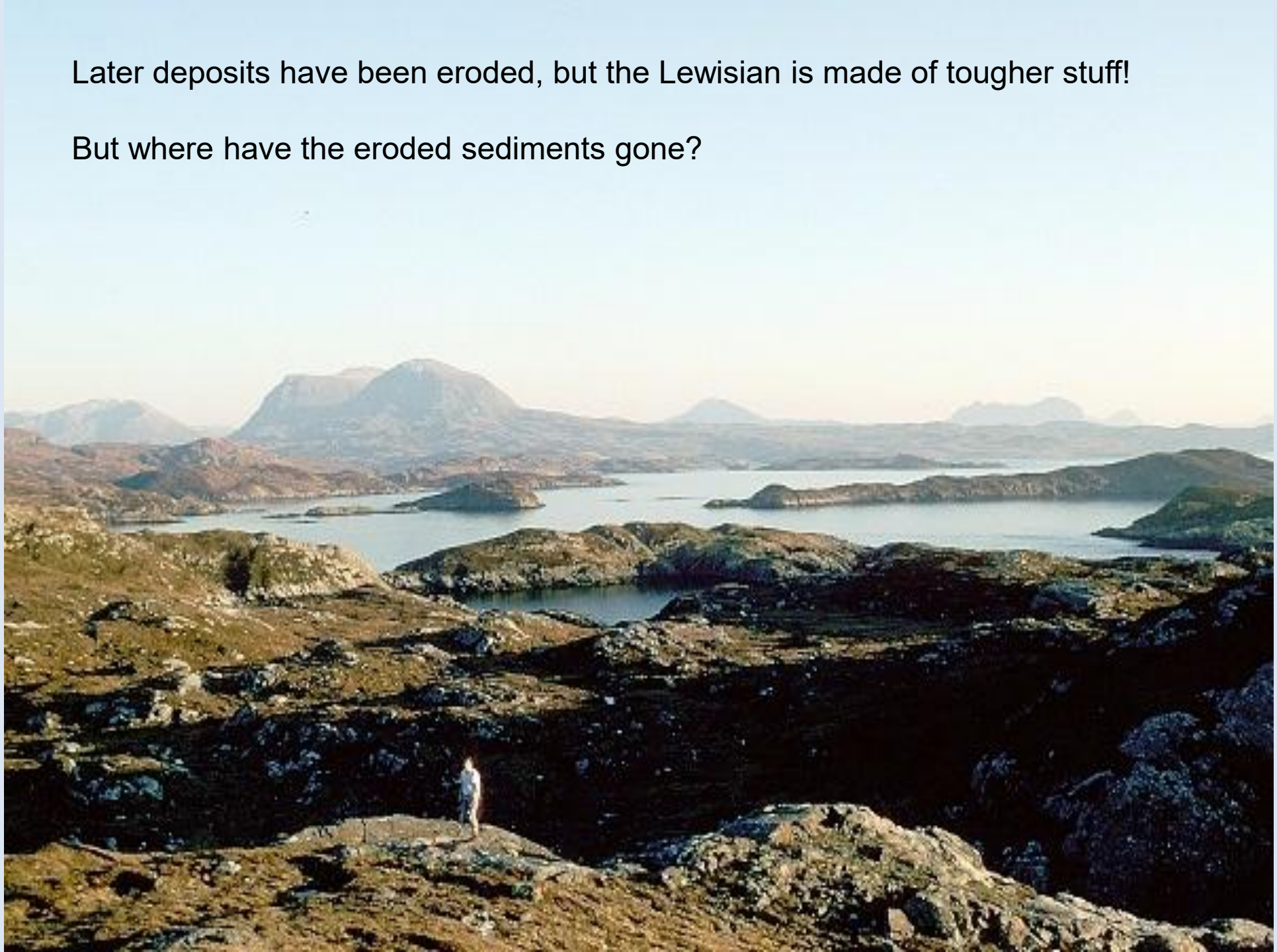
Rodinia -750 Ma

Just a warning about the uncertainties in all this! Much is hypothetical, awaiting further research.

The Hebridean Terrane seems to have been left uncovered as an eroding surface during this period

Later deposits have been eroded, but the Lewisian is made of tougher stuff!

But where have the eroded sediments gone?



Scotland in Rodinia

- The Hebridean Terrane seems to have been left uncovered as an eroding surface during this period
- North Highland and Grampian Terranes seem to be formed of sediments derived from Lewisian-type rocks
- North Highland Terrane sediments were probably derived from the Grenvillian Mountain Belt as Rodinia assembled, from 1000 Ma to 870 Ma forming...

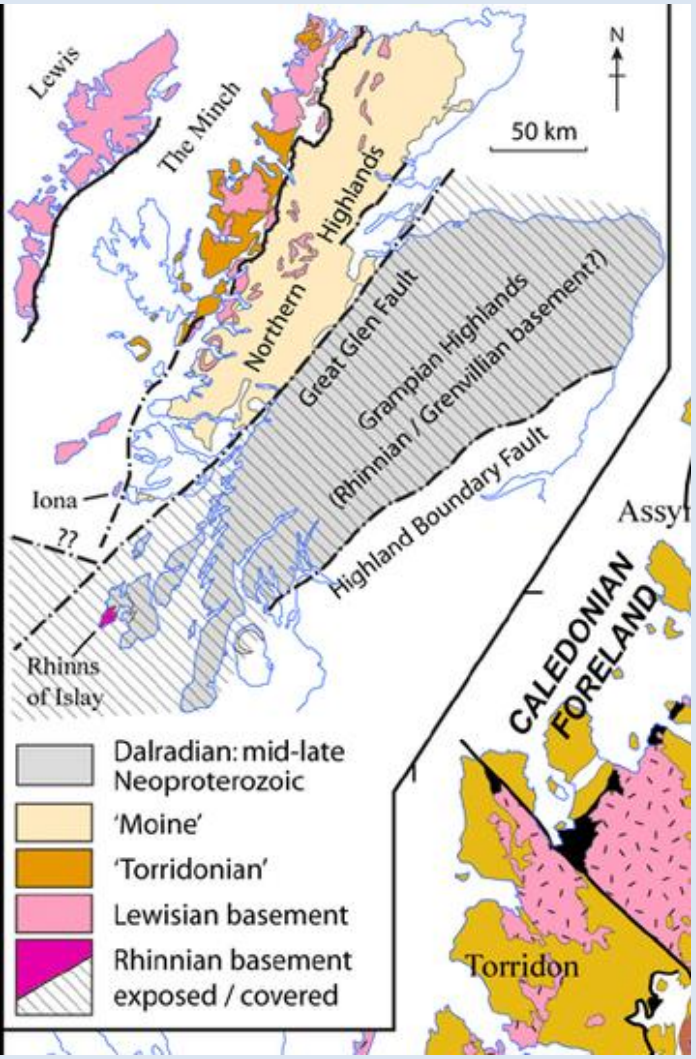
The Moine Supergroup

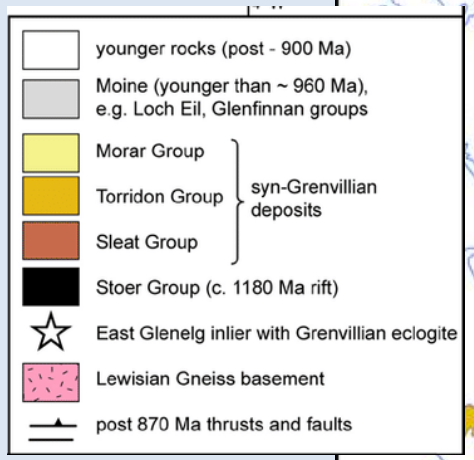
- Grampian Terrane sediments are derived from the break-up of Rodinia from 800 Ma to 540 Ma, forming…

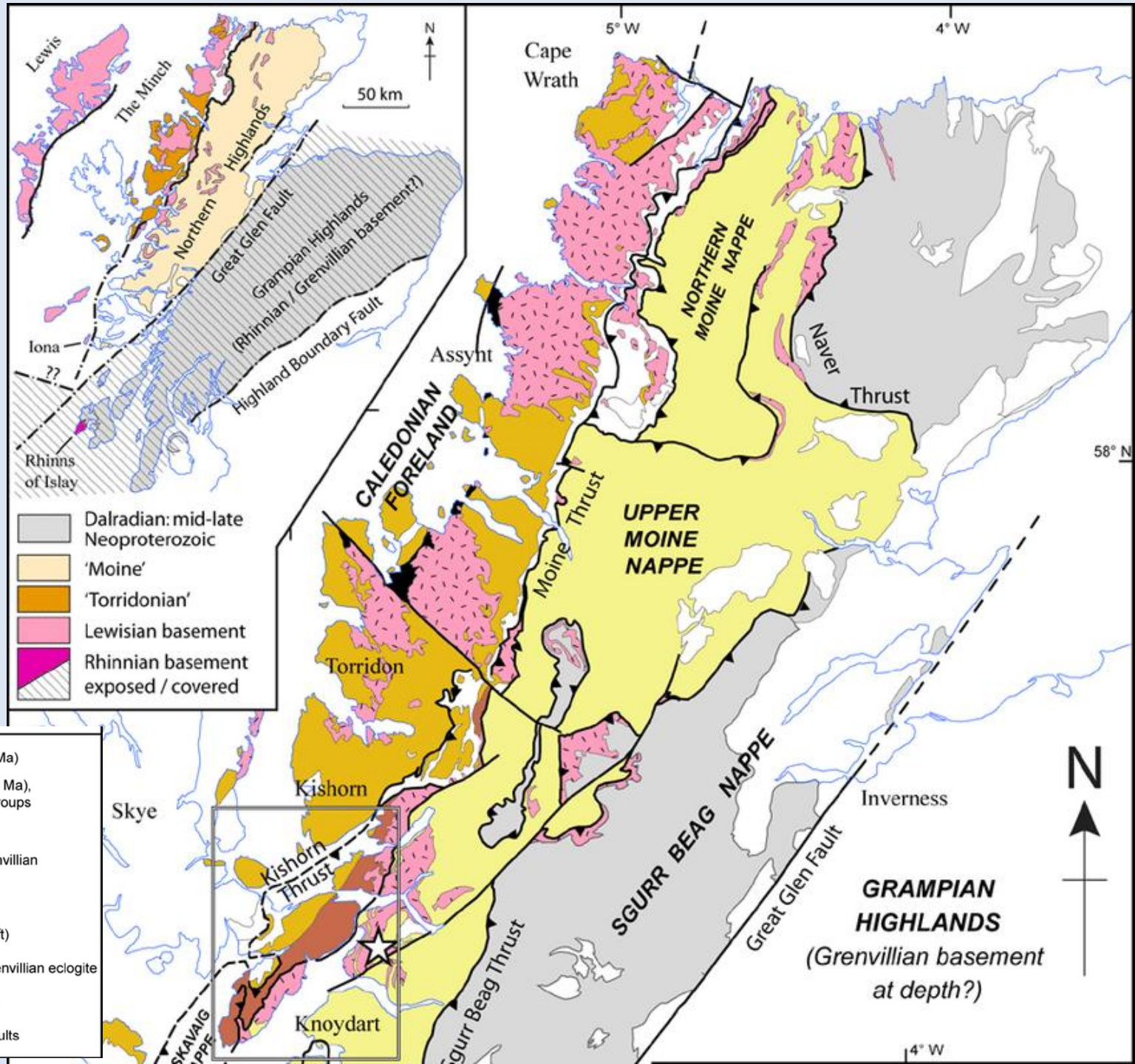
The Dalradian Supergroup

Simplified terrane map of Scotland

North Highland and Grampian Terranes seem to be formed of sediments derived from Lewisian-type rocks.







Scotland in Rodinia

- North Highland Terrane 1000 Ma to 870 Ma

The Moine Supergroup

- Grampian Terrane from 800 Ma to 540 Ma

The Dalradian Supergroup

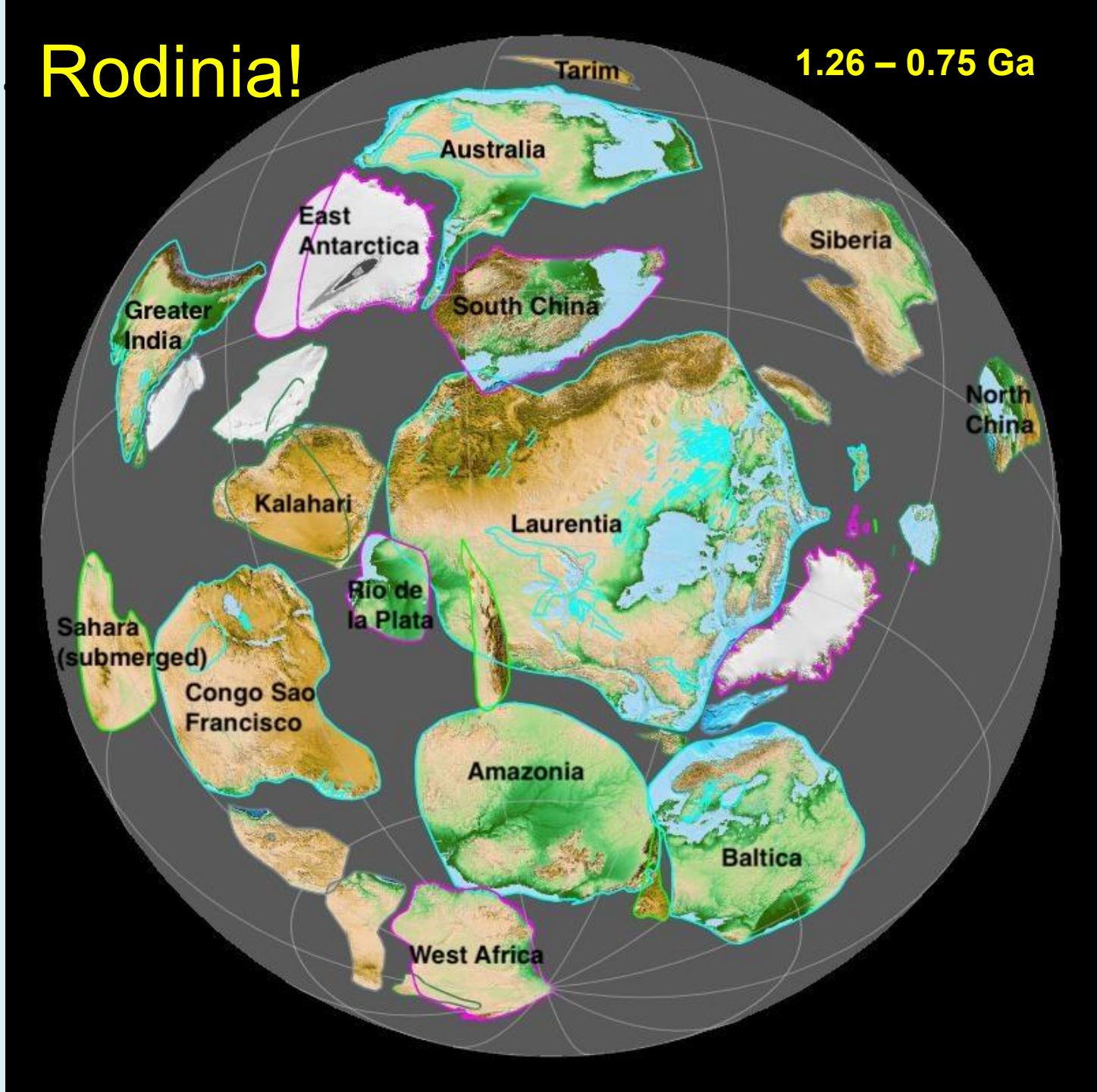
- Both Moine and Dalradian sediments have been much metamorphosed since deposition.
- Inliers of Lewisian-type rocks on the Rhinns of Islay and in the North Highland Terrane probably represent fragments of the Laurentian continental basement underlying the Moine and Dalradian.

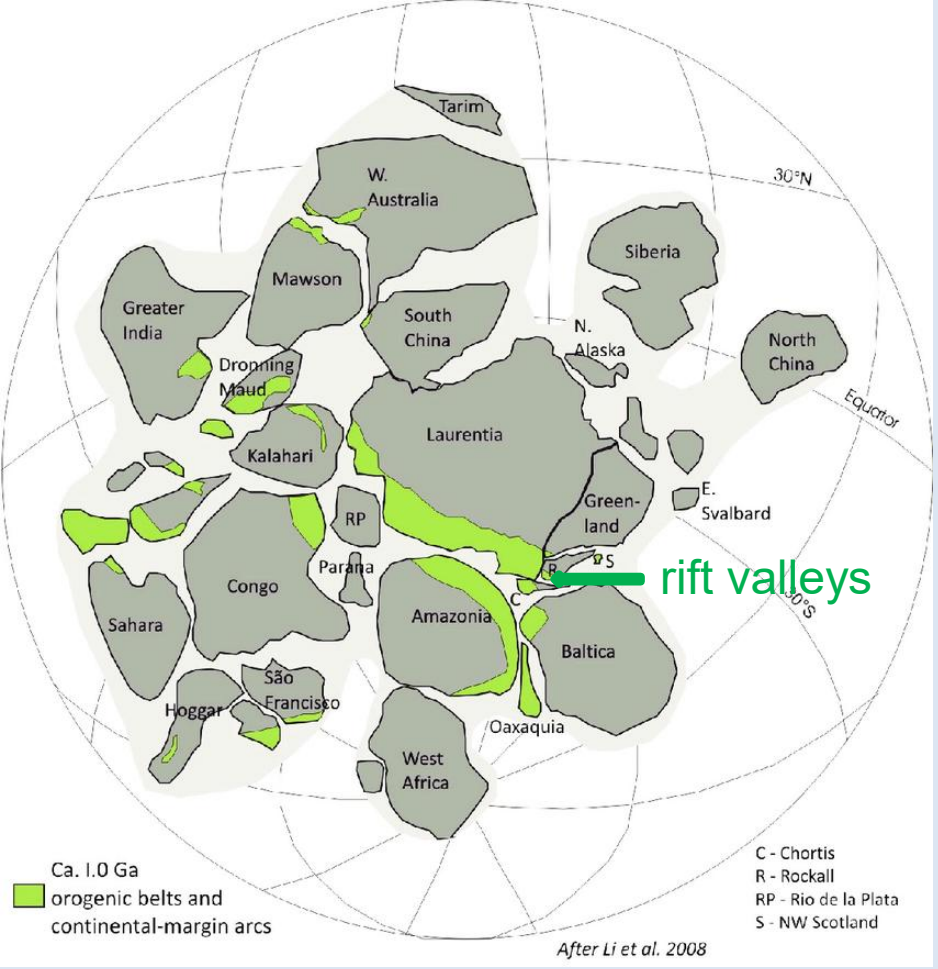
But before we leave the Hebridean Terrane, it's story is not yet finished!

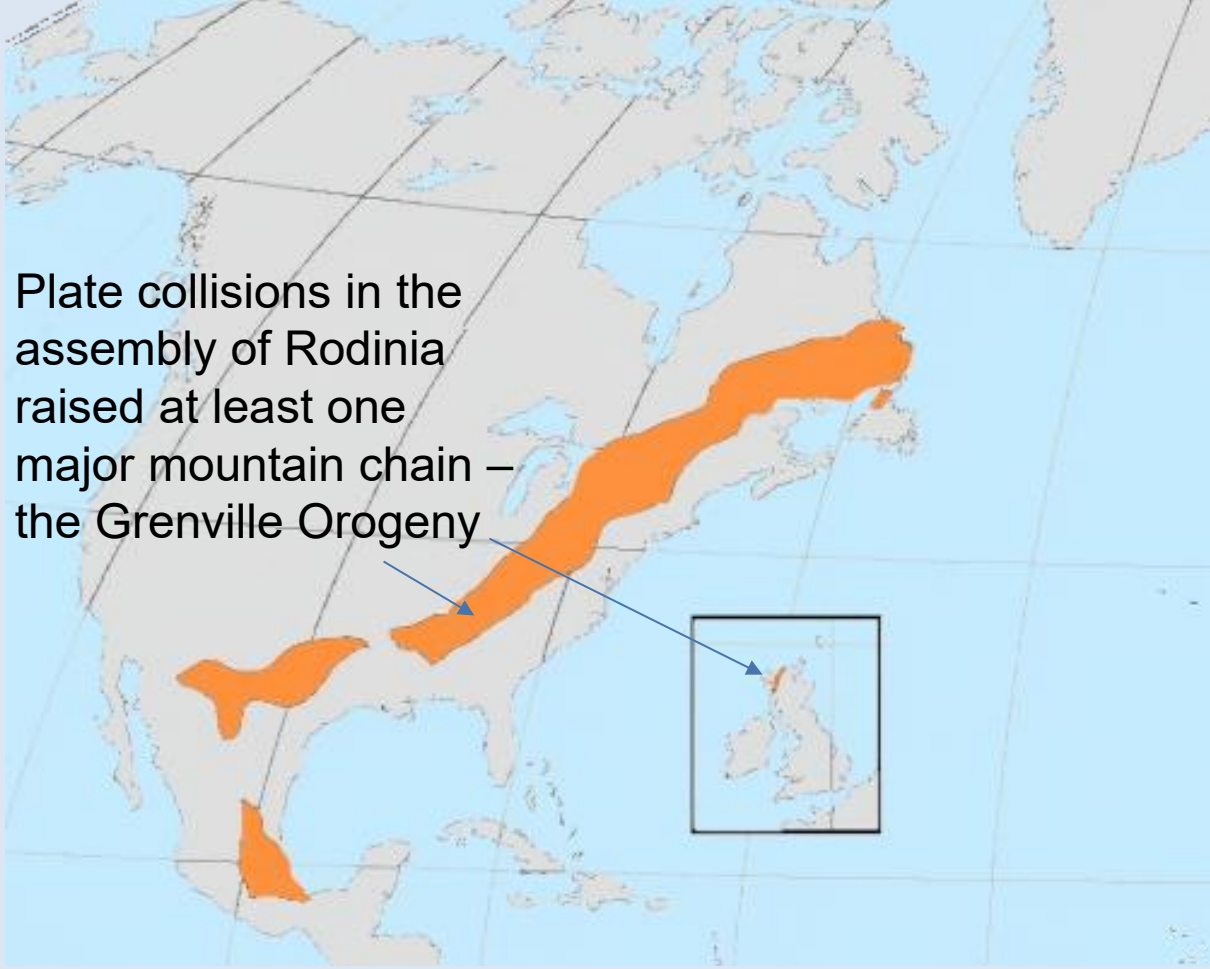
Now becoming part of… Rodinia!

Patches of green represent the main part of the Grenvillian orogenic belt – mountains formed by plate collisions as Rodinia assembled, and whose remnants can still be identified across many of the present continents.

Much debate about the configuration of the continents within the supercontinent.







Rift valleys (grabens) opened across the Laurentia, and erosion and transport filled these valleys with vast quantities of sediment, some in low relief valleys on the Hebridean Terrane.

These form the oldest sedimentary rock sequence in Scotland, still essentially unmetamorphosed.

We will return to Rodinia many times!

Palaeoclimate for Laurentia, with the Hebridean Terrane, deduced from comparison of these sediments with modern analogues:

- Latitude 10°-30° south
- Long hot dry summers
- Cool wet winters, up to 1m rainfall

Let us focus on just one of the grabens, near the southern edge of Rodinia...

... between the Minch Fault and the Moine Thrust

... 80 km across, at least 200 km long

... fed by sediments from the north-west, carried by rivers from eroding mountains

... **creating the**

Torridonian

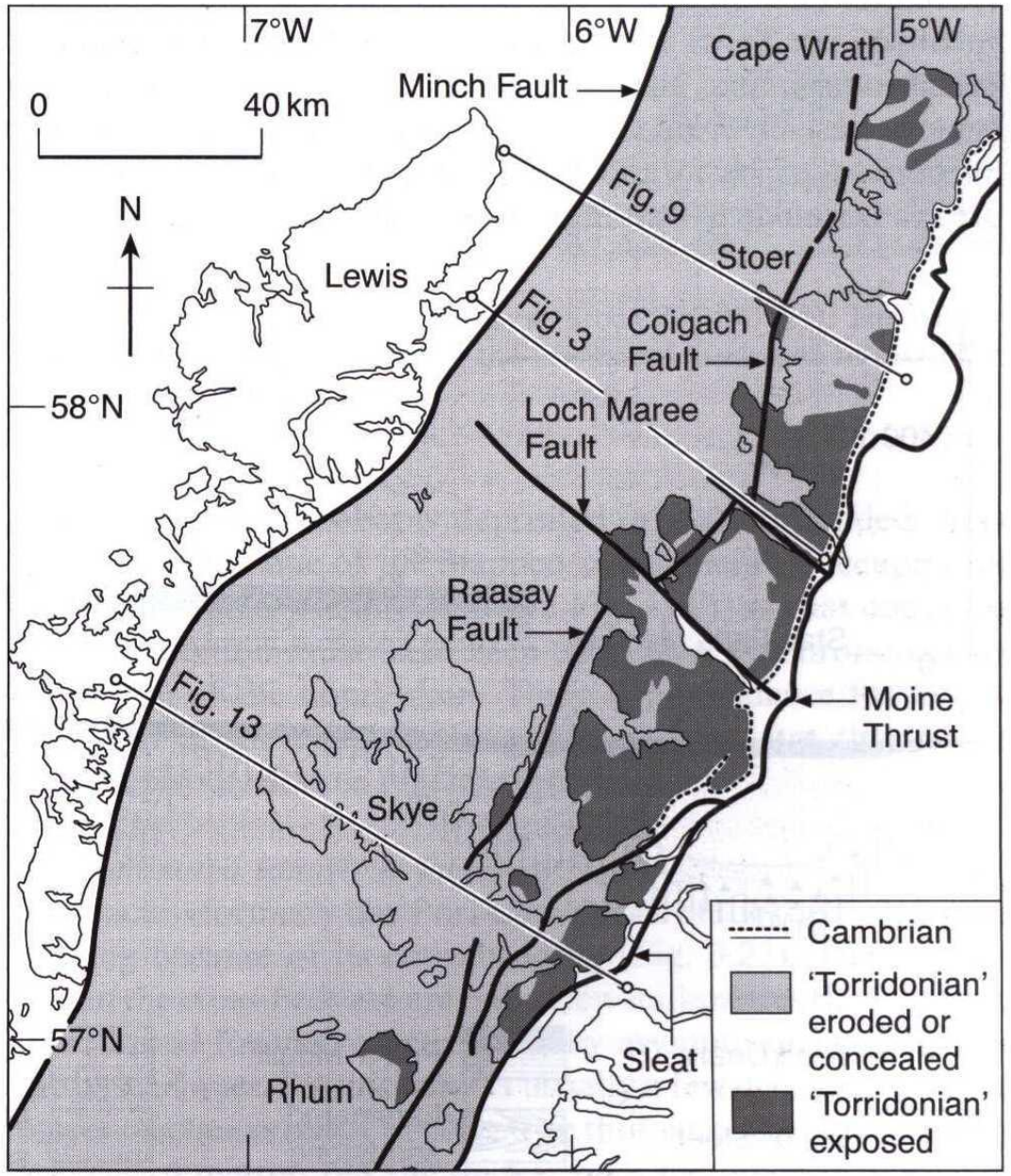


Fig. 3.17. Sketch map of northwest Scotland showing the present and former extent of the 'Torridonian', together with some major faults.

Depositing the Torridonian

Three groups, two older ones localised and distant from each other:
Sleat group in SE Skye
Stoer group forming the Stoer peninsula, north of Lochinver.

Then on top of both Sleat and Stoer groups, the extensive...

Torridon group, divided into 3 formations:

- **Diabaig formation**
- **Applecross formation**
- **Aultbea formation**

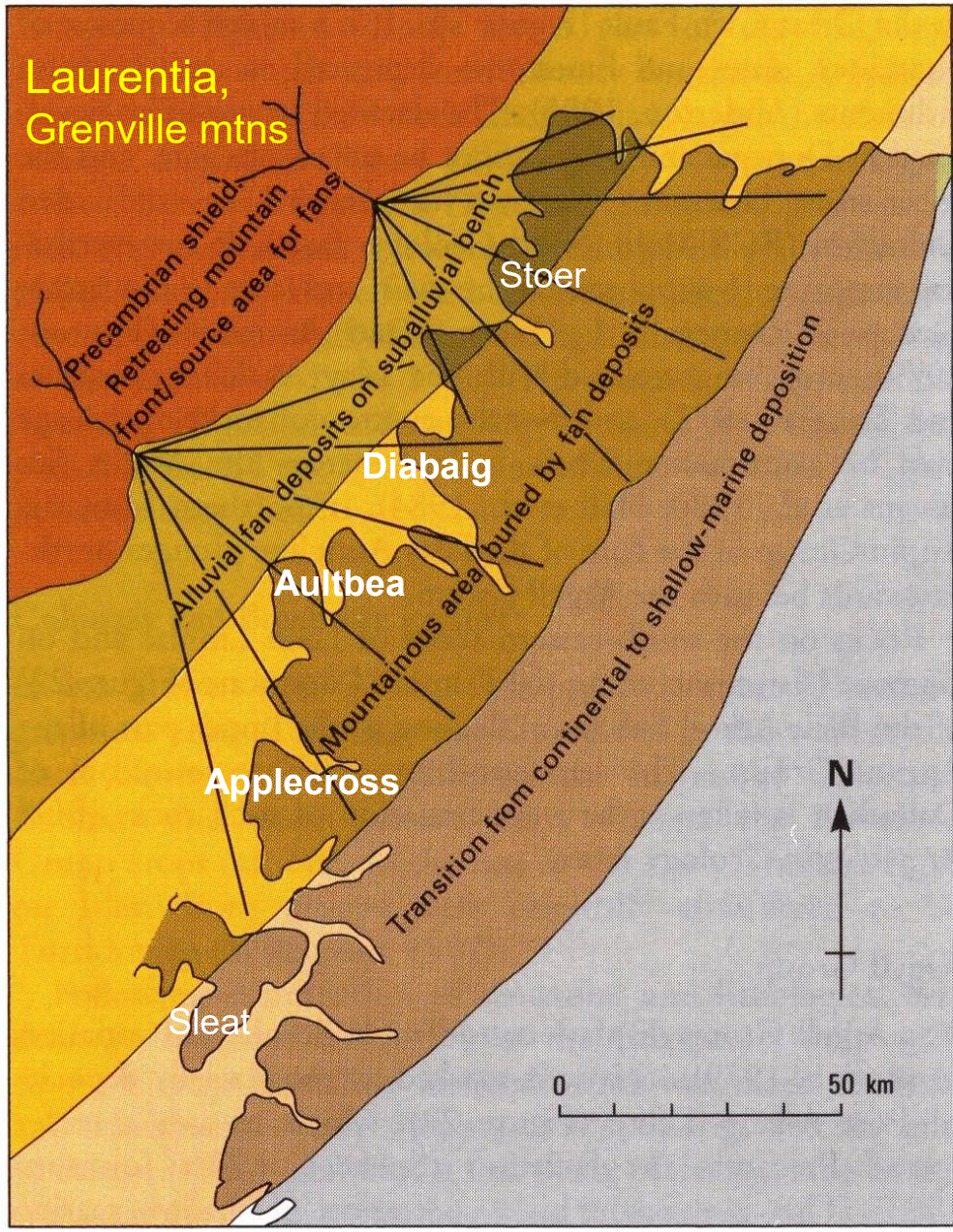


Figure 21 Depositional environment of the Applecross and Aultbea formations. After Williams (1969).

Depositional Basins - a place where sedimentary deposition takes place.

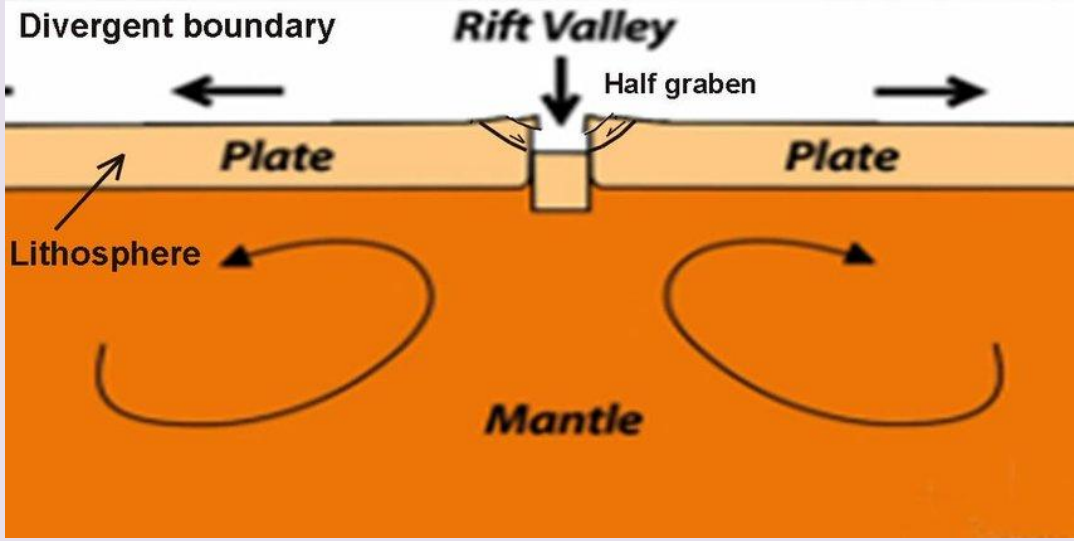
Important places for deposition of sediments that generate and accumulate petroleum.

Basins may be formed at:

Convergent plate margins:

- Linear basins in which thick sediments accumulate.
- Often two parallel basins separated by a volcanic island arc

Divergent plate margins:



- Tectonic basins, produced by continental separation.
- Often involve rifting, with *graben* formation
- Evolution of basins involves cycles of deformation and deposition
- As a basin begins to form, initial sedimentation then further deepens the basin as deposition continues.
- Deformation controls subsequent sediment, and folds and faults them.

We are mainly concerned with divergent margins forming rift valleys – grabens and half-grabens.

Generalised Depositional Basins

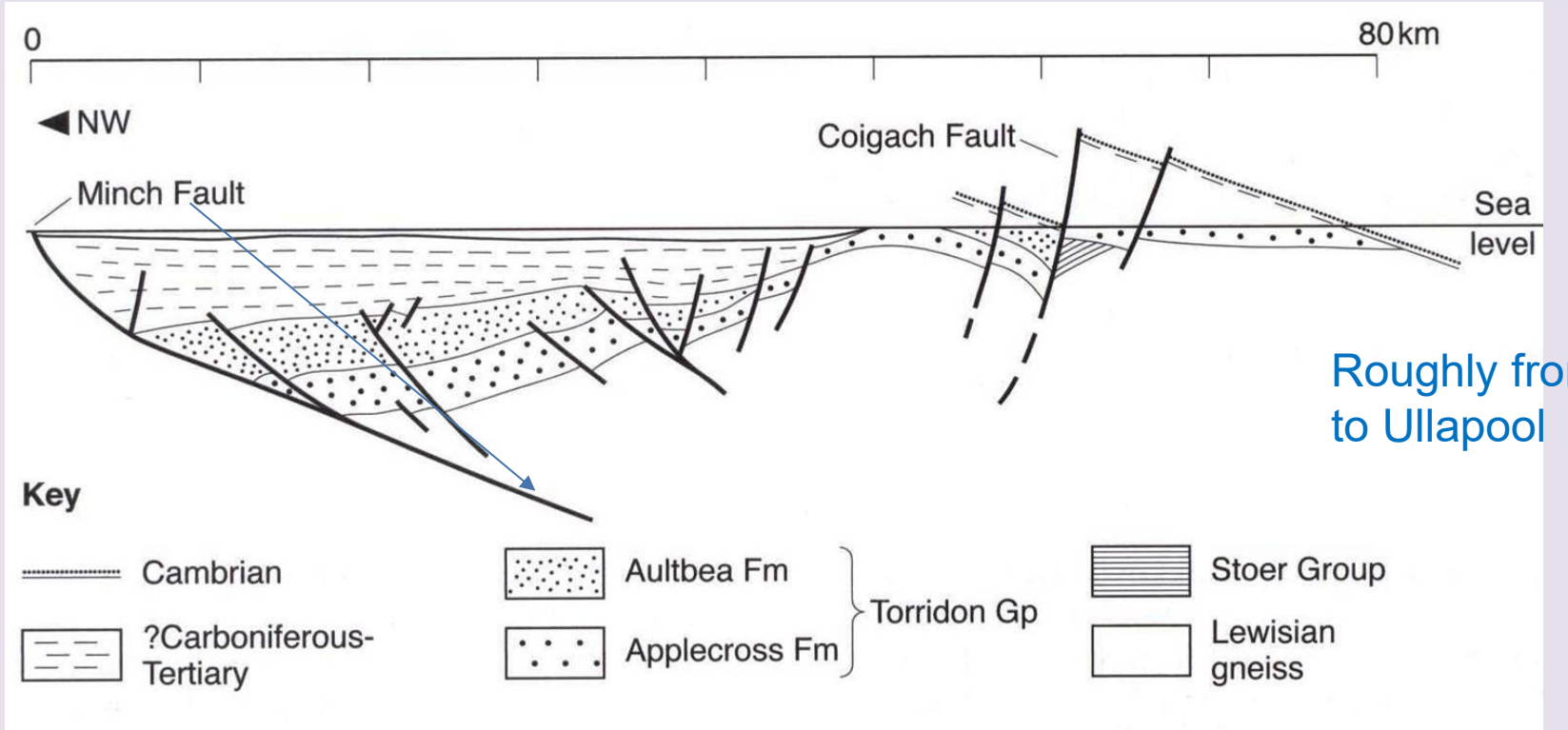
- A basin bounded by highlands on one side and lowlands on the other.
  - clastic sediments from the highlands,
  - finer sediments from lowlands

- Along mountainous coasts, shales are deposited in the basin and the lagoon.

Sand and gravel beds are deposited as barrier bars, beaches, and delta distributary channels.

- Along lowland coasts with clear water, carbonate deposition occurs, as reef organisms require clear marine water.

So what do we have in the Minch Basin in the Torridonian?

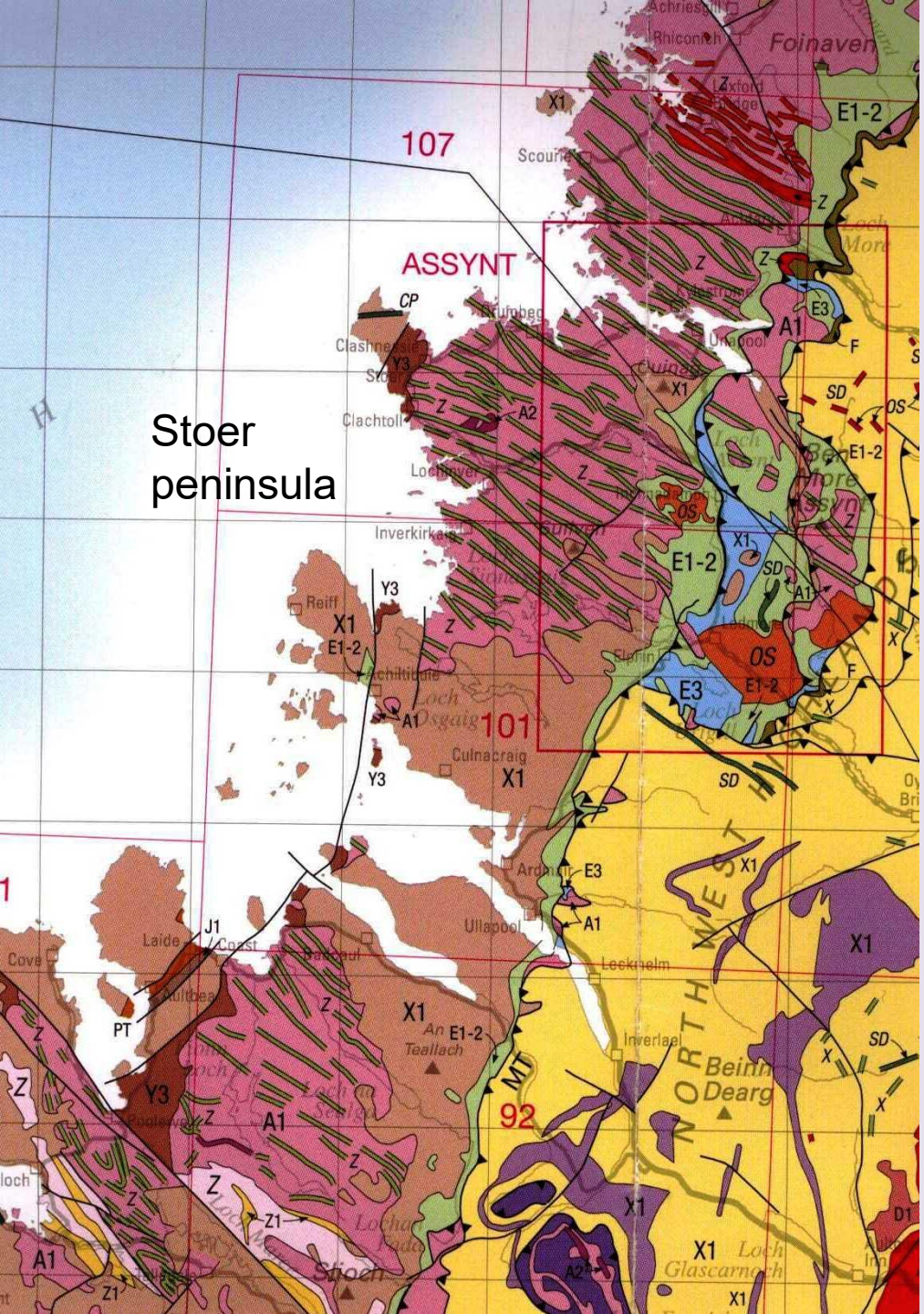


Roughly from Stornoway to Ullapool

Stoer Group

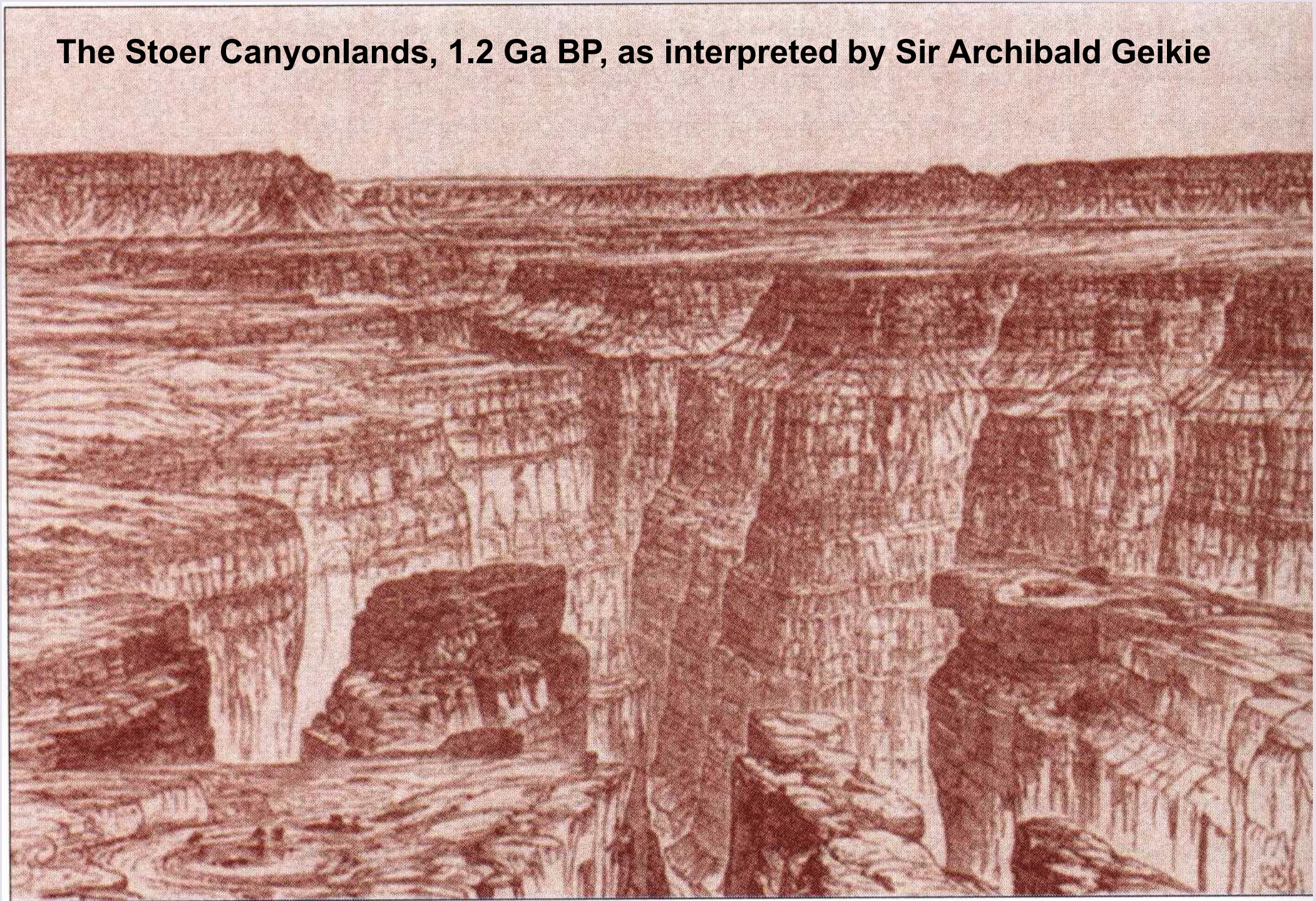
- Formed ~1200 Ga BP (much older than Sleat Gp, and preceding the main Grenville Orogeny)
- Only a few outcrops, from the Stoer peninsula in the north to Inverewe in the south
- Deposits 2 km thick, and must have been much more extensive than present outcrops
- Red beds; continental aeolian, fluvial and deltaic deposits
- Laid unconformably on an eroded Lewisian landscape

Stoer peninsula



Basal breccio-conglomerate filling a 50 m deep canyon in the Lewisian surface. Clachtoll

The Stoer Canyonlands, 1.2 Ga BP, as interpreted by Sir Archibald Geikie

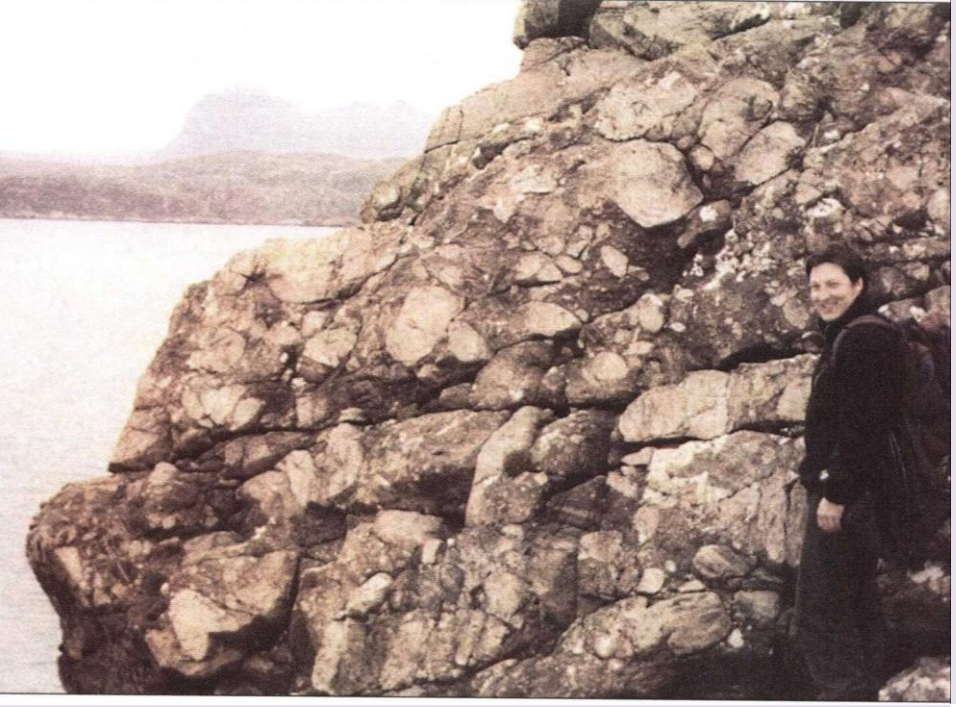


This is a sedimentary landscape, while the Stoer Canyonlands were formed in Lewisian Gneiss.

So not really a realistic example.

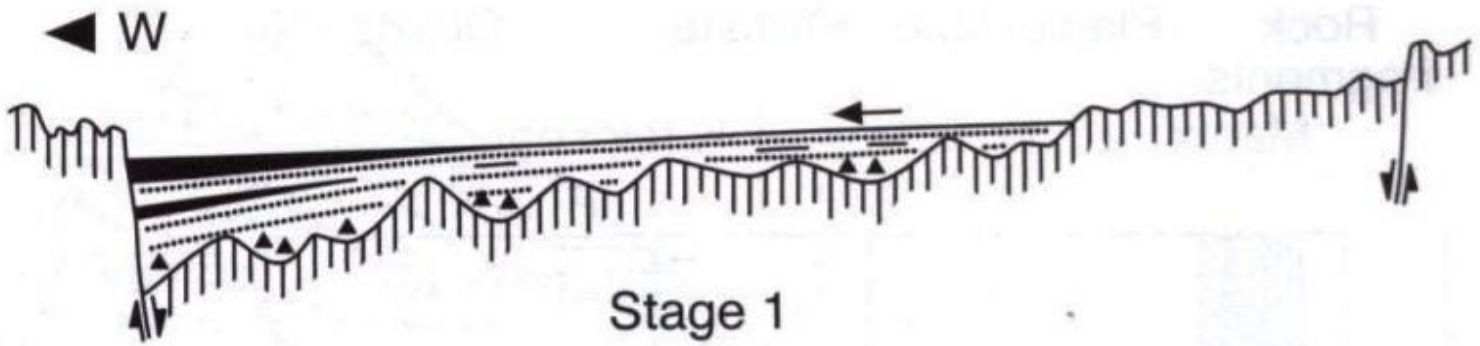
What is probably realistic is the lack of any sign of land plants, or lower life forms, but bacteria, archaea and algae were beginning to colonise sub-aerial environments. With photosynthesising bacteria, archaea and algae now colonising sub-aerial environments, the oxygen content of the atmosphere was probably rising to a few percent as the Stoer Group was formed.

Canyonlands, Utah



Stoer Group

- **Basal breccia**, clasts exclusively from Lewisian, with large angular clasts at the very bottom, becoming more rounded (transported short distances), then passing upwards into pebbly red sandstones, all infilling the canyons.



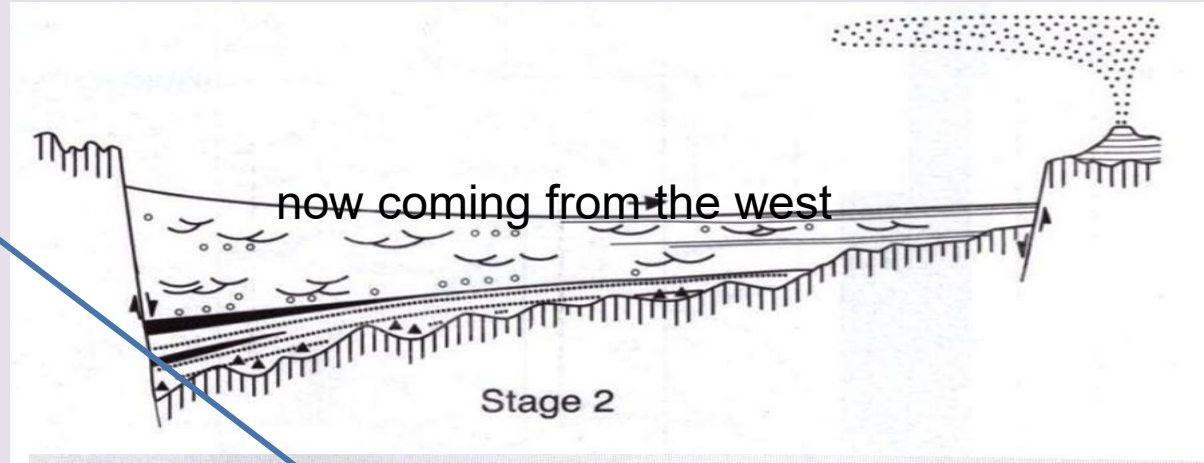
- **Muddy sandstone facies** above this, with desiccated sheets of red siltstone or carbonates, probably represent seasonal mudflats, drying out in summer.

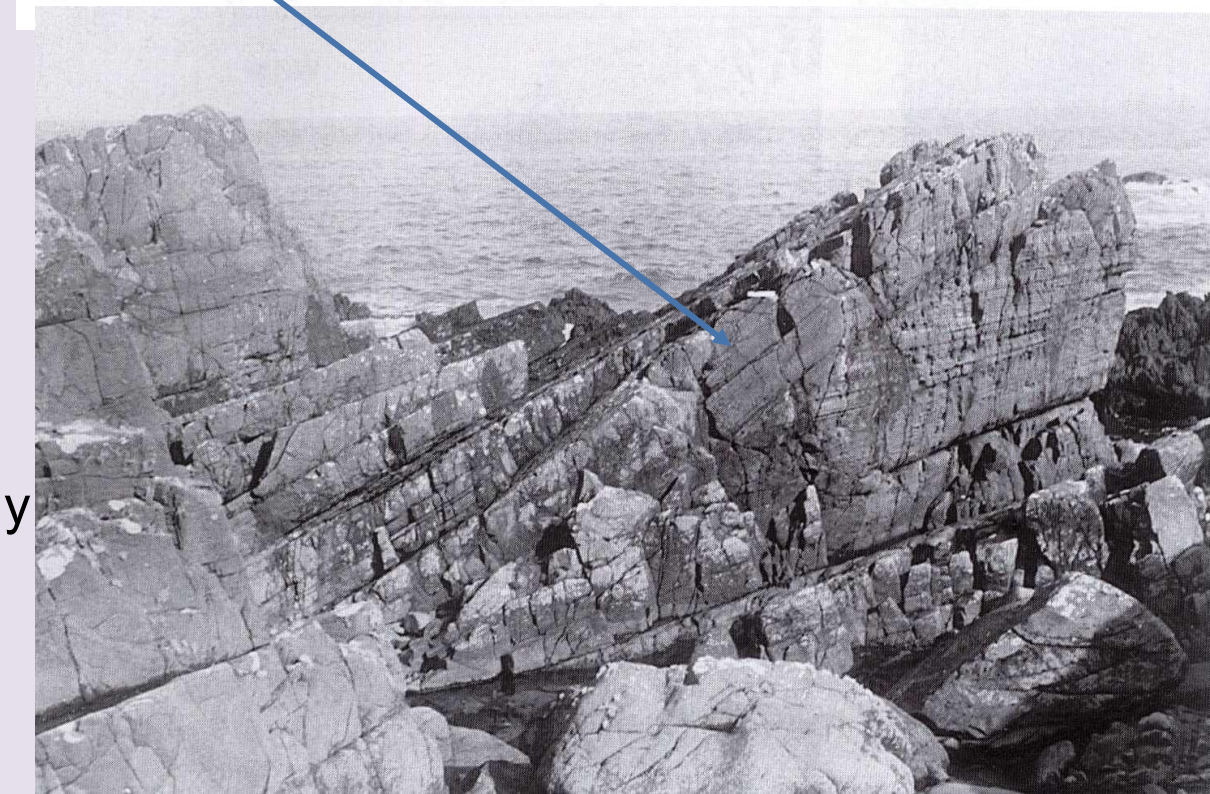
Stoer Group

Conglomerate facies comes next, fining upwards, probably deposited in braided river channels and the occasional flood plain event.

Laminated sandstone facies is strikingly cross-bedded, but with occasional thick sandstone beds. The cross-bedding is typical of wind-blown sand dunes migrating across a desert floor (barchans), while the thick sandstones represent occasional torrential flood events.

The base is laid on an eroded surface of the muddy sandstone facies.





Modern braided river, Norway

Compare with River Lochy between Strone Hill and Tyndrum

Eroding mountain range depositing sediments in a broad valley below

South Africa

Stoer Group

Poll a'Mhuilt facies within the **Bay of Stoer facies** represent deposits in a temporary lake in a rifting environment where loose sands were being swept into a trough, all being subject to soft-sediment deformation.

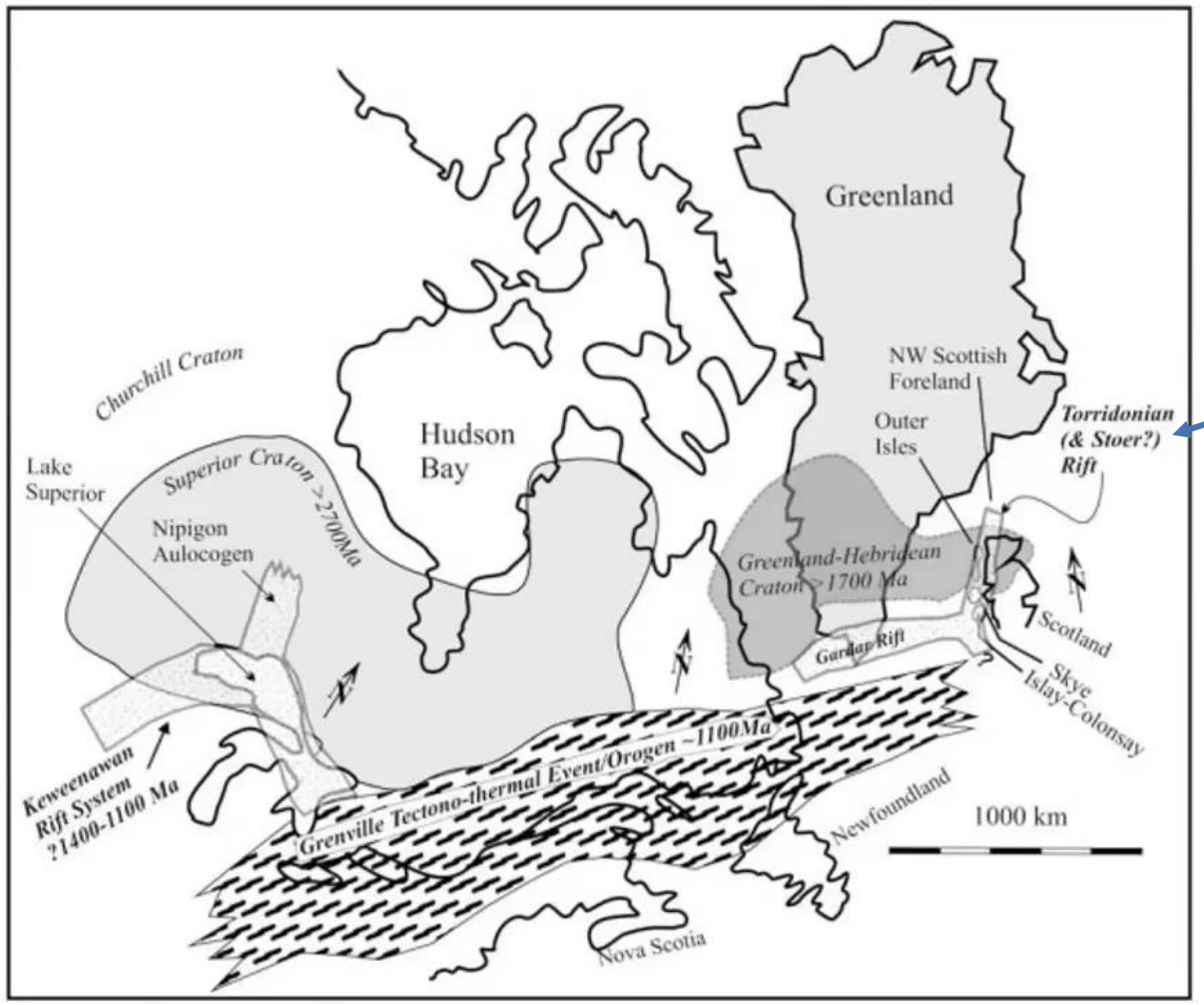
Some deposits contain 25% devitrified glass fragments from local rift volcanoes.

Stoer itself is located roughly in the middle of the rift.

The Meall Dearg Formation concludes the Stoer Group, with sandstones deposited in a slow-moving braided river environment. And at the top of the Stoer Group, the source material is still essentially from Scourian gneisses of the Lewisian.

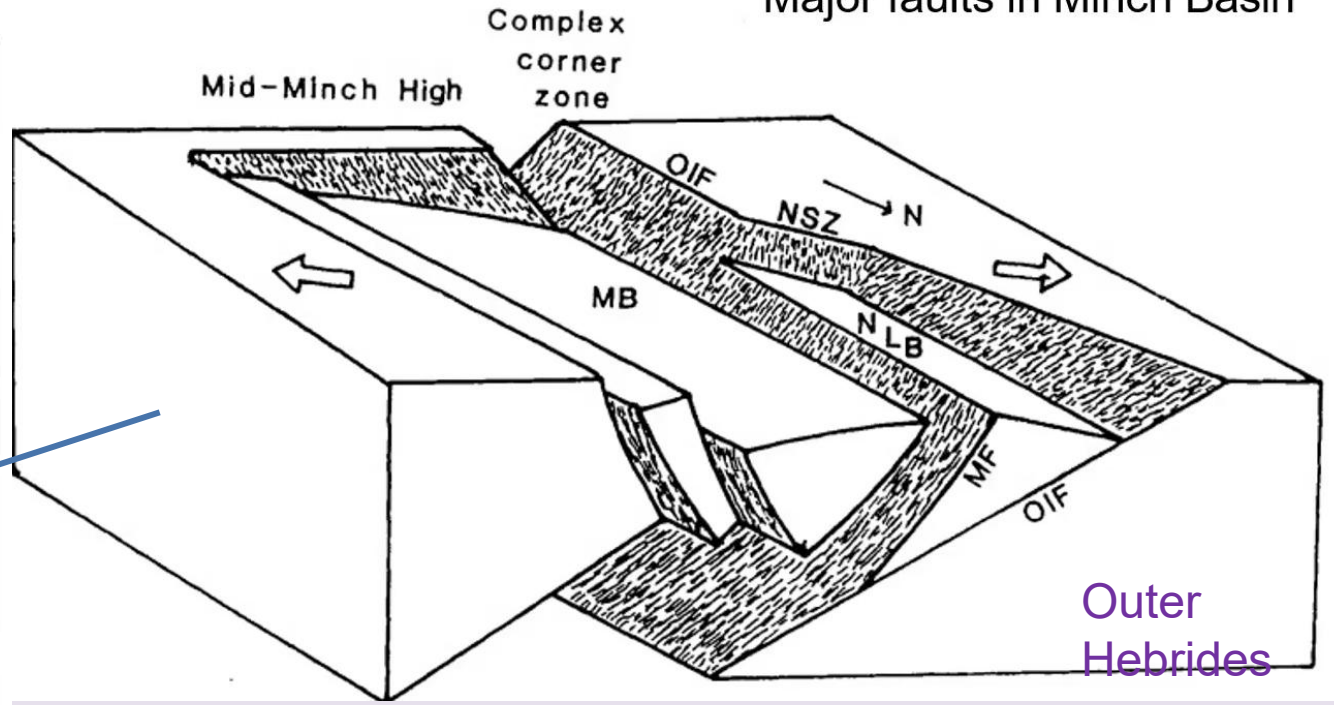
Wind-driven waves in shallow lake produced these ripples in the muddy floor of the lake.

Stoer Group, Stoer Peninsula

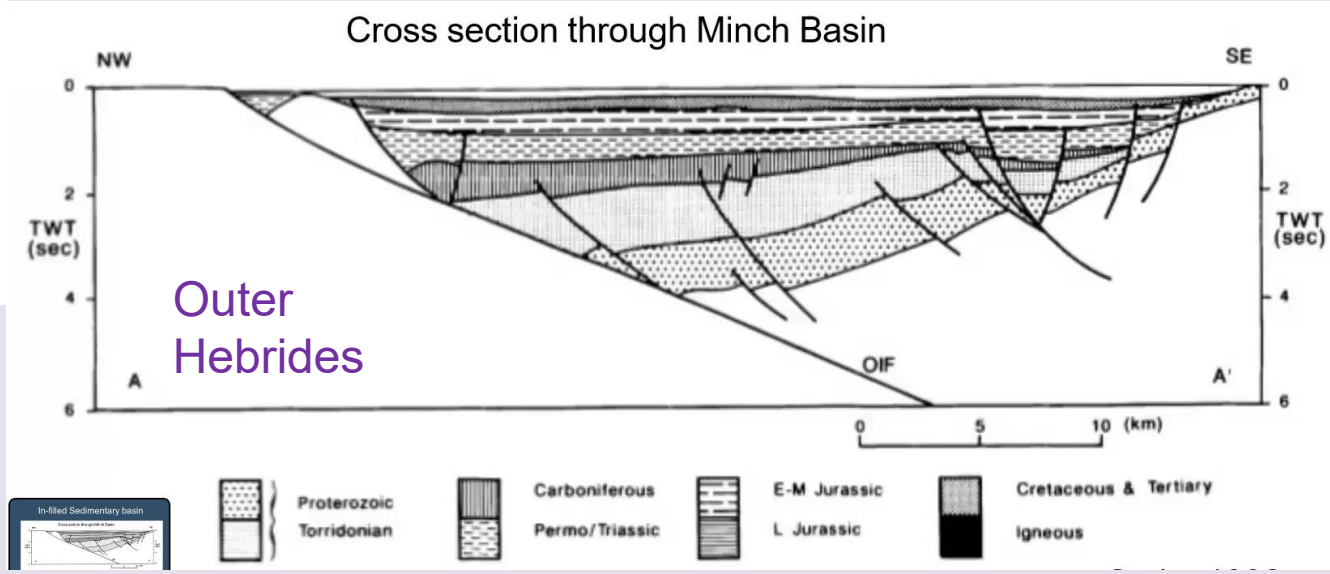


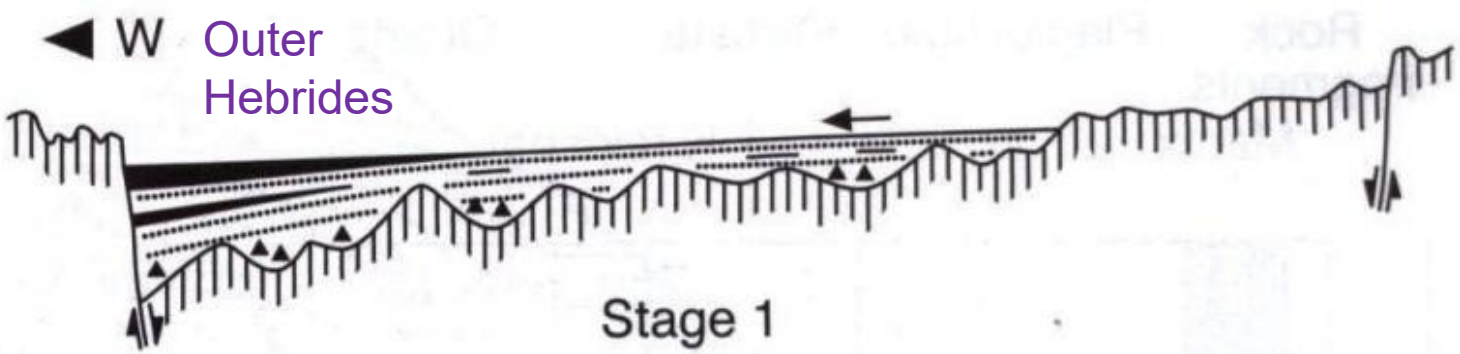
Alan M. Stein

Major faults in Minch Basin



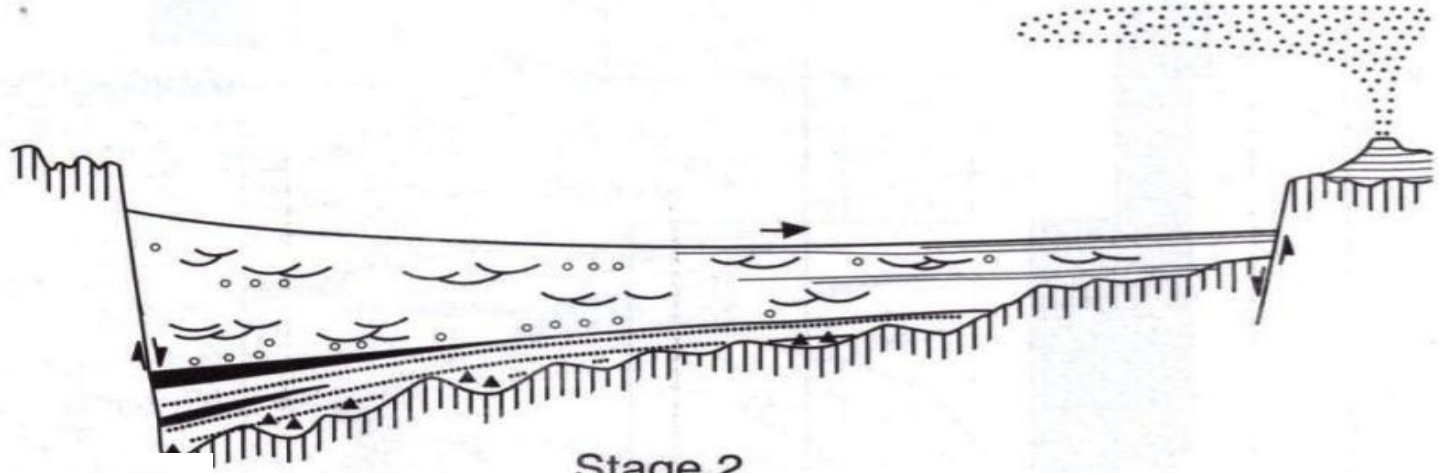
Cross section through Minch Basin

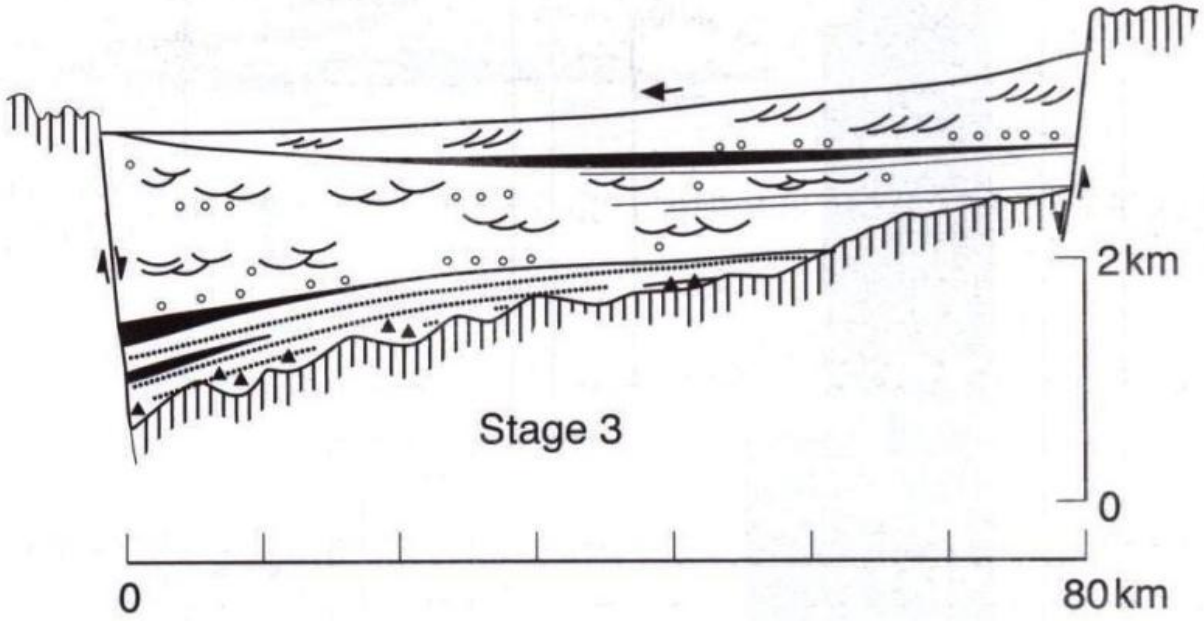




Locally derived sediments from east to form breccia and conglomerate facies.

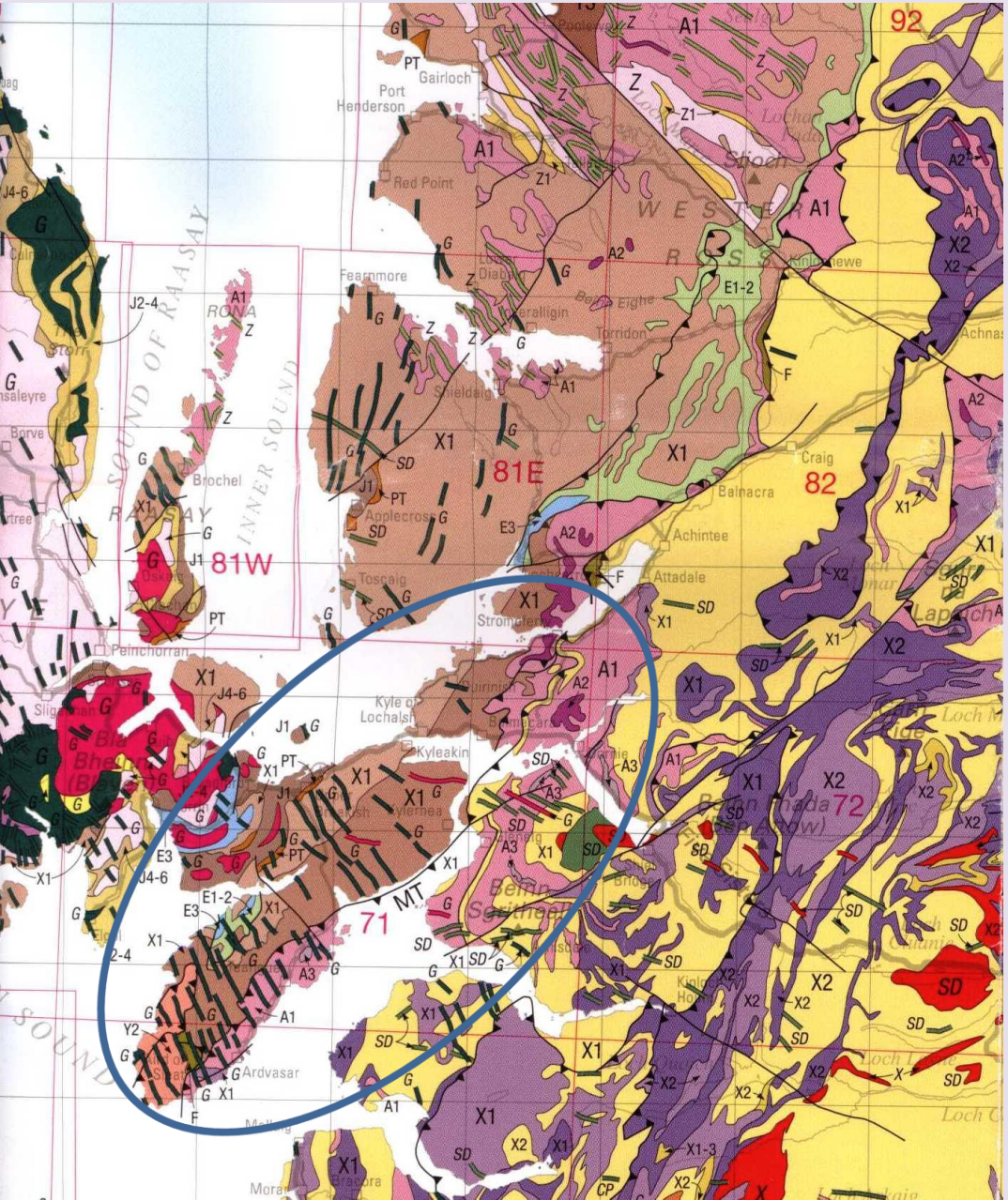
Bay of Stoer facies sediments come from the west



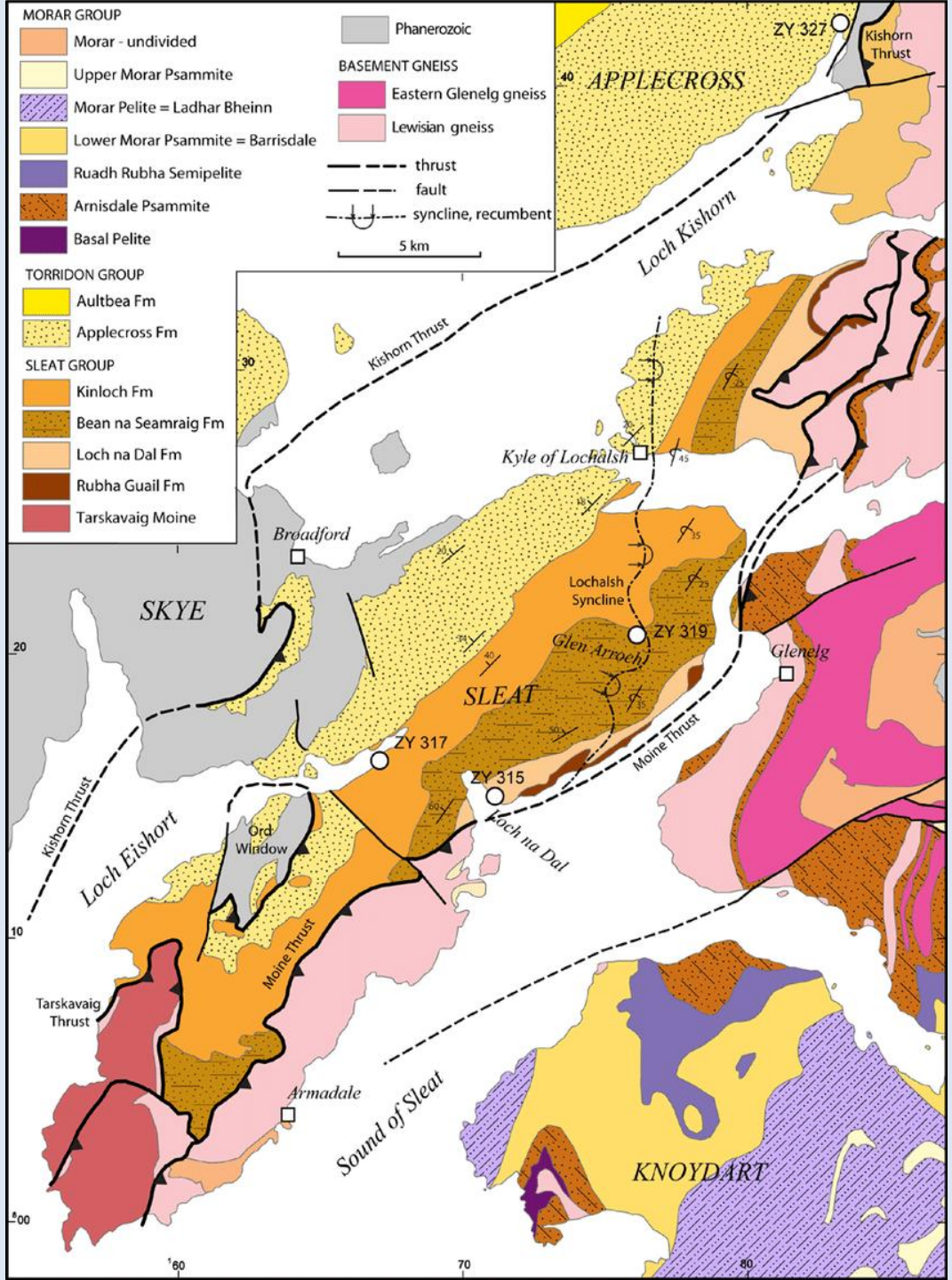


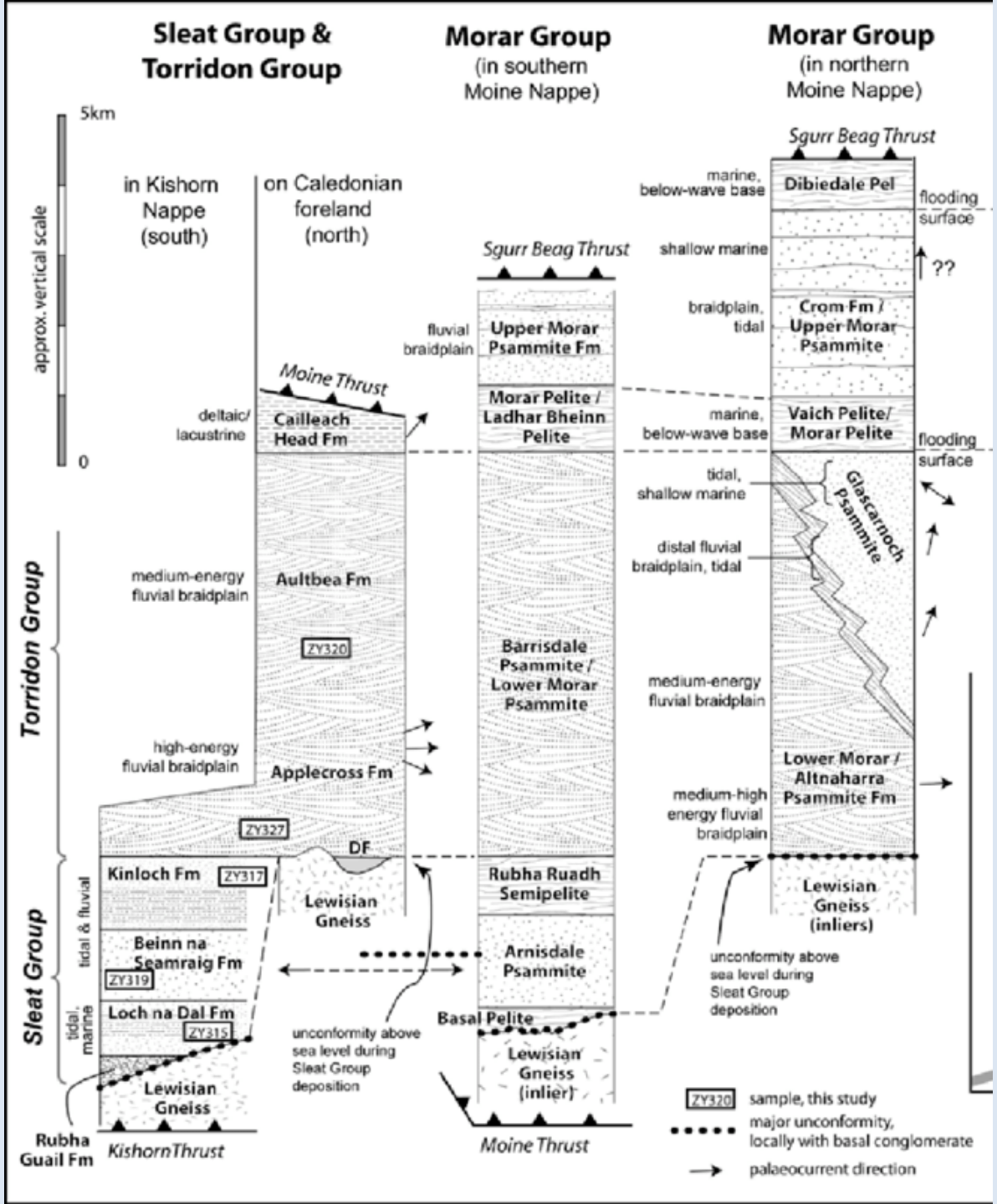
Sediments from the east to form Meall Dearg facies

Sleat Group



- Deposited 1.0 – 0.95 Ga; 3.5 km thick!
- No visible relationship to Stoer Group, and probably deposited in a separate basin.
- At the bottom, breccia of gneiss fragments on Lewisian base, visible at Kyle of Lochalsh
- Mainly coarse grey sandstones above, with cross-bedding
- Fining upwards into fine-grained sandstones and grey shales, showing wave ripples, desiccation cracks
- Interpreted as a large alluvial fan prograding from hills into a lake
- Later beds indicate a braided river interspersed with shallow water lake/marine interludes
- A few thin tephra-fall deposits from volcanic activity
- Overlain conformably by the Torridon Group
- Probably represents the initial infilling of a topographic low in the graben.


MORAR GROUP
Morar - undivided
Upper Morar Psammite
Morar Pelite = Ladhar Bheinn
Lower Morar Psammite = Barrisdale
Ruadh Rubha Semipelite
Arnisdale Psammite
Basal Pelite
TORRIDON GROUP
Aultbea Fm
Applecross Fm
SLEAT GROUP
Kinloch Fm
Bean na Seamraig Fm
Loch na Dal Fm
Rubha Guail Fm
Tarskavaig Moine
Phanerozoic
BASEMENT GNEISS
Eastern Glenelg gneiss
Lewisian gneiss
thrust
fault
syncline, recumbent
5 km
APPLECROSS
ZY 327
Kishorn Thrust
Loch Kishorn
Kyle of Lochalsh
Broadford
SKYE
Lochalsh Syncline
Glen Arroch
ZY 319
Glenelg
SLEAT
ZY 317
ZY 315
Moine Thrust
Loch na Dal
Loch Eishort
Ord Window
Tarskavaig Thrust
Armadale
Sound of Sleat
KNOYDART


Sleat Group & Torridon Group
Morar Group (in southern Moine Nappe)
Morar Group (in northern Moine Nappe)
5km
approx. vertical scale
0
in Kishorn Nappe (south)
on Caledonian foreland (north)
Sgurr Beag Thrust
Moine Thrust
Kishorn Thrust
Torridon Group
Sleat Group
deltaic/ lacustrine
fluvial braidplain
medium-energy fluvial braidplain
high-energy fluvial braidplain
tidal & fluvial
tidal, marine
marine, below-wave base
shallow marine
braidplain, tidal
tidal, shallow marine
distal fluvial braidplain, tidal
medium-high energy fluvial braidplain
flooding surface
??
Cailleach Head Fm
Aultbea Fm
Applecross Fm
Kinloch Fm
Beinn na Seamraig Fm
Loch na Dal Fm
Rubha Guail Fm
Lewisian Gneiss
Upper Morar Psammite Fm
Morar Pelite / Ladhar Bheinn Pelite
Barrisdale Psammite / Lower Morar Psammite
Rubha Ruadh Semipelite
Arnisdale Psammite
Basal Pelite
Lewisian Gneiss (inlier)
Dibiedale Pel
Crom Fm / Upper Morar Psammite
Vaich Pelite/ Morar Pelite
Glascarnoch Psammite
Lower Morar / Altnaharra Psammite Fm
Lewisian Gneiss (inliers)
ZY320
ZY327
ZY317
ZY319
ZY315
DF
unconformity above sea level during Sleat Group deposition
sample, this study
major unconformity, locally with basal conglomerate
palaeocurrent direction

So to the Torridon Group …

Up to 6 km thick!

- 150 My time gap after Stoer Group!
- rests conformably on the Sleat Group
- rests unconformably on the highly eroded Stoer Group
- rests mostly directly on Lewisian basement with a highly varied palaeo-topography; relief from 100 m near Cape Wrath to 600 m at Loch Maree

The Torridon Group

Four formations:

- Diabaig
- Applecross
- Aultbea
- Cailleach Head

Palaeoclimate:

- Long, hot dry season
- Cool winter, rainfall 500-1000 mm
- Equivalent to modern climates found in latitudes 10°- 30°

Dating: 1.0-0.8 Ga BP

Base of Diabaig formation: ~990 Ma

(200 Ma later than top of Stoer Group)

Top of Torridon Group: ~800 Ma

Tectonic setting:

- two active faults, 80 km apart
  - ➢Minch fault
  - ➢precursor fault of the Moine Thrust
- forming a rift valley
- most source material came from west

Torridon mountains in the Applecross and Aultbea formations

Note the lack of significant dip or folding – no evidence of metamorphism either.

The Torridon Group

Four formations:

- Diabaig
- Applecross
- Aultbea
- Cailleach Head

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- Long, hot dry season
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- forming a rift valley
- most source material came from west

The Torridon Group

Four formations:

- Diabaig
- Applecross
- Aultbea
- Cailleach Head

Palaeoclimate:

- Long, hot dry season
- Cool winter, rainfall 500-1000 mm
- Equivalent to modern climates found in latitudes 10°- 30°

Dating:

1.0-0.8 Ga BP

Base of Diabaig formation: ~990 Ma

(200 Ma later than top of Stoer Group)

Top of Torridon Group: ~800 Ma

Tectonic setting:

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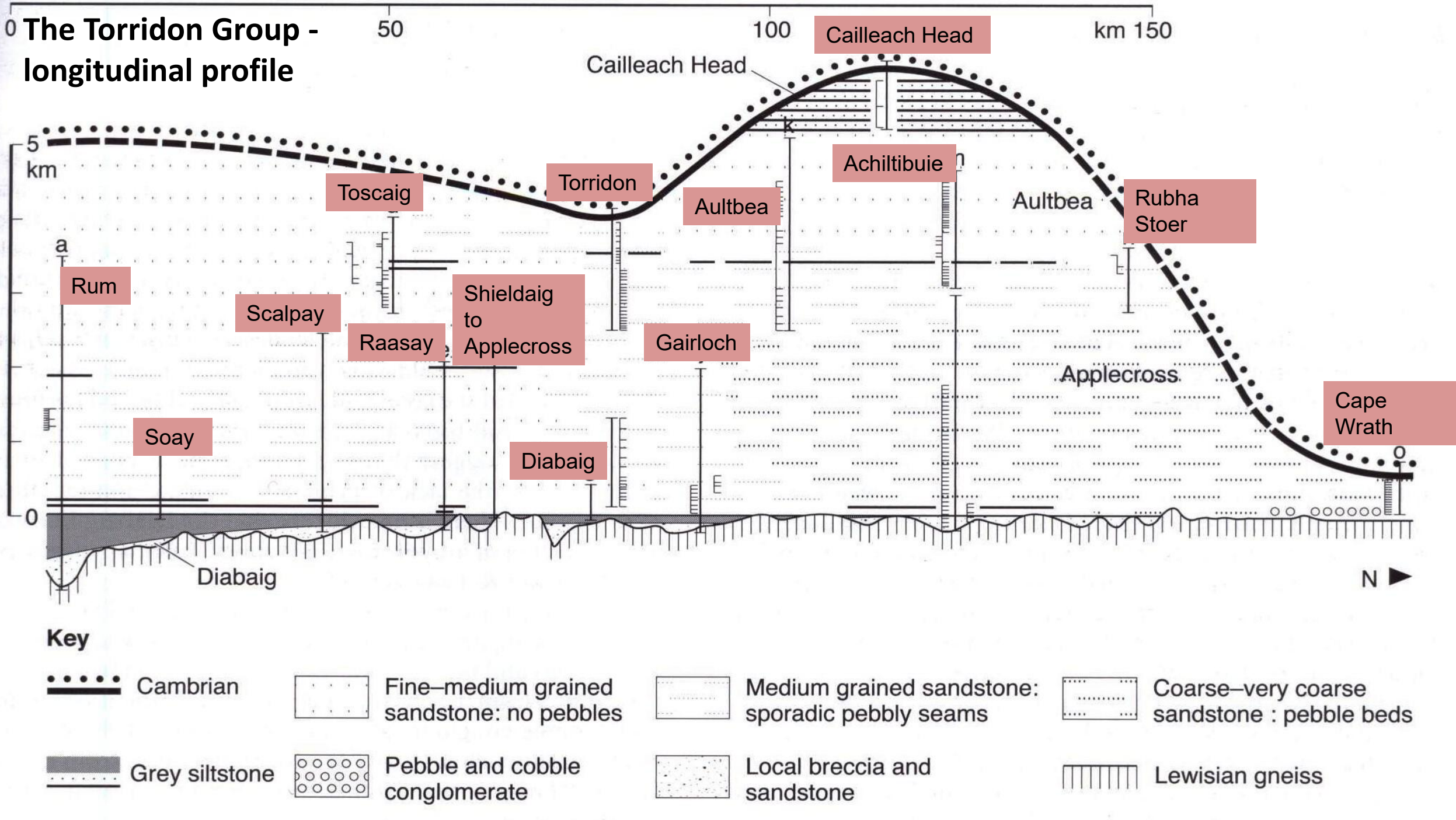
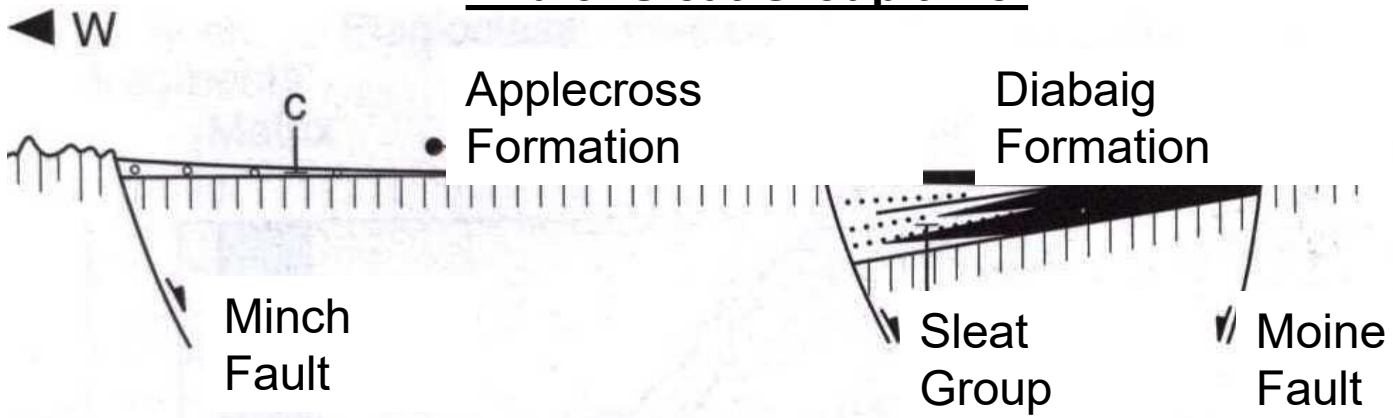
The Torridon Group - longitudinal profile



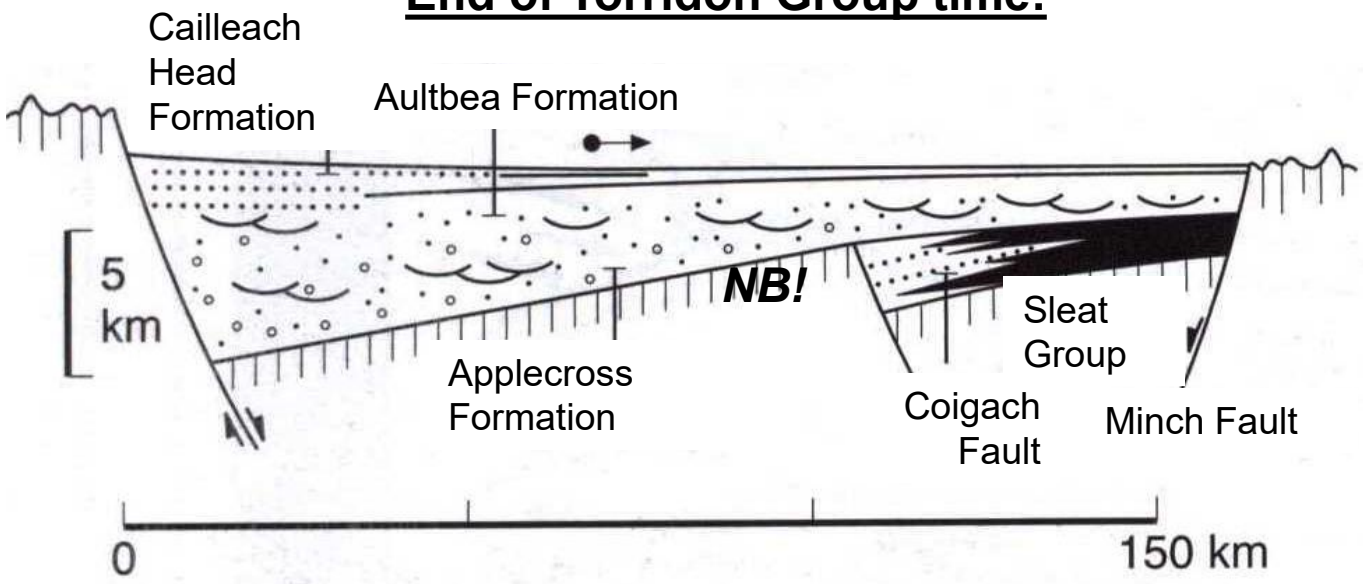
Transverse profile - Sleat and Torridon Groups

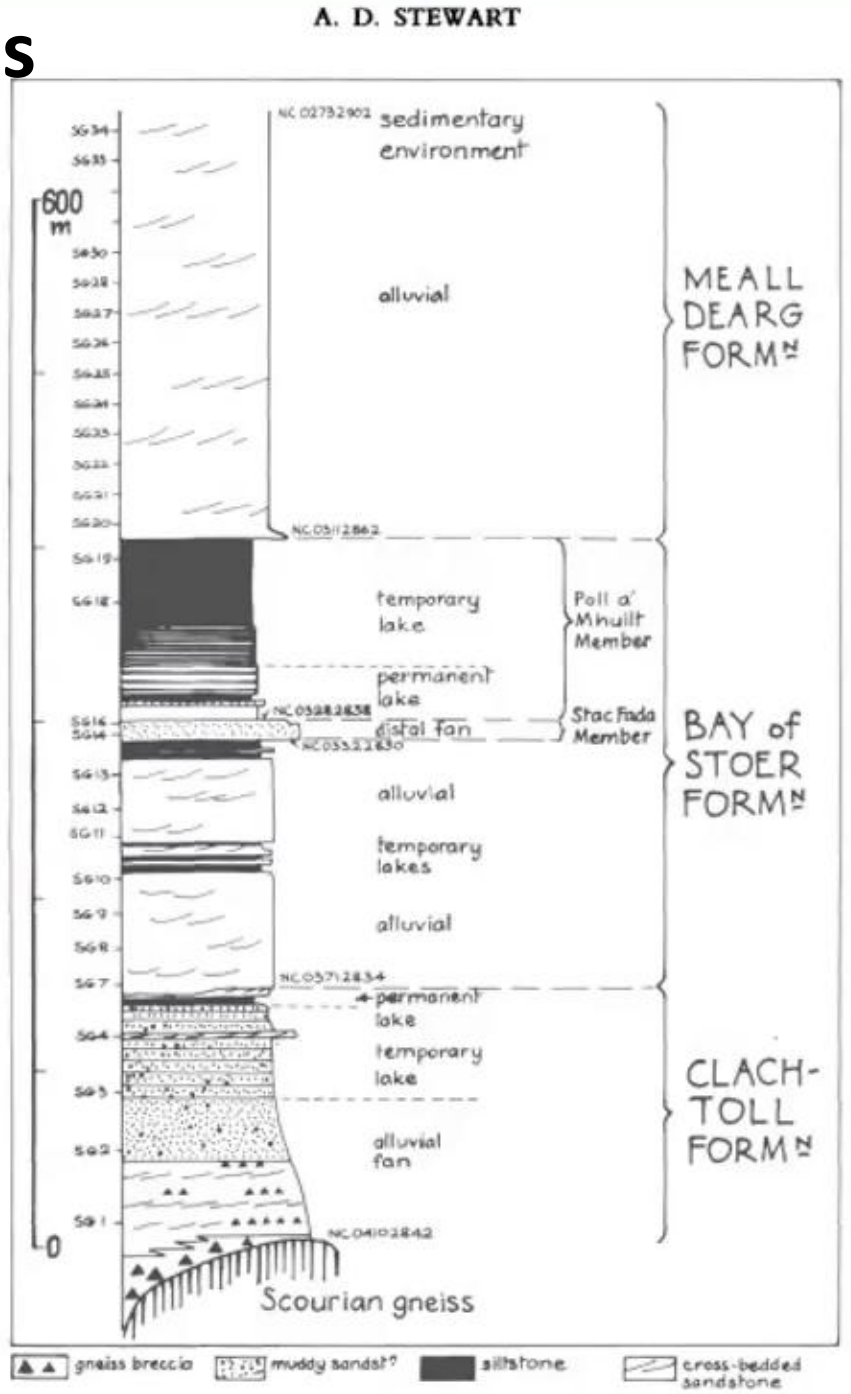
End of Sleat Group time:



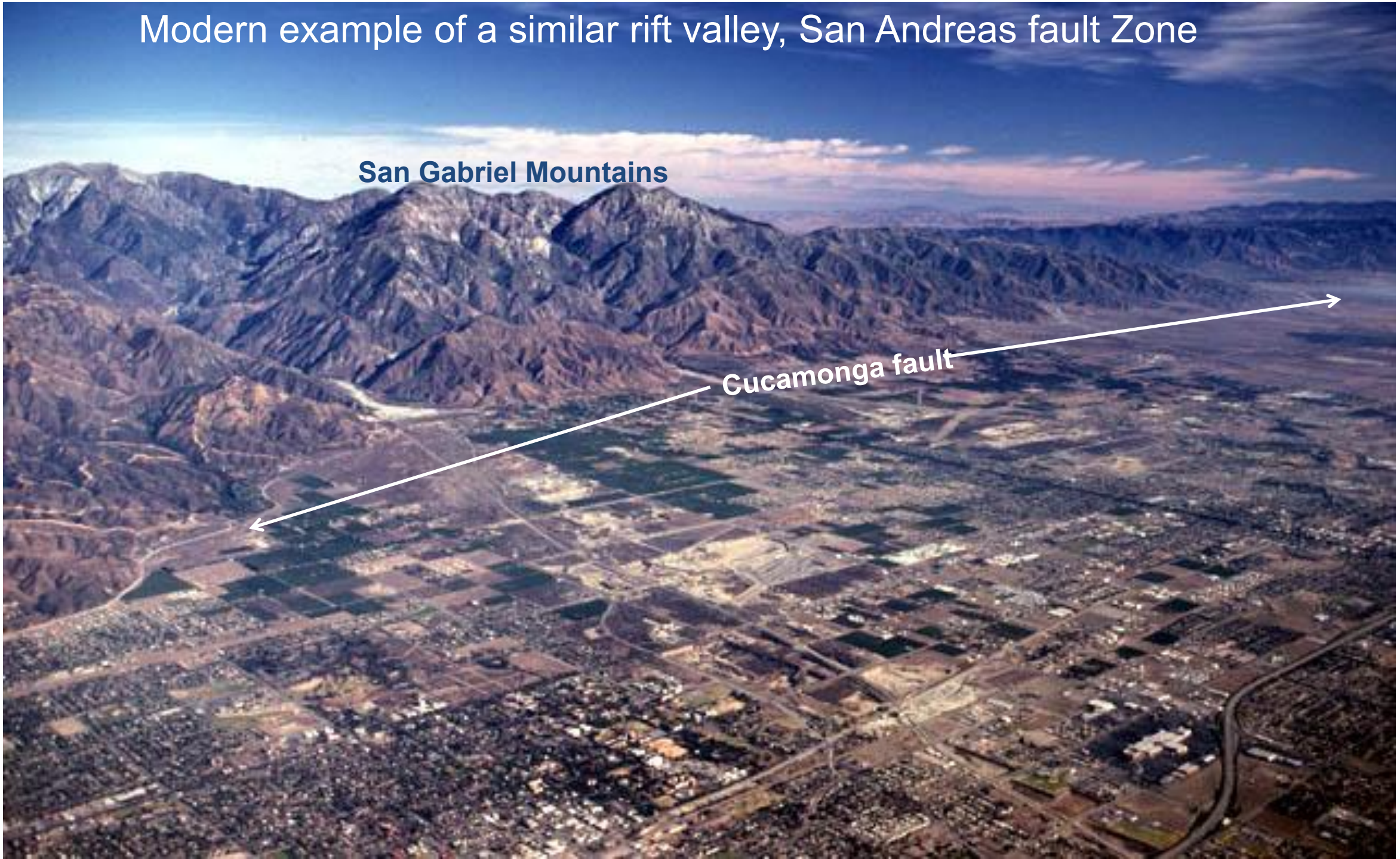
Profile across Torridonian at latitude of Skye

End of Torridon Group time:





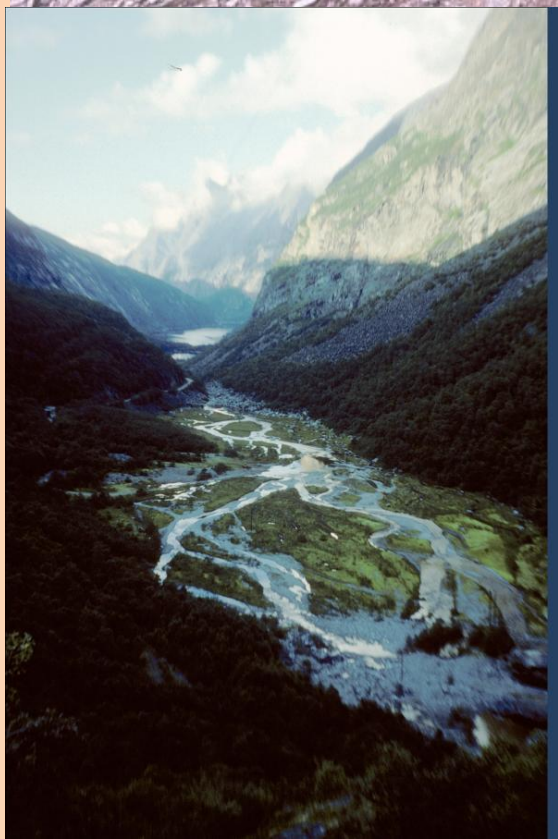
Modern example of a similar rift valley, San Andreas fault Zone



Diabaig Formation

The basal formation of the Torridon Group, exposed on Raasay and around Loch Torridon:

- Breccias infilling the lower parts of the palaeovalleys in the basement landscape as fan deposits (scree slopes and stream fans) along the valley sides
- Tabular sandstones – finer material beyond the scree slopes
- Grey shales laid down in ephemeral fresh water lakes in the valley centres
- Transport distances short for most deposits, but at least one major river depositing thick cobble conglomerates near Inverpolly



Fan and scree deposits on valley flanks, Norway.

Lake in distance will one day be filled by sediment, forming a grey shale

Applecross Formation

- 2 – 3 Km thick
- Coarse red sandstones, with pebbles
- Finer sandstones towards the top
- Much soft-sediment deformation
- Fossil remains of a microscopic lake flora in thin grey shales in between the finer sandstones (but no evidence of life on land).

Aultbea Formation

- 1 – 2 km thick
- Finer red sandstones, without pebbles
- Even more soft-sediment deformation
- Interpreted as braided river sand deposits – sand bars in long rivers, with channels 1 - 3 m deep, bearing sediments from erosion of the Grenville Mountains
- Semi-arid environment, but without vegetation, so rapid run-off in flood events

Cailleach Head

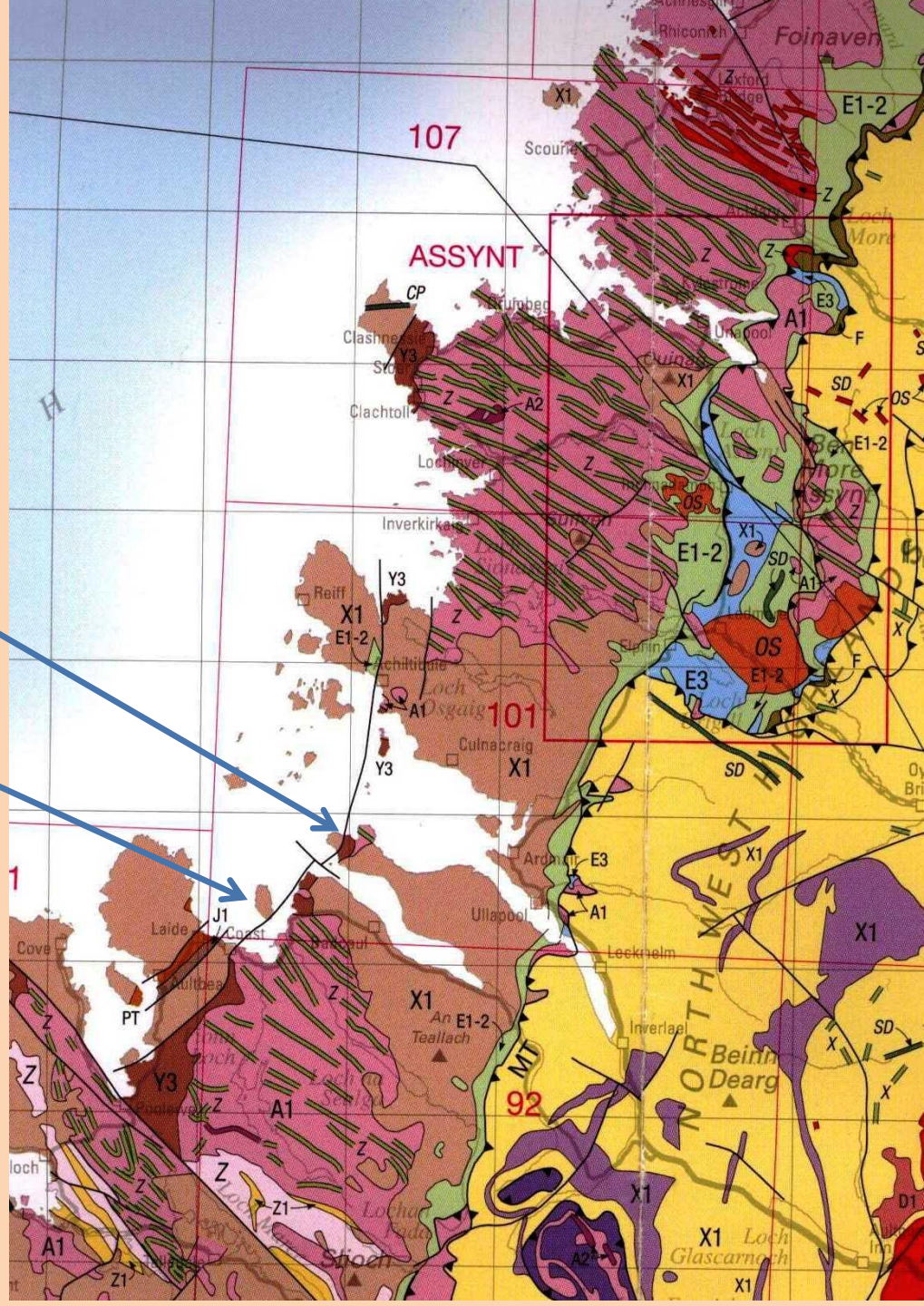
Cailleach Head Formation

- The topmost formation of the Torridon Group
- Limited exposures – Cailleach Head, Scoraig and Gruinard Island
- Cyclical deposition sequences known as *cyclothems,* each one about 22m thick in this usual sequence:

Cross-bedded non-micaceous sandstone
Cross-bedded very micaceous sandstone
Tabular red sandstones, with wave ripples on top
Laminated dark grey shales, often with desiccation cracks on top surface

All laid on a planar erosion surface

Interpreted as progradation of deltas into a freshwater lake, around 5-6 m deep.



The End of the Torridonian Era? Not quite!

- By about 770 Ma BP, rifting in the Torridonian graben has ended.
- 'Scotland' is now around the Equator
- The Torridonian rocks remain relatively unaffected except by weathering and erosion until present day
- Since than no metamorphism, just a gentle tilt!
- Oh, and by the way, the oxygen content of the atmosphere has risen fast, possibly now over 10%, wonder why?

Some more questions:

- Just what is the nature of the Minch Fault – how did it begin?
- Why have the Torridonian rocks suffered so little deformation in 1000 million years, yet next door the North Highland Terrane has been severely folded and crushed?
- What happened to all the sediments produced by over 200 Ma of continental erosion?
- Many more loose ends!
- And we have yet to cover some significant Torridonian events.

So when in 544 Ma, these rocks are submerged beneath the sea, a highly eroded surface is ready to be buried by new sediments. The Cambrian period has then begun! But we have much to explore before we get to that stage. Next time: Tuesday 3rd March, **Events of the Torridonian**.