

Revising the story in the rocks of Scotland from the bottom up!



4.5 Ga: Early Earth



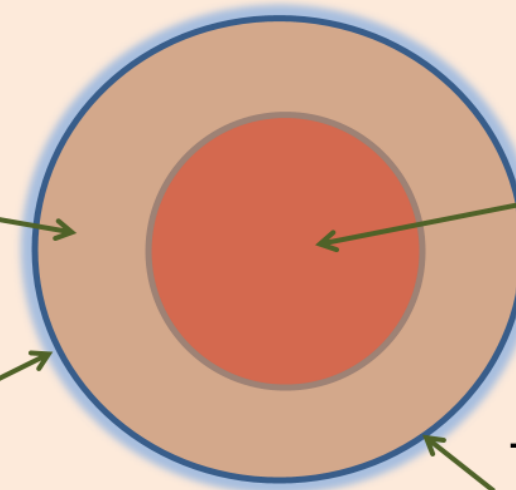
Formed by the gravitational attraction of cold interplanetary gas and dust into a single spherical ball.

The released gravitation potential energy transfers to the kinetic energy we call thermal energy > molten ball.

This begins the Hadean era which lasts 536 million years

Silicate-rich
outer shell –
essentially
basaltic
composition

Primary
atmosphere



Iron-nickel
alloy core

Thin fragile
crust

During the Hadean Era the Earth's structure gradually develops

- Radiation into space → cooling
- Atmosphere → cooling by convection
- Water vapour condensing... → primitive oceans?
- Molten mixtures are immiscible and separate by density
- Over time crust thickens from the base → early cratons
- Weathering and erosion start → surface rock cycle starts

Granitic compositions are less dense
> come to the surface

Basaltic compositions are less dense
> form a middle layer

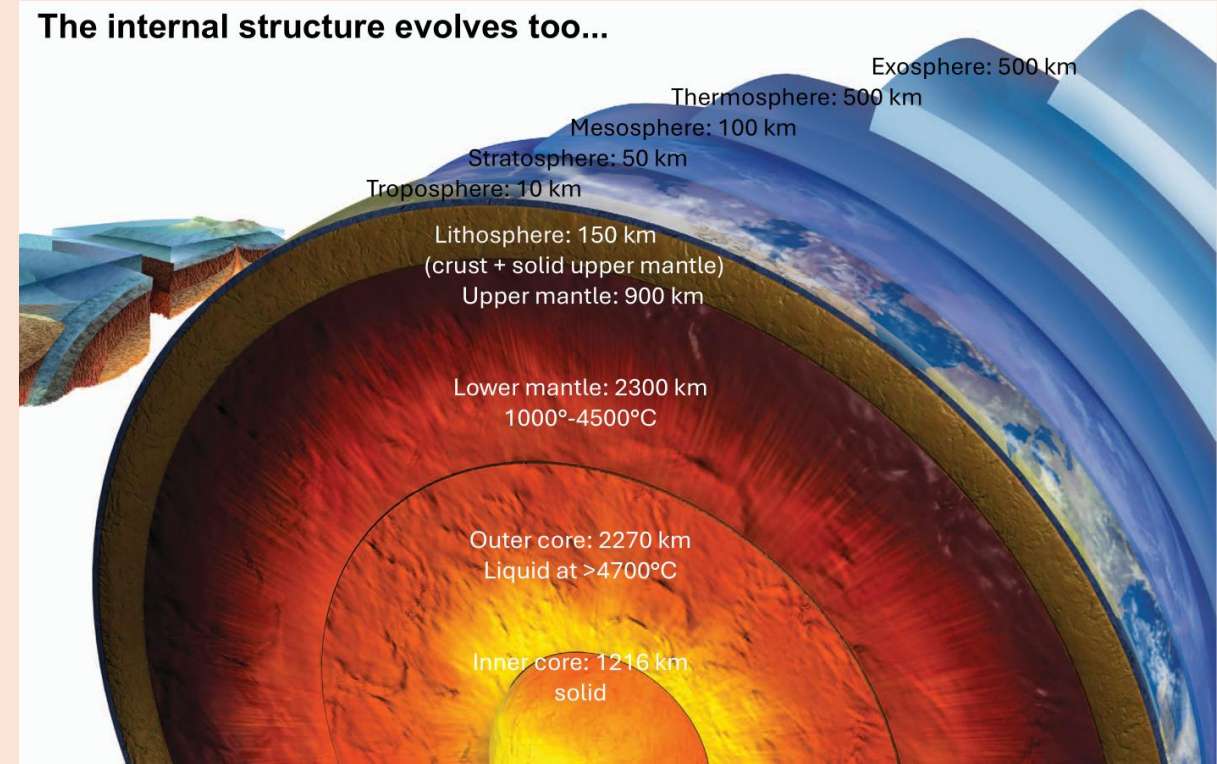
Metallic mixtures are very dense
> sink to form the core

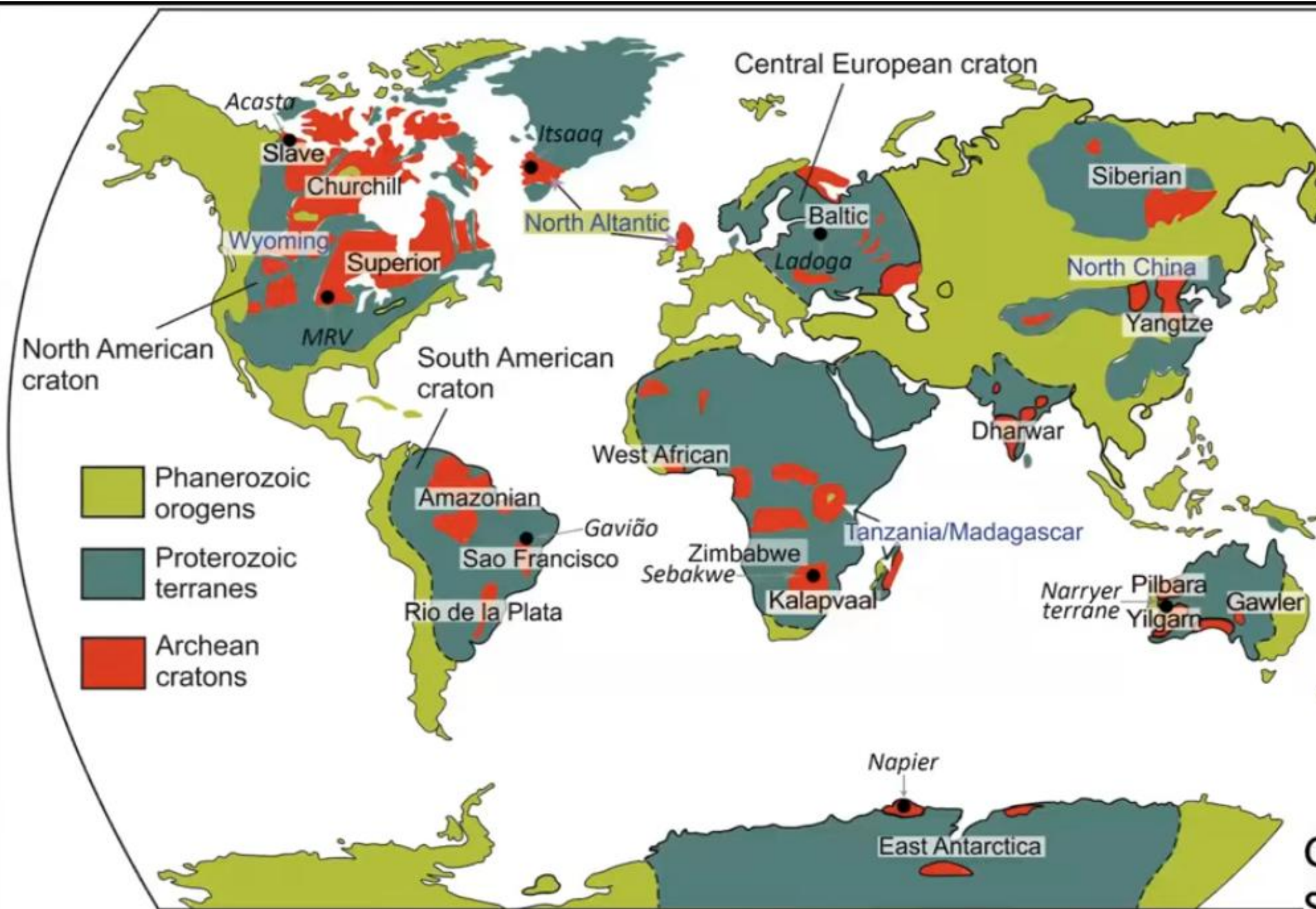
At surface mainly only a crystalline rock cycle:

- molten material rises and solidifies,
- crust breaks up,
- re-melts,
- recycled,
- altered at depth
- ...repeat many times

Below the crust the molten mantle continues to convect.

The internal structure evolves too...





Most of the earliest cratons are re-worked and grow over the next billion+ years.

But the cratons are still there!

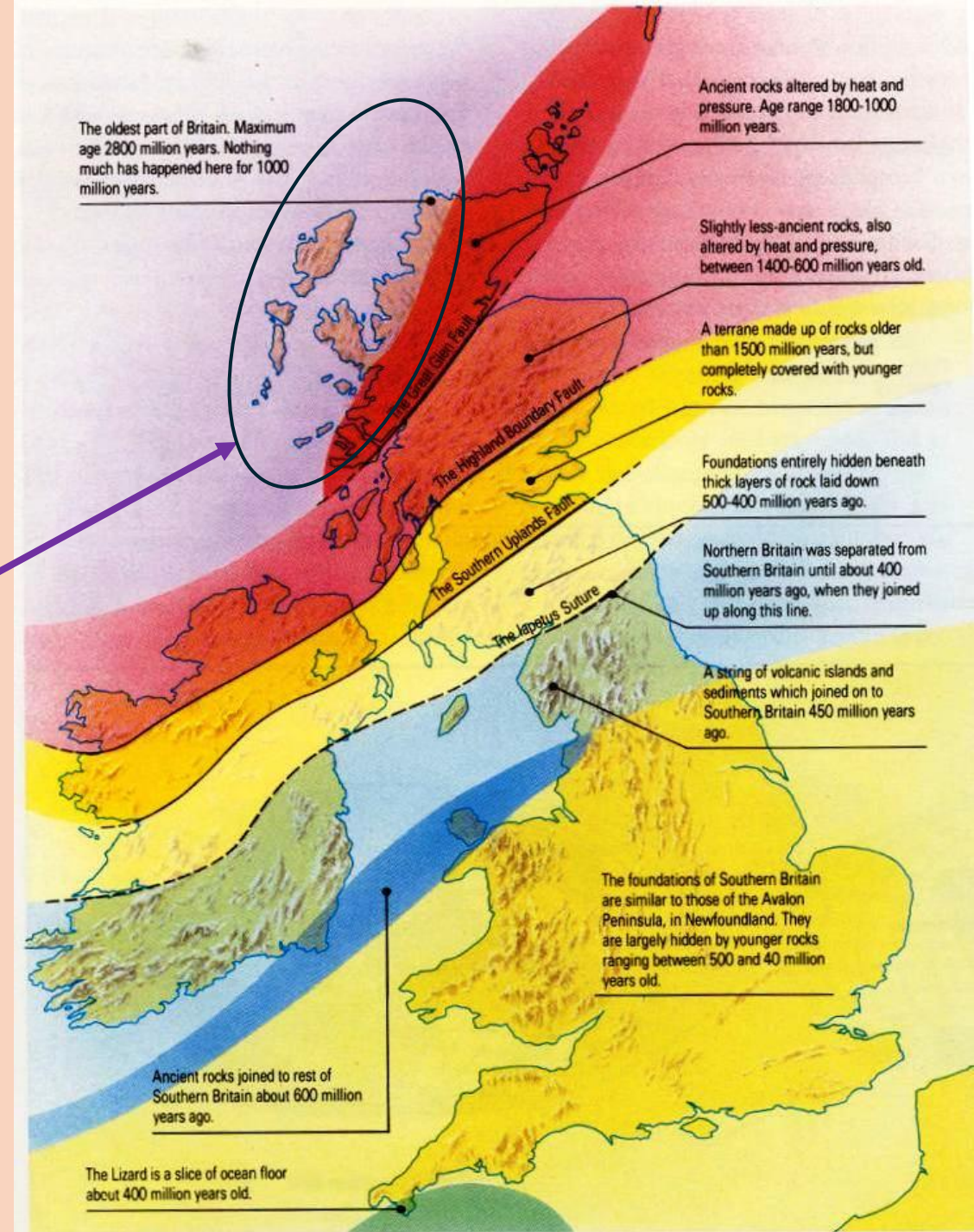
Groves and Santosh, 2021

Terrane map of Great Britain

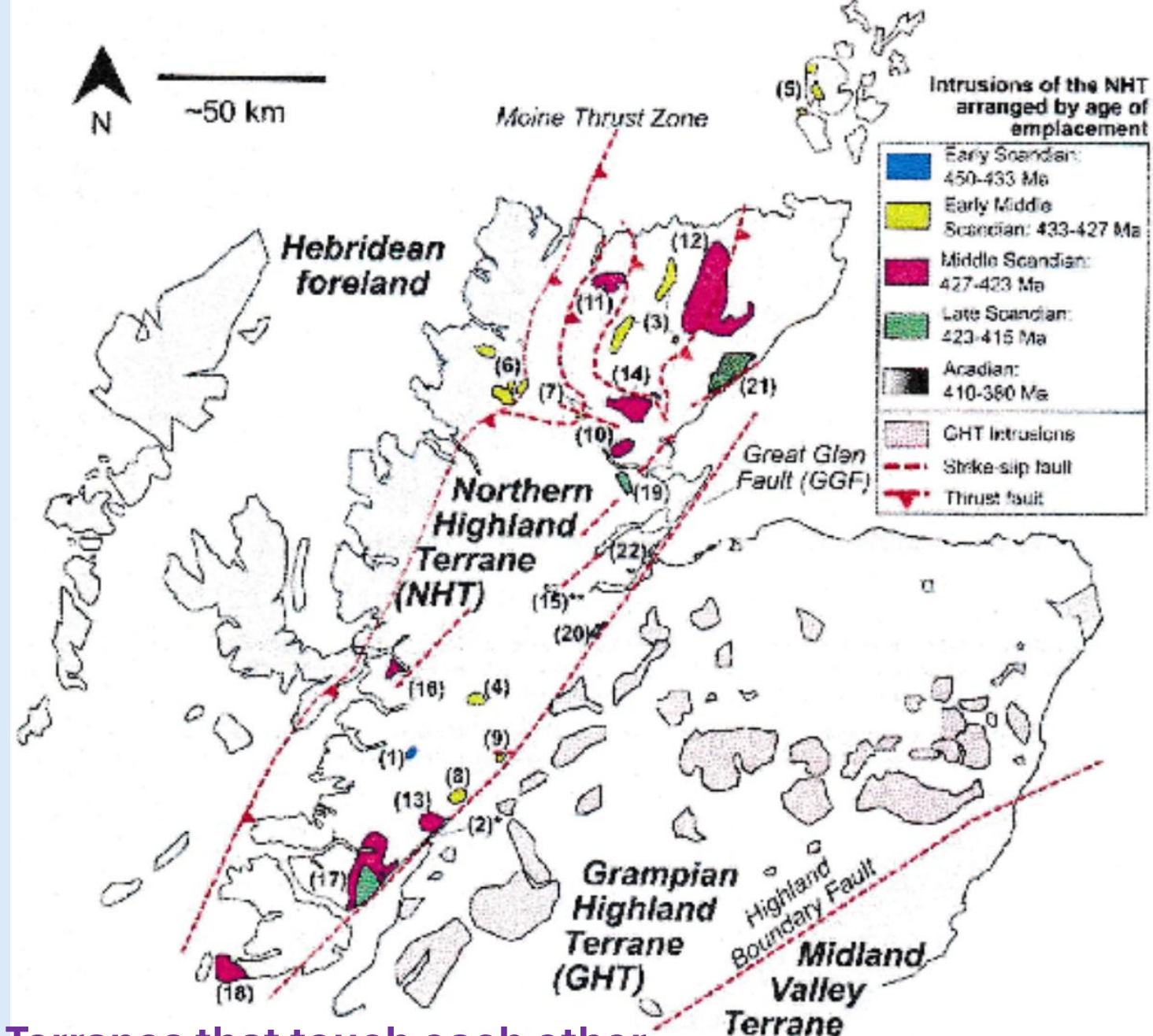
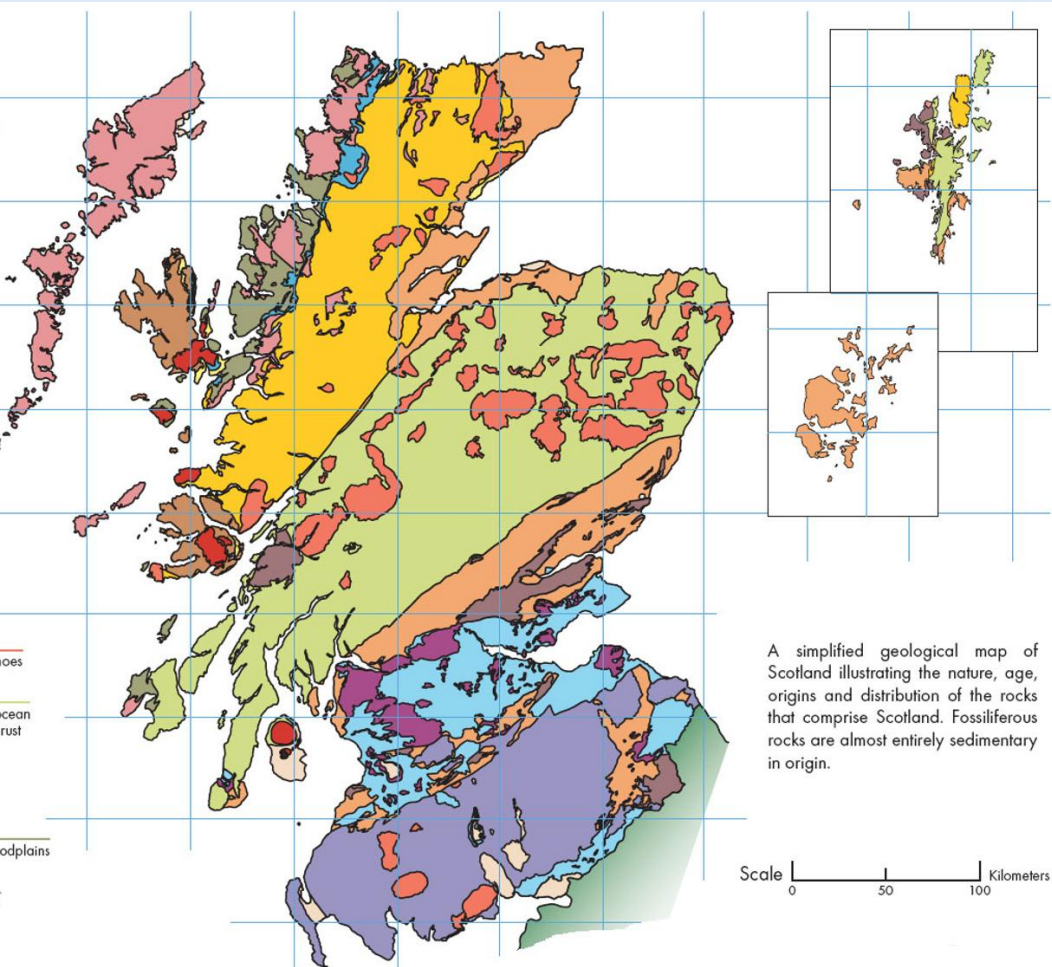
The present-day British Isles is a complex assemblage of many terranes!

Which is what makes Britain so interesting geologically!

And pieces of at least one **craton** can be seen in one terrane of Scotland – the Hebridean Terrane of North West Scotland.



The Geology of Scotland in maps of many colours



Terranes that touch each other are separated by major faults and thrusts.

Plate Tectonics

Over millions of years, cratons accumulate more material on and around them, forming continental crust surrounded by attached oceanic crust.

These form the **plates** of the Earth's lithosphere, which are moved by the friction of mantle convection below and by the 'slab pull' of subducting plate edges as plates collide.

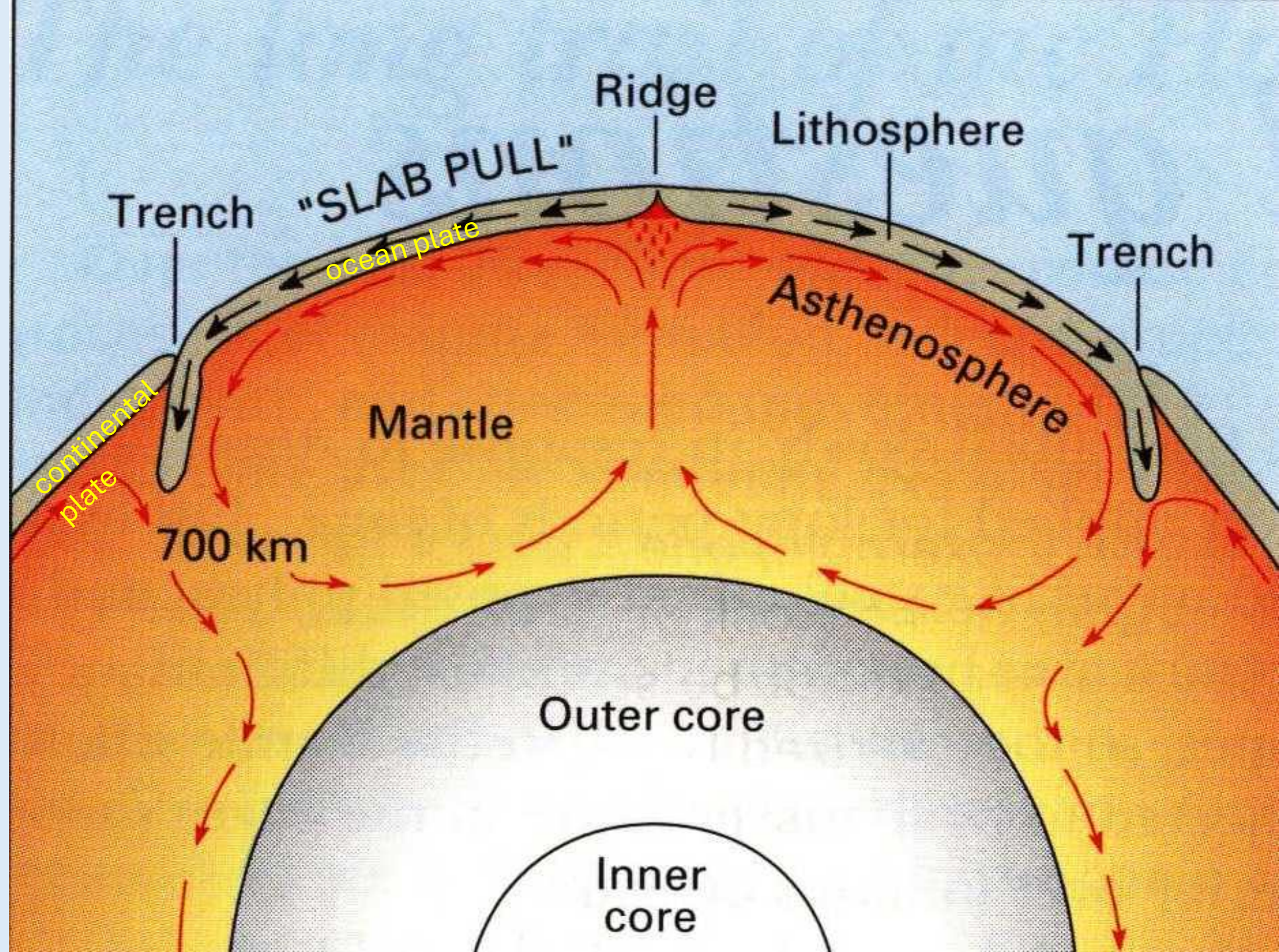


Plate Tectonics

As they move around the globe, 'granitic' continental plates collide with 'basaltic' ocean plates.

Oceanic crust is more dense than continental crust, so normally subducts below continental crust.

New oceanic crust is continually formed at mid-ocean ridges as mantle convection pulls oceanic crust apart and new molten 'basaltic' material wells up from the mantle below.

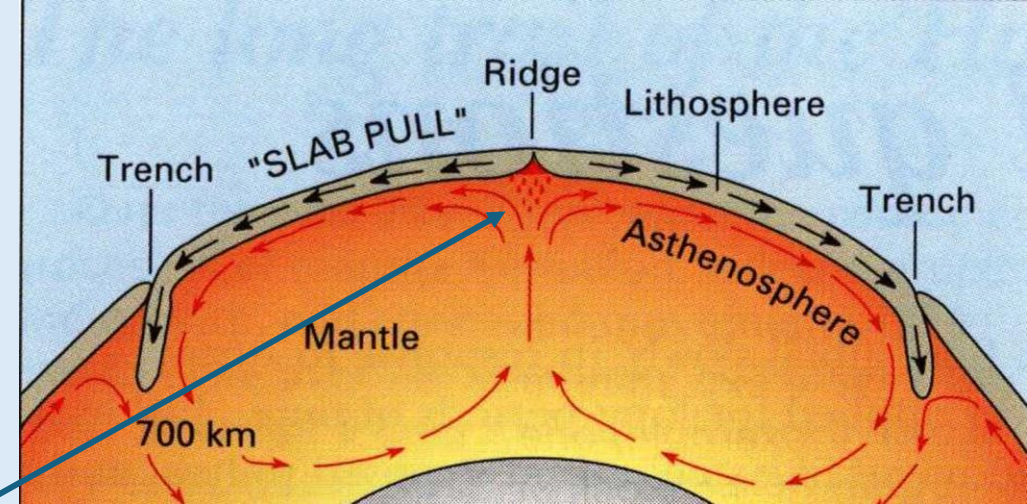
So oceanic plates are continually recycled, while continental plates receive new material underneath from the recycling process and move on until...

...sooner or later two continental plates collide and weld together to form a larger continental mass.

Every so often this results in several continental plates becoming welded into a single supercontinent.

Supercontinents are inherently unstable and break up after 100-200 million years, and the cycle starts all over again.

This cycle of supercontinent formation, breakup, and dispersal, followed by convergence and patching, occurs on average every 450 million years or so and is called the **Wilson Cycle**.

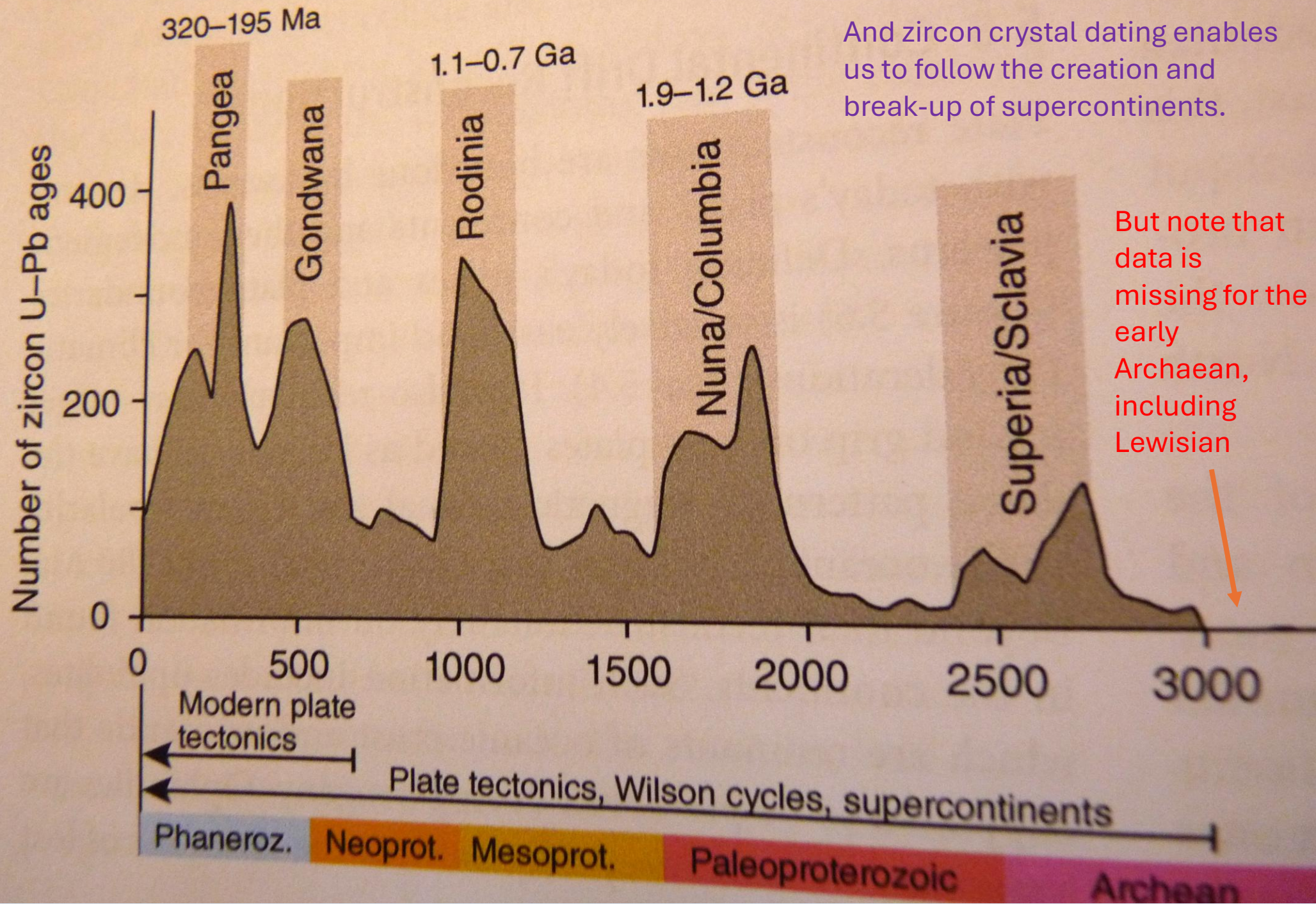


So what are the Earth's oldest known rocks?
(Dated from zircon inclusions)

Nuvvuagittuq Greenstone belt,
(Northern Quebec estimated at 4.16 Ga)

Acasta gneiss
(NW Canada, 4.03 Ga, igneous origin)

Isua gneiss
(Greenland, 3.9 Ga, sedimentary origin)



And zircon crystal dating enables us to follow the creation and break-up of supercontinents.

Let's bear plate tectonics in mind as we consider

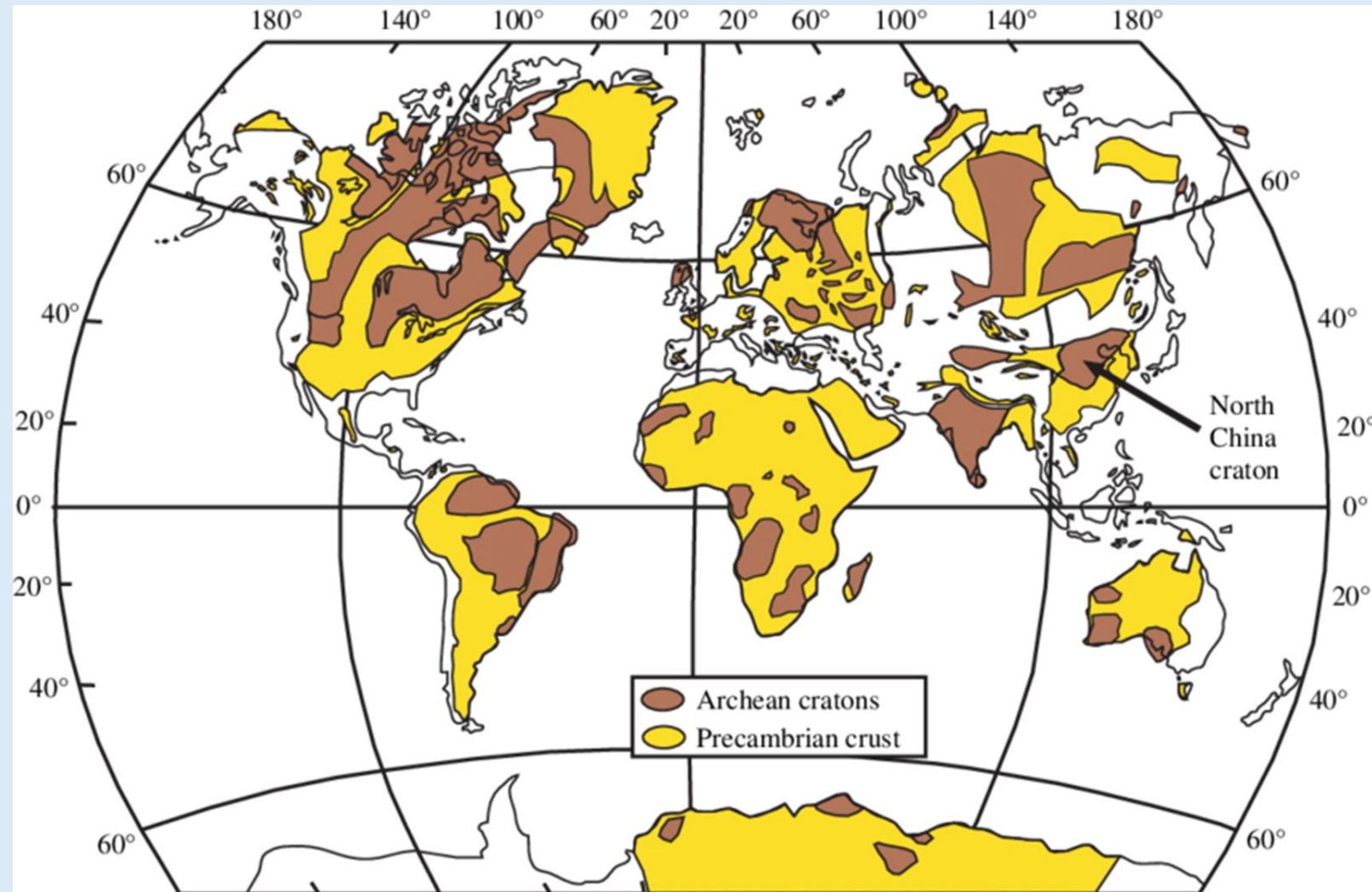
Scotland's Basement

The basement at the surface is late **Archaean**: in NW Highlands and Outer Hebrides, 2.8-3.1 Ga.

But what lies below? No sign of anything older, but these rocks – gneisses – have been formed by metamorphism from earlier granitic rocks > **granulite gneiss**.

These Archaean rocks probably lie directly on lithospheric upper mantle rocks, separated by the **Moho discontinuity**.

The Archaean cratons of the globe



Parental Supercratons - Sclavia and Superia

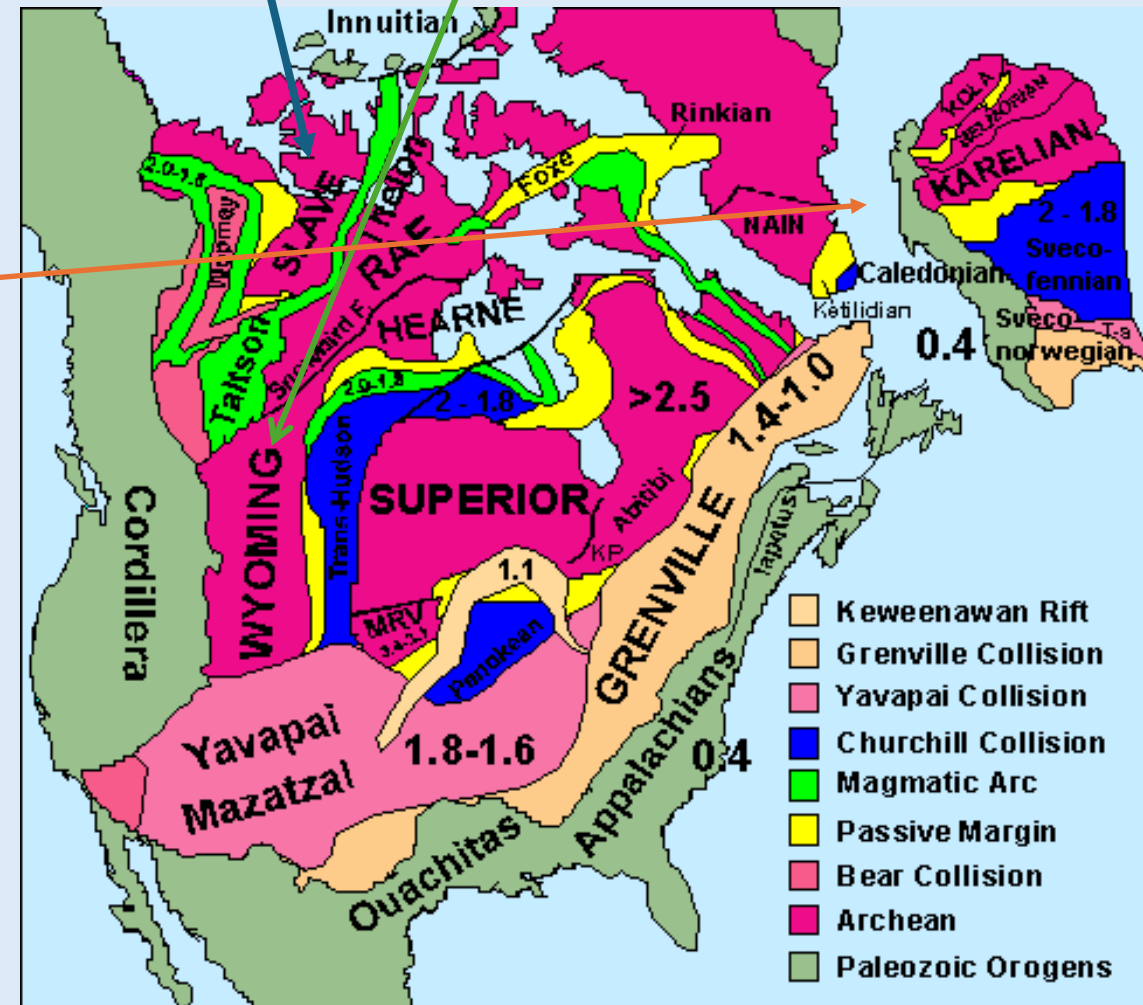
Sclavia has been proposed as the parental supercraton to the Slave and Wyoming cratons in N America, the Dharwar craton in S India, and the Zimbabwe craton.

While **Superia**, 2.7 Ga, is composed of several pre-existing craton terranes, Quebec, Ontario, Manitoba, and northern Minnesota (core of Canadian Shield).

But no sign of the Hebridean Terrane there, though note Archaean Greenland and Karelia – just maybe the wee Scottish Lewisian was in there somewhere?

Between planet formation (4.5 Ga) and 3.0 Ga it has already become very complicated.

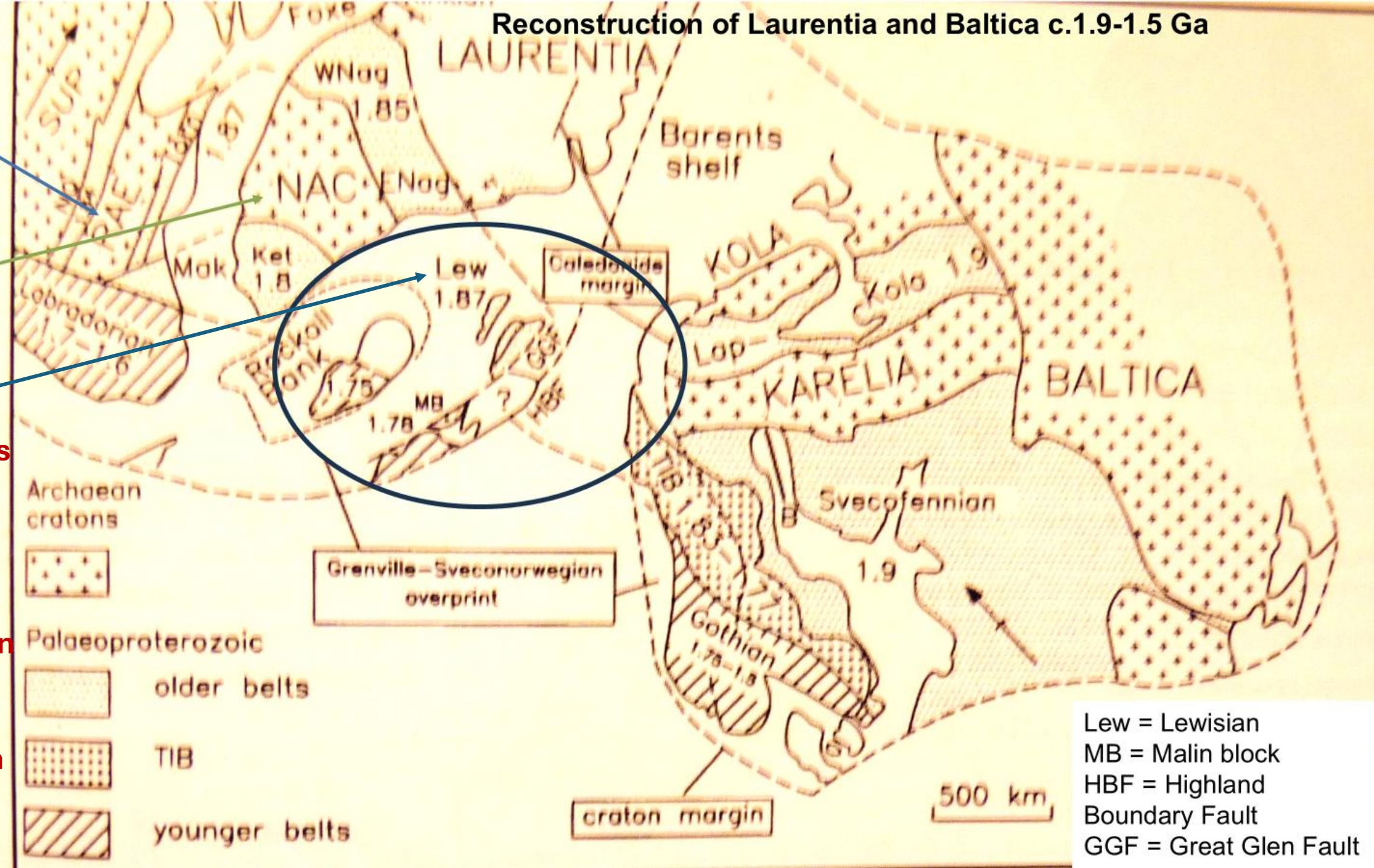
Or maybe much has been subducted back into the mantle. We may never know!



Reconstruction of Laurentia and Baltica c.1.9-1.5 Ga

Rae craton
North Atlantic craton
North-west Scotland

This shows some current ideas on the origin of Lewisian rocks of the Hebridean Terrane



Lew = Lewisian
MB = Malin block
HBF = Highland Boundary Fault
GGF = Great Glen Fault

The top of Scotland's basement

- Most of the early crust has long disappeared – subducted back into the mantle.
- Oceanic crust recycles very quickly – oldest at present is only 200 Ma
- So at the bottom of our Scottish rock pile, we are unlikely to find anything older than 4 Ga
- At the surface, the oldest we find in Scotland is ~2.9 - 3.1 Ga.
- So there may be rocks between 3 Ga and 4 Ga buried below, but probably little different in character to what we find at the surface.
- What do we find at the surface?





Dark amphibolite
dyke c.2.4 Ga cutting
original 2.9 Ga gneiss

original pale grey
gneiss 2.9 Ga

pink granite dyke
cutting both gneiss and
amphibolite 1.7 Ga

Note: immiscible mafic (basaltic) and granitic compositions

The Lewisian

- Oldest rocks in Europe, well-travelled, and much changed by the experiences!
- Almost all have been buried deep, typically 25-50 km down then back up again.
- Intense pressure and high temperature (650°C) cause physical and chemical changes – **metamorphism**.
- Not high enough to melt, which is why these rocks are still there – unlike any below that melted!
- All these highly metamorphosed Lewisian rocks are called **gneiss**
- Most gneisses were probably igneous rocks in origin – granites > grey – pink gneisses, and mafic (basaltic) gabbros > dark grey gneisses.
- Dates for Lewisian rocks indicate a major metamorphic event at about 2.5-2.7 Ga, altering rocks from about 3.0 Ga - probably already metamorphic.
- Oldest rocks in Outer Hebrides – 3.2-2.8 Ga, oldest rocks on mainland – c.3.0 Ga

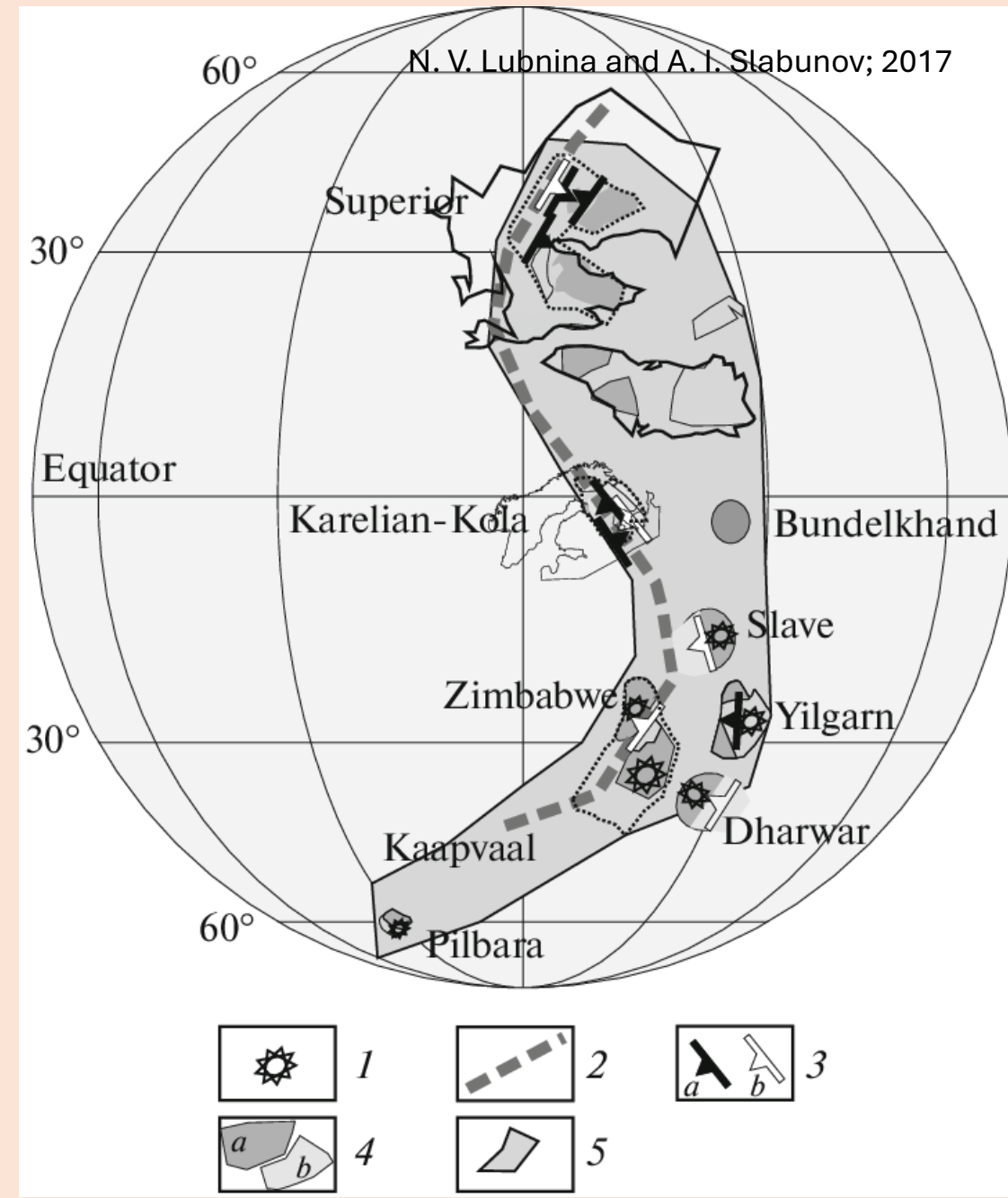
The earliest supercontinent? **Kenorland** - hypothesised to have formed c.2.72 Ga.

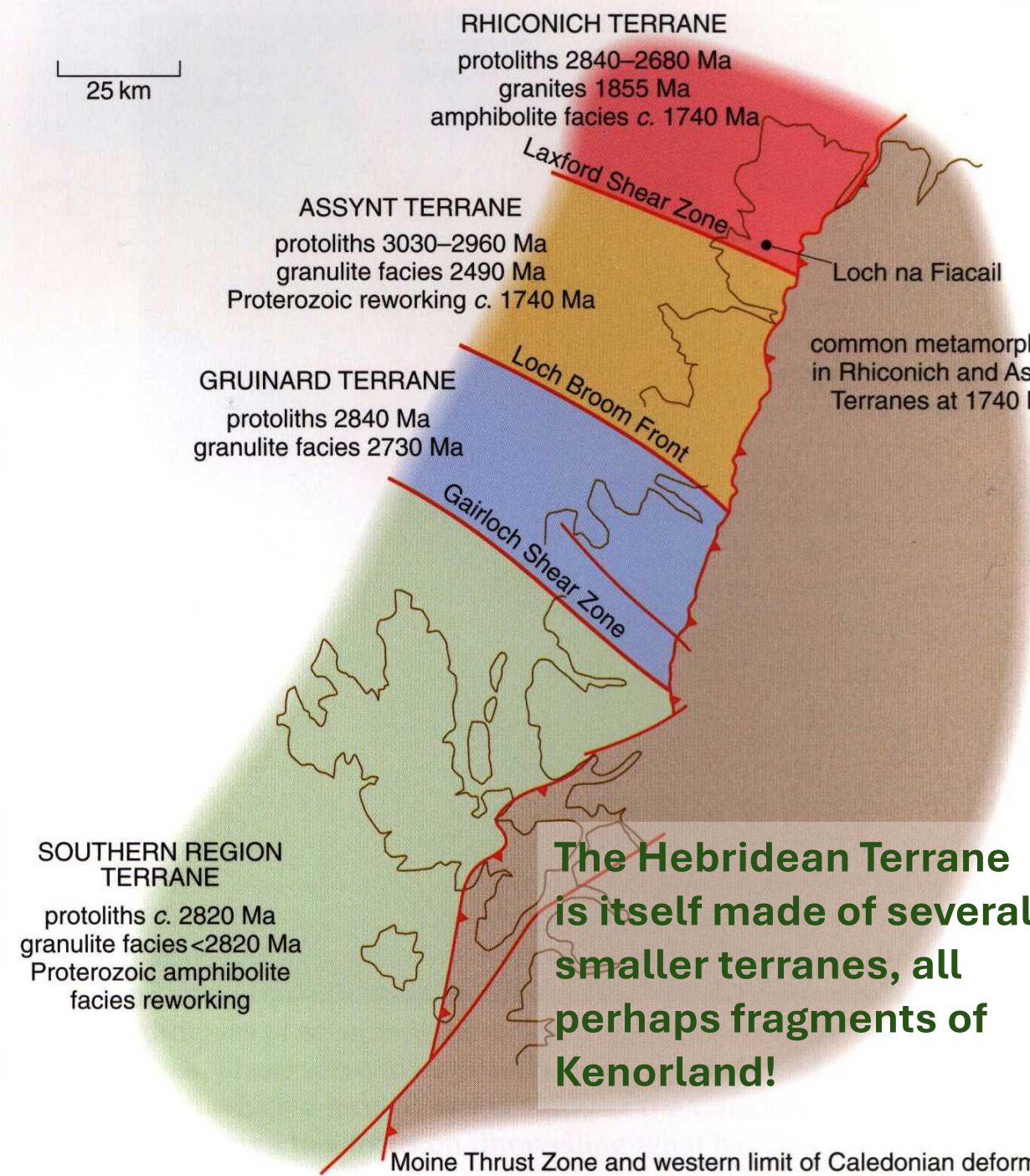
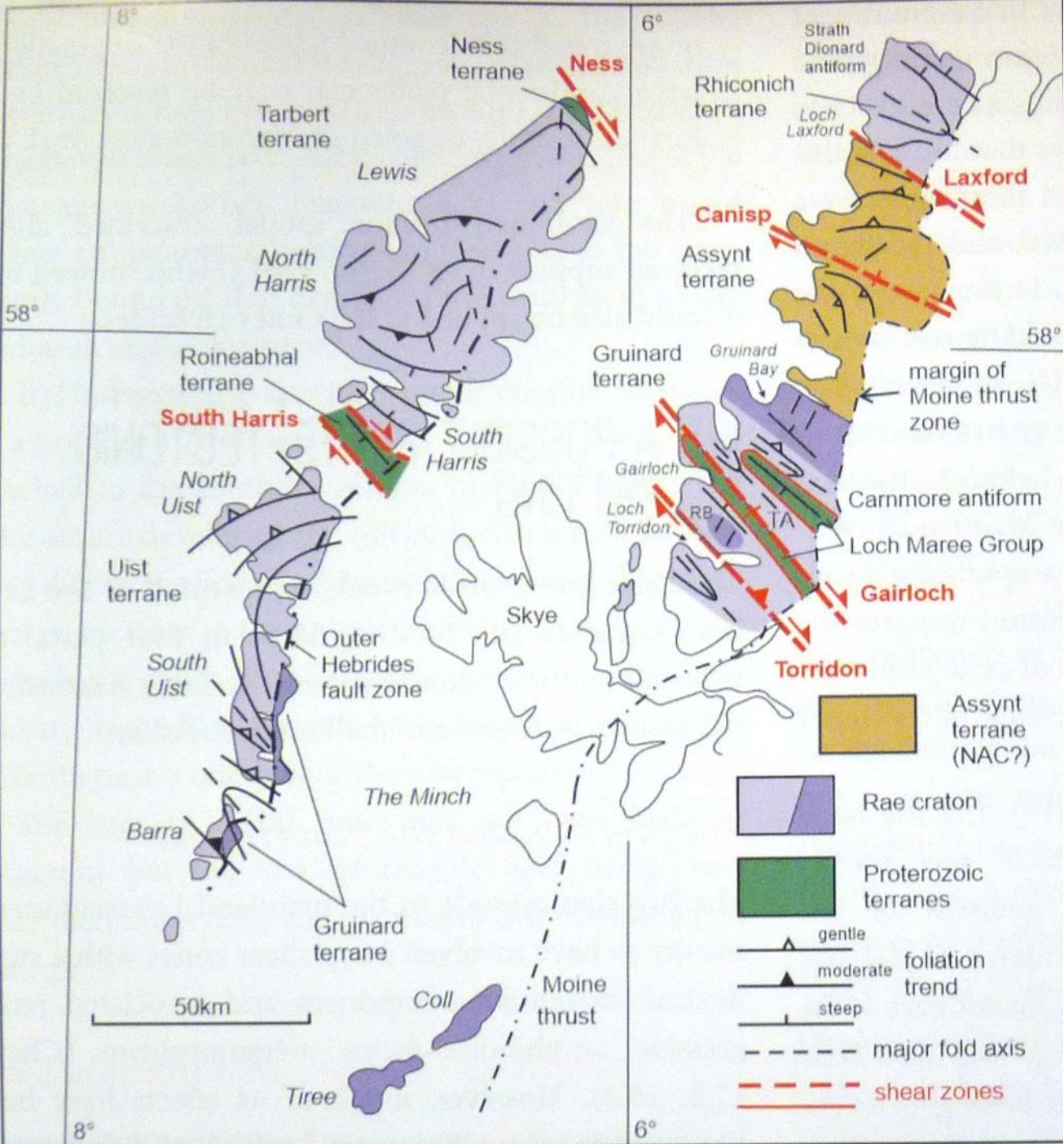
Formed from two or more earlier cratons that later formed Laurentia (including the Hebridean terrane), Baltica, Western Australia and Kalahari. The core, the Baltic/ Fennoscandian shield, traces its origins back to over 3.1 Ga.

Formed from the accretion of several smaller terranes, including the Hebridean – so was there an earlier supercontinent?

Rifted 2.48-2.10 Ga, leaving intruded mafic dykes and sedimentary rift basins on many continents.

Break-up contemporary with the Huronian glaciation (60 My duration, Snowball Earth type), 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.





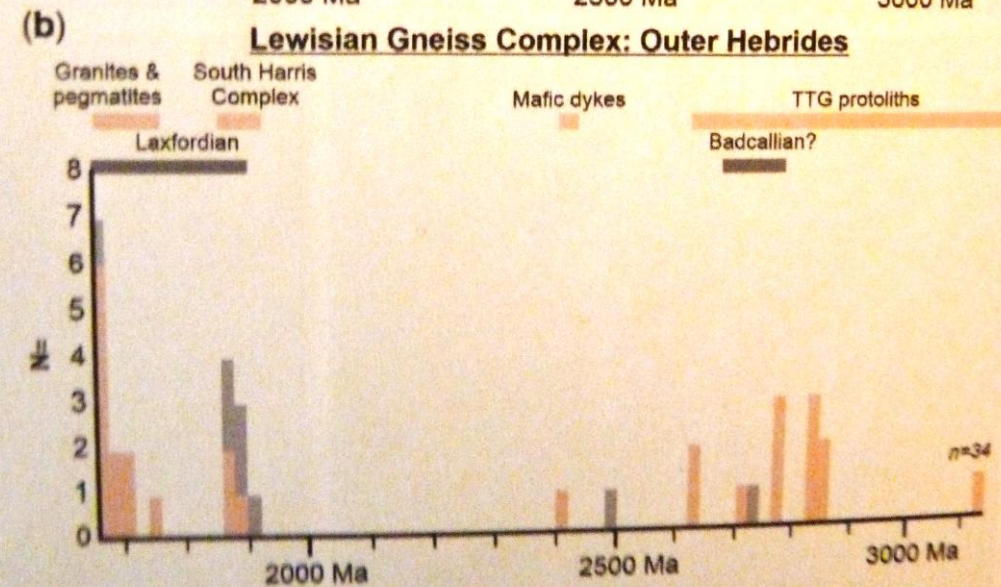
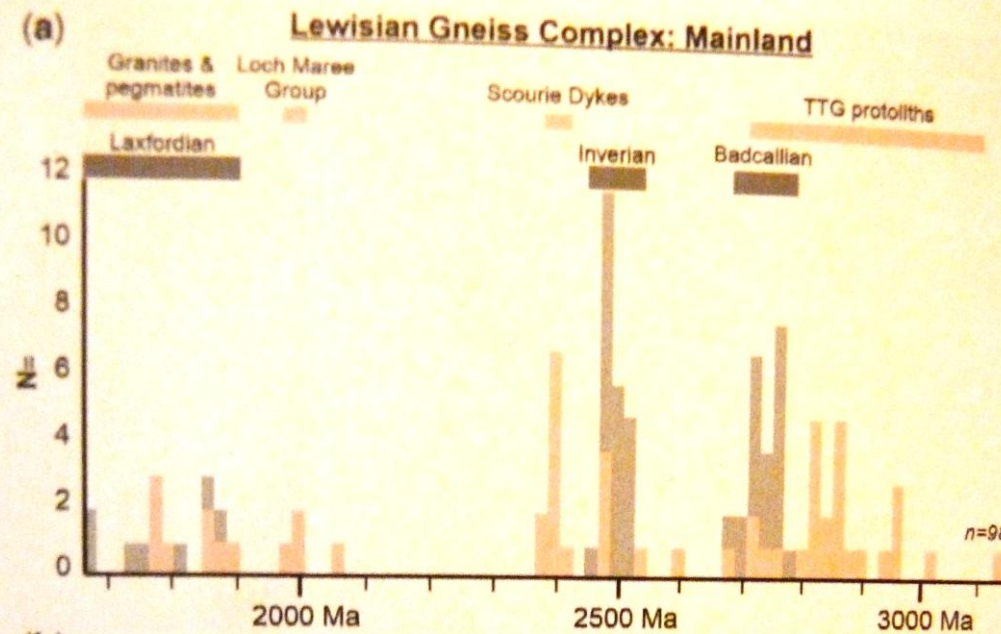
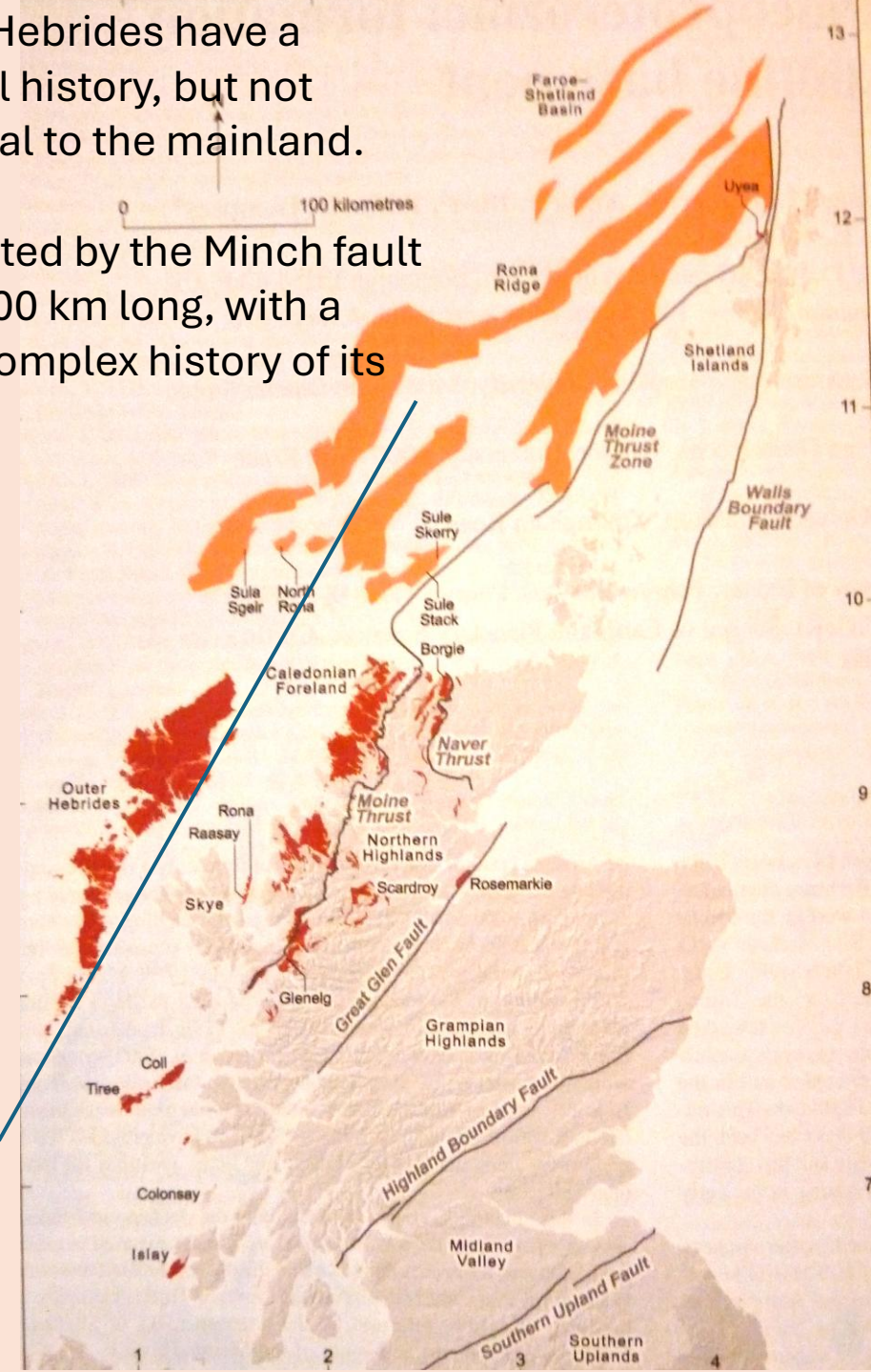


Fig. 3.5. Histogram compilation detailing the U-Pb zircon age data from samples from (a) the mainland and (b) the Outer Hebridean portions of the Lewisian Gneiss Complex. Pink indicates protolith ages, and grey indicates metamorphic ages. Interpreted ages are those of the ... detailed in the relevant text. Source: © George

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

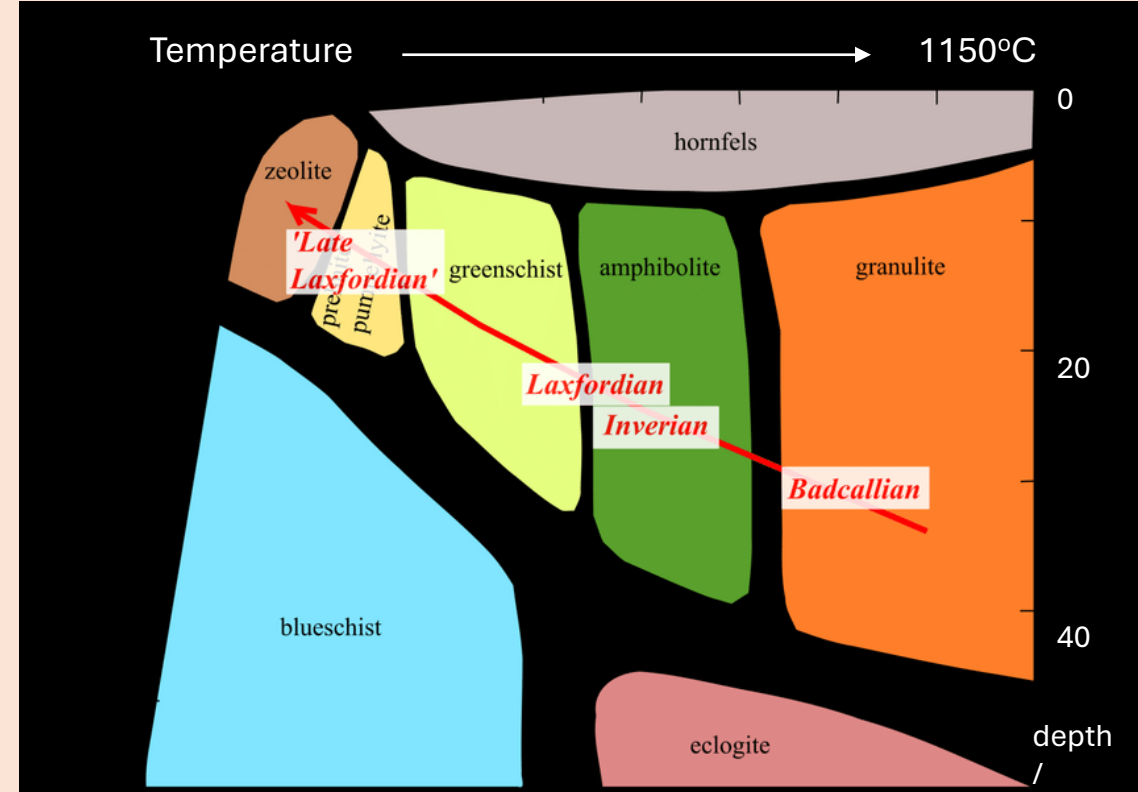
Separated by the Minch fault zone 200 km long, with a long, complex history of its own.



Minch fault

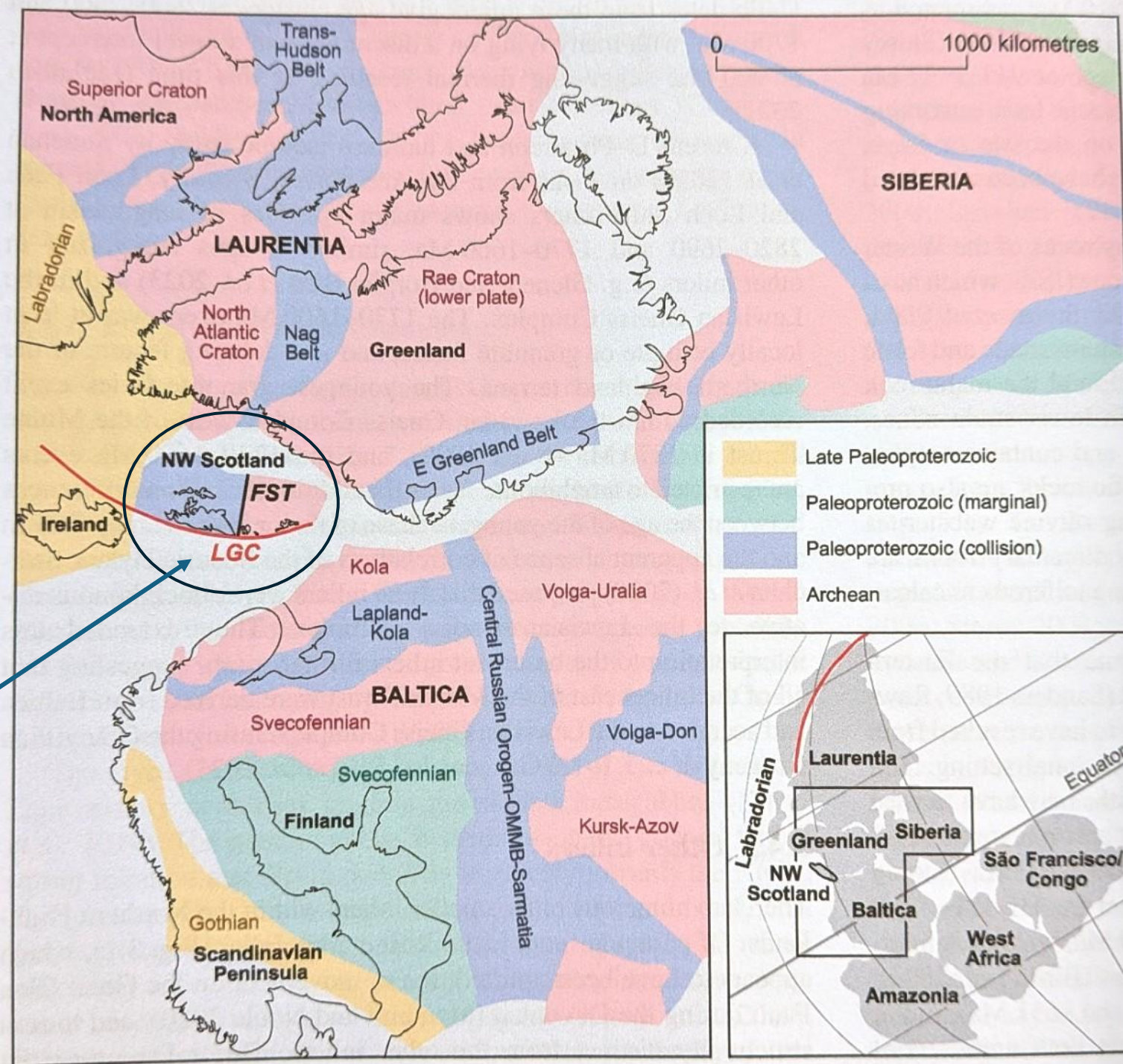
The Scourian Complex

- 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



The Scourian Complex

- Rock compositions correspond with the compositions of many other high grade Archaean terranes elsewhere in the world.
- Mostly banded granite-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 **from c.3.5 Ga or earlier?**
- A few rare metasediments.
- All much altered by further events in the following 1 billion years.

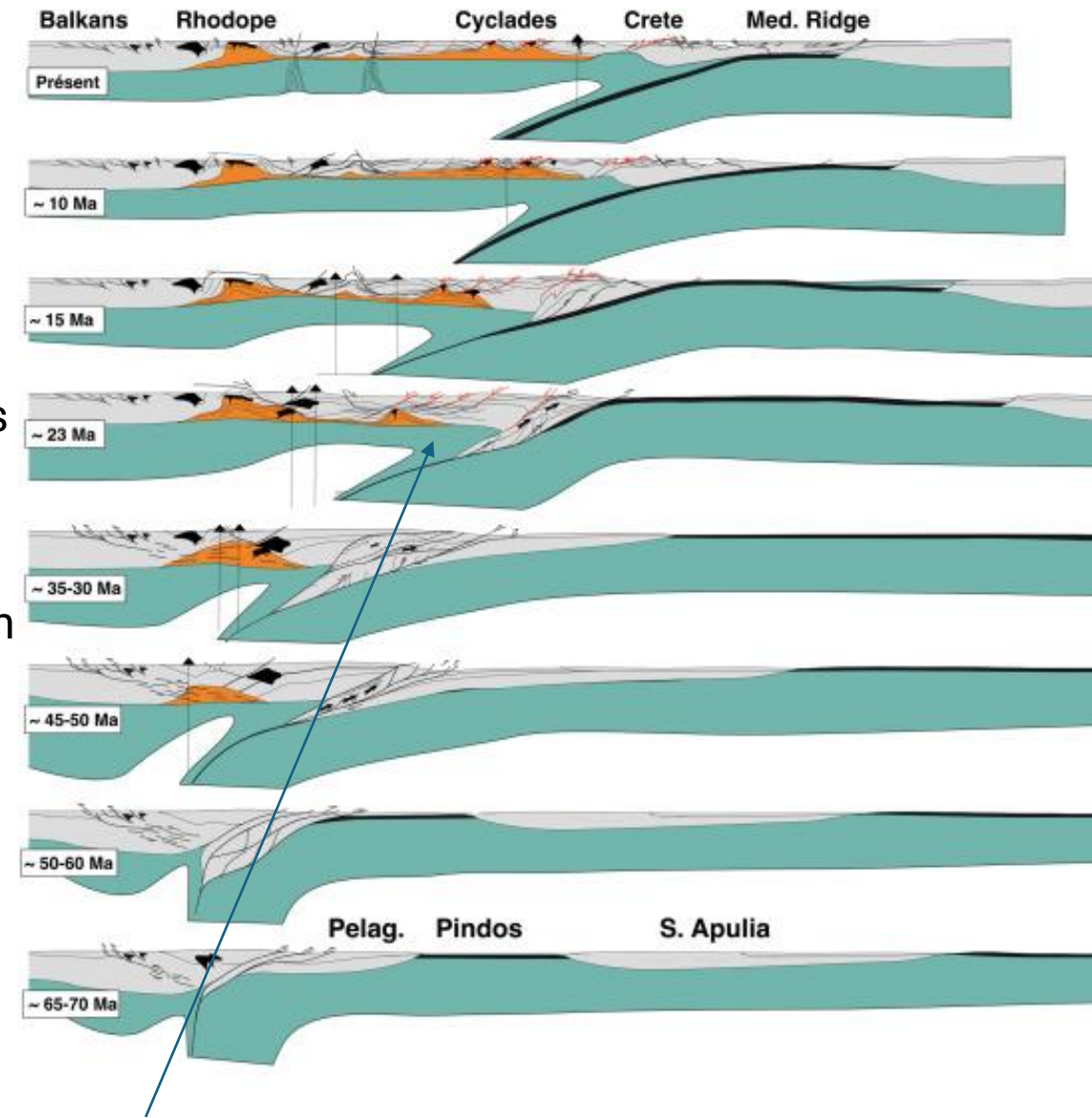


The Scourian Complex

Badcallian 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 result of the subduction stretching the continental crust.
- most abundant rock type of the dykes is quartz-dolerite.
- occurred over some 400 Ma, into the following Laxfordian

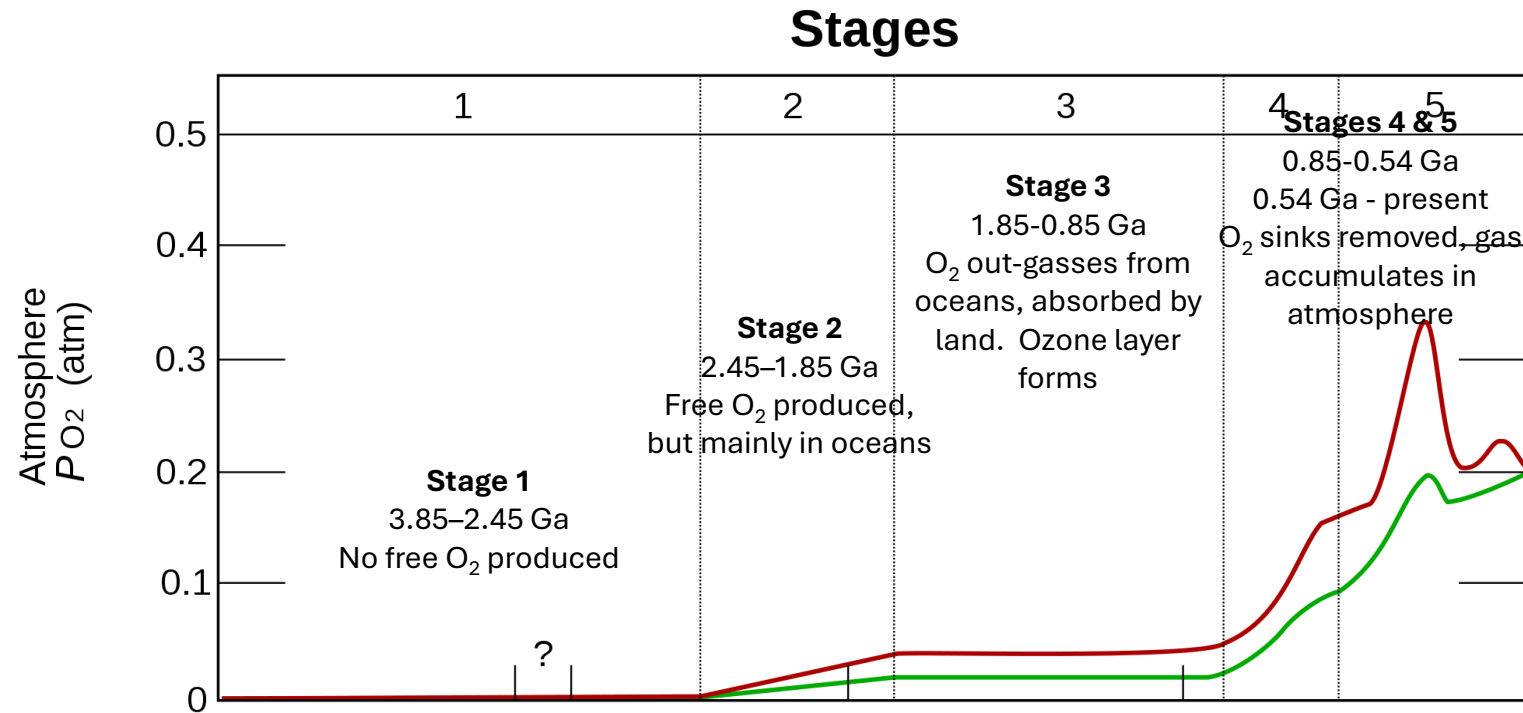


Present day equivalent subduction event causing extension.

From the Archaean into the Proterozoic - The Great Oxygenation Event! 2.4 – 2.0 Ga

which...

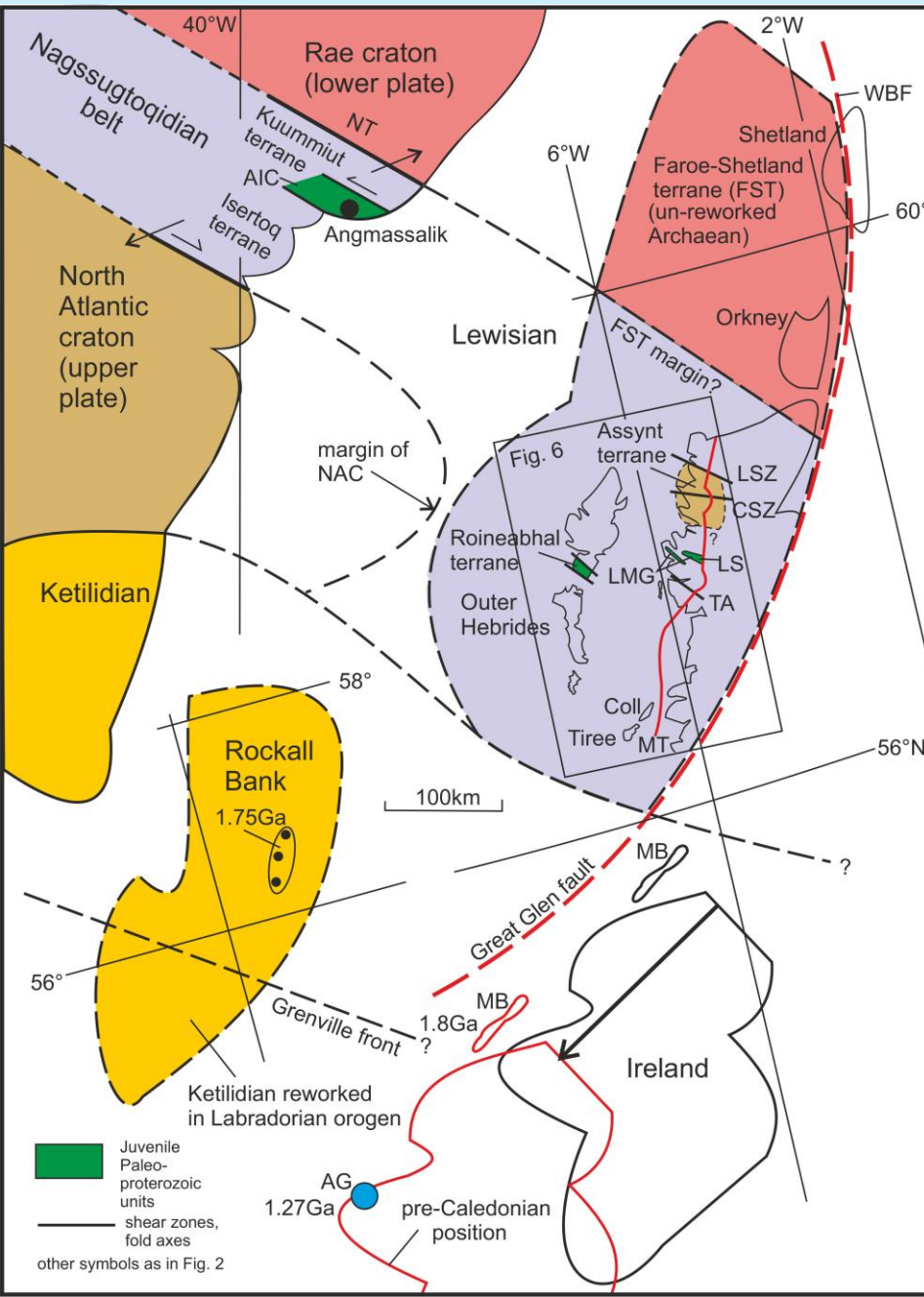
- was a disaster for the anaerobic life (cyanobacteria) that had produced the oxygen by photosynthesis!
- probably created the largest extinction event in Earth's history.
- removed atmospheric methane, triggering the Huronian glaciation, possibly the longest Snowball Earth episode ever.



Oxygen build-up in the Earth's atmosphere

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

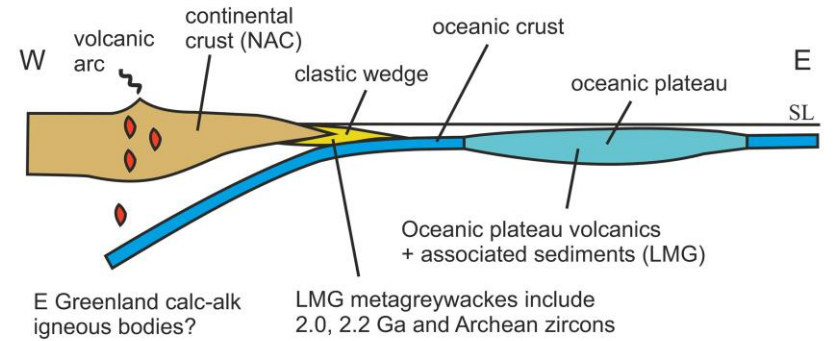
The Laxfordian Orogeny – 1.9-1.0 Ga



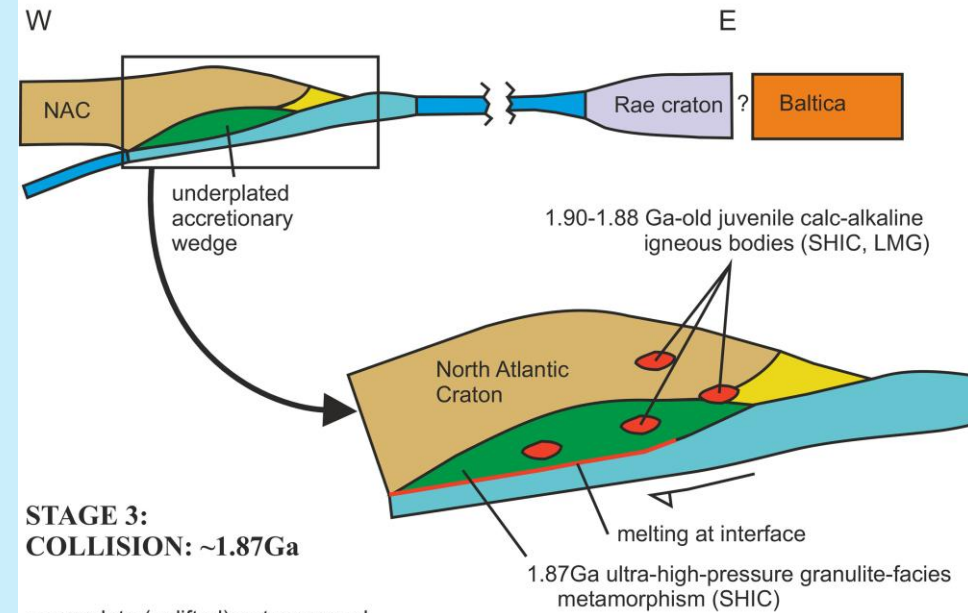
Related to the contemporary orogeny in the **Nagssugtoqidian belt in Greenland**, as the North Atlantic Craton collided with the Rae craton.

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

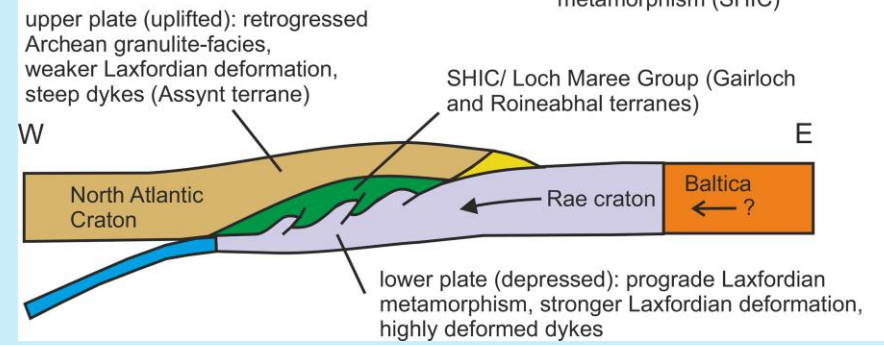
STAGE 1: SUBDUCTION: ~1.98Ga



STAGE 2: ACCRETION: ~1.90Ga



STAGE 3: COLLISION: ~1.87Ga

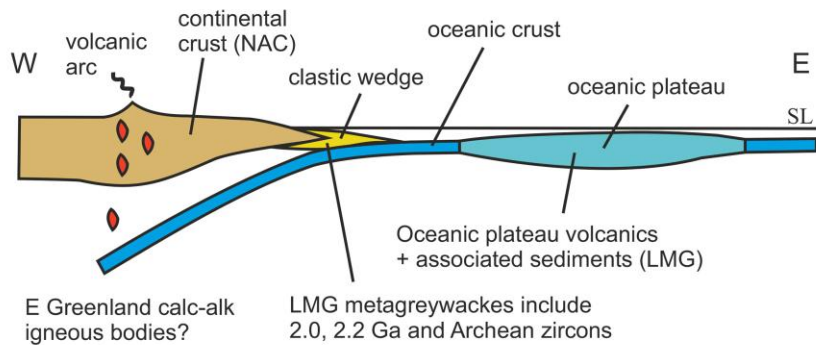


The ultimate Laxfordian exposure!

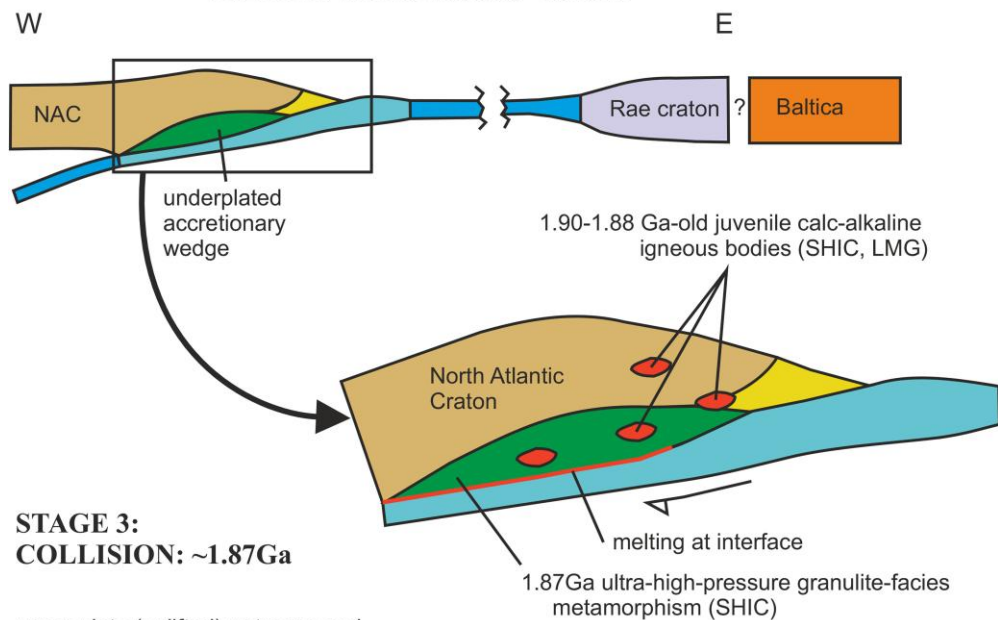
Grey, striped = Badcallian gneiss, cut by...
...black = foliated amphibolite Scourie dykes...
... then later cut by pink = granite veins...
...and all deformed by Laxfordian orogeny



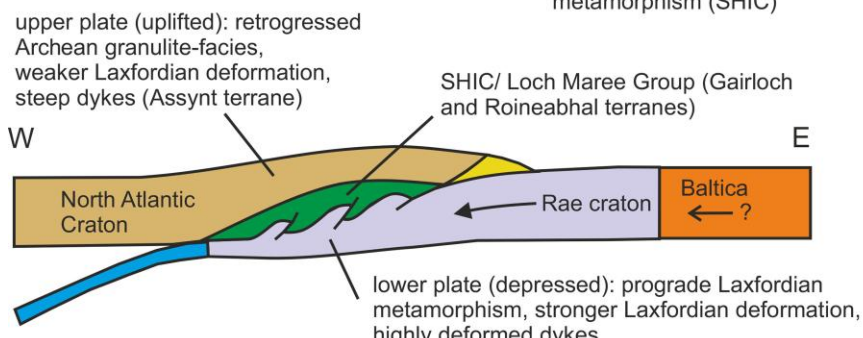
STAGE 1: SUBDUCTION: ~1.98Ga



STAGE 2: ACCRETION: ~1.90Ga

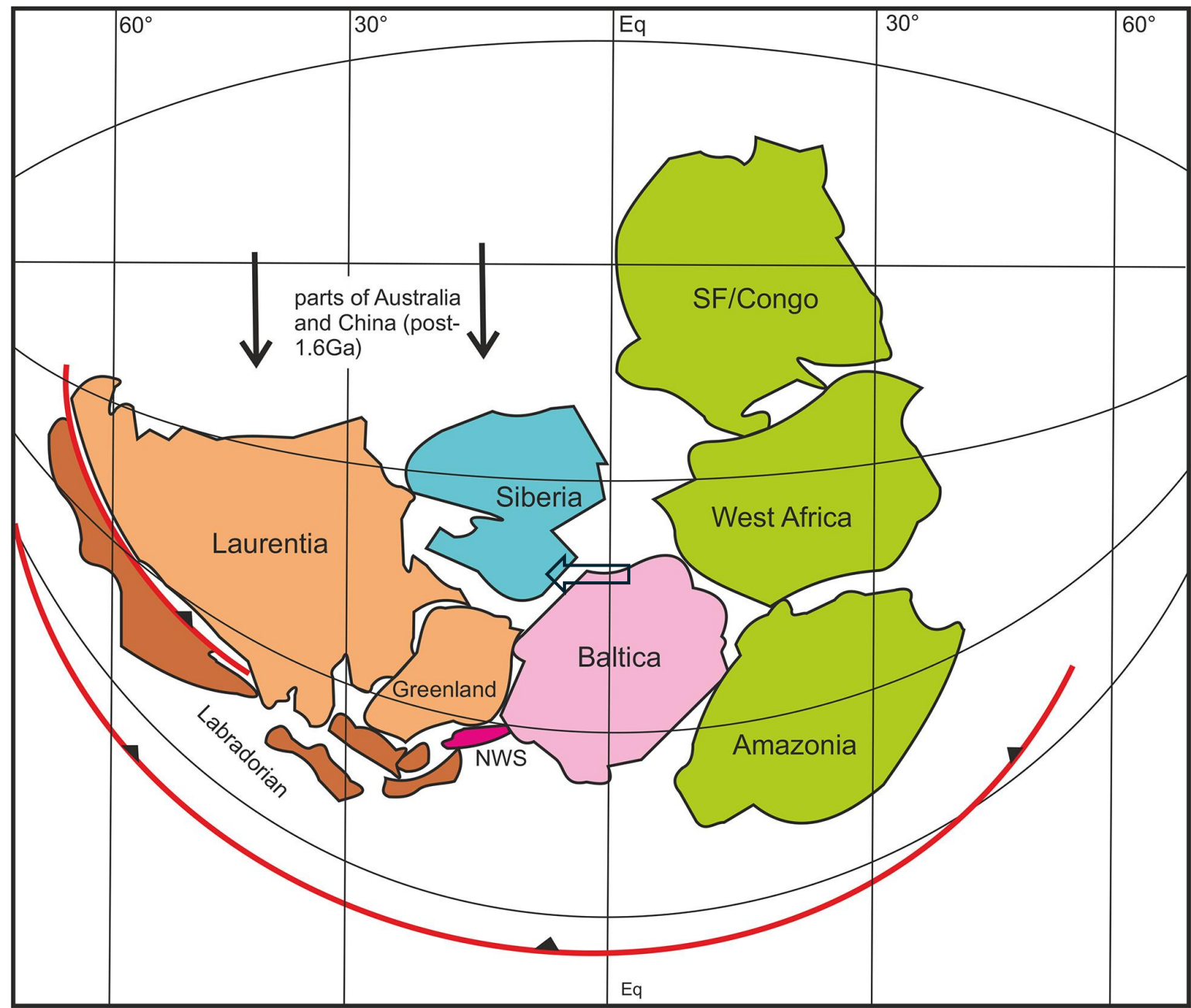


STAGE 3: COLLISION: ~1.87Ga

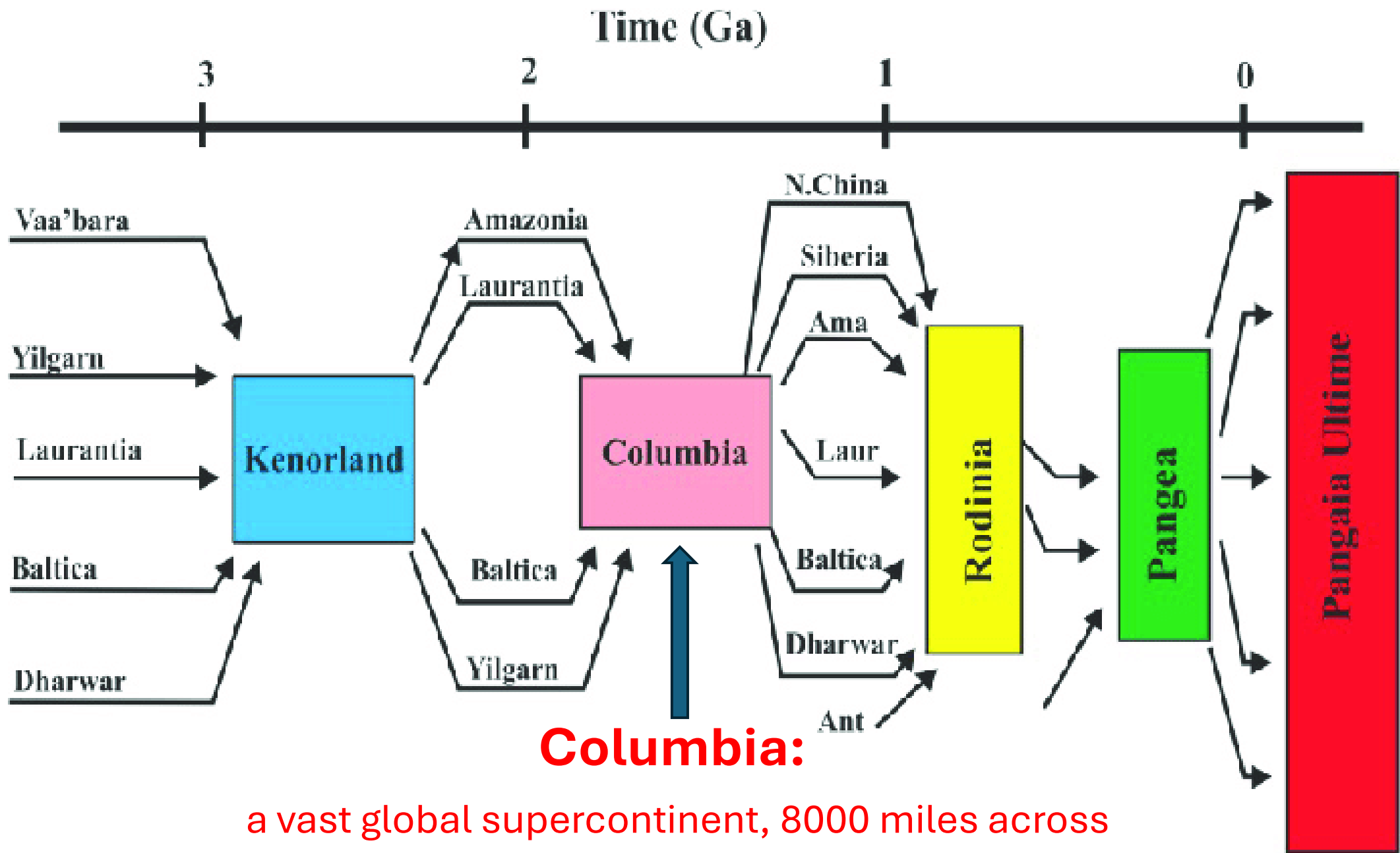


As a result of many such collisions, the next supercontinent is formed:

Nena / Columbia



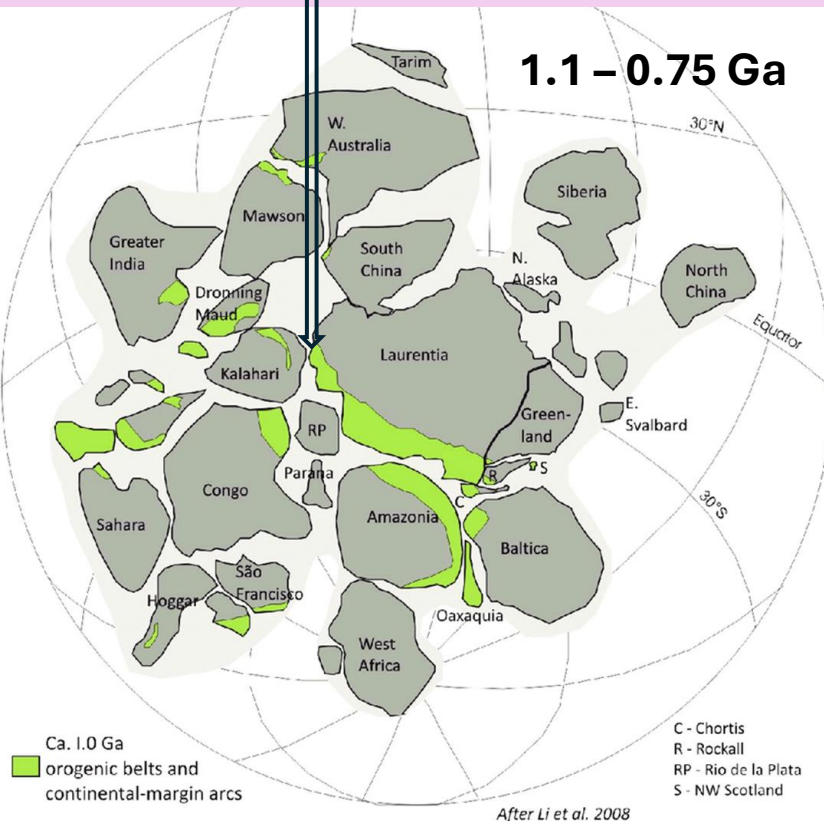
It's time to see how the global picture is changing – just an overview of the succession of supercontinents.



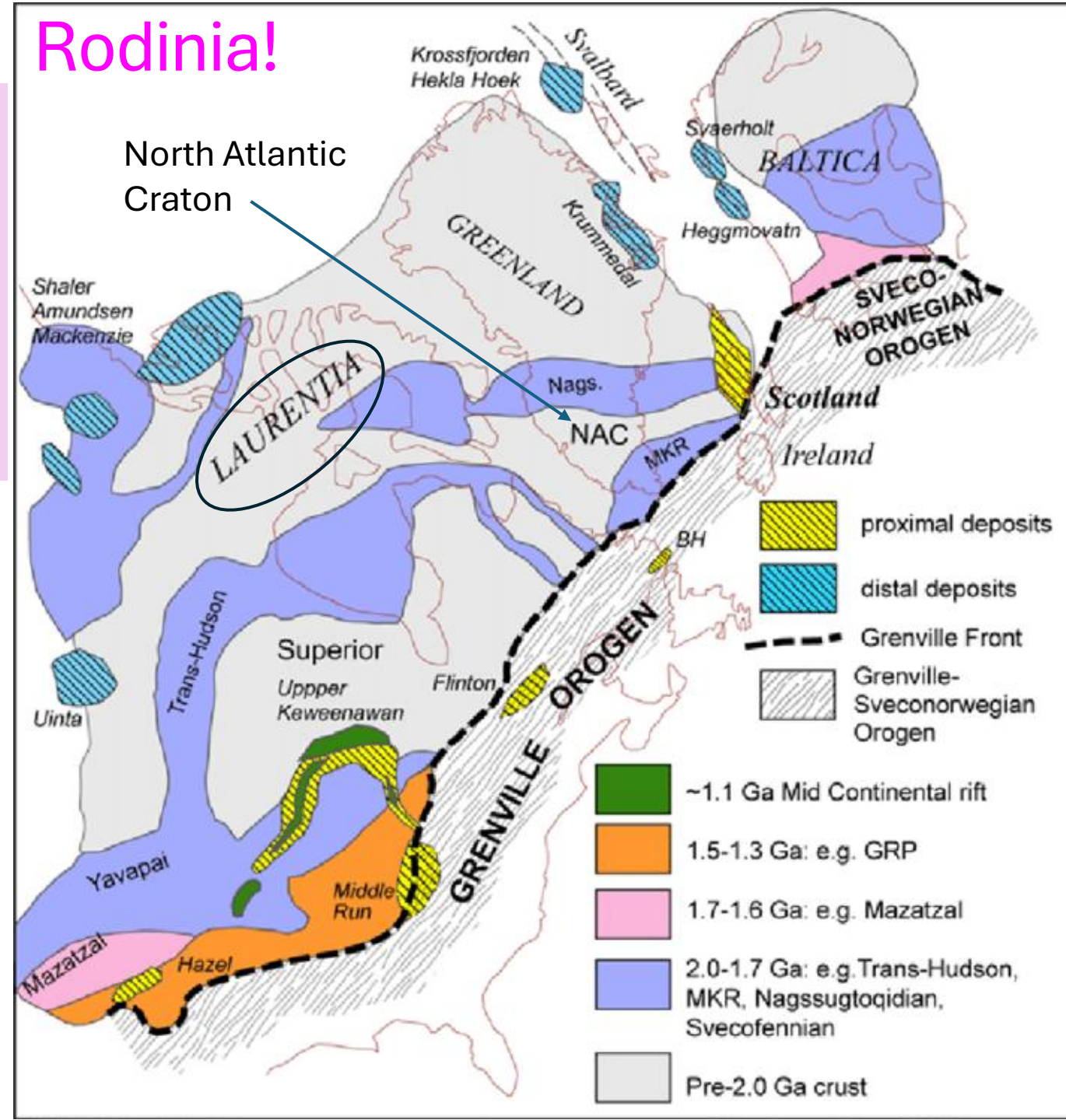
A few hundred million years later ...

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

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.

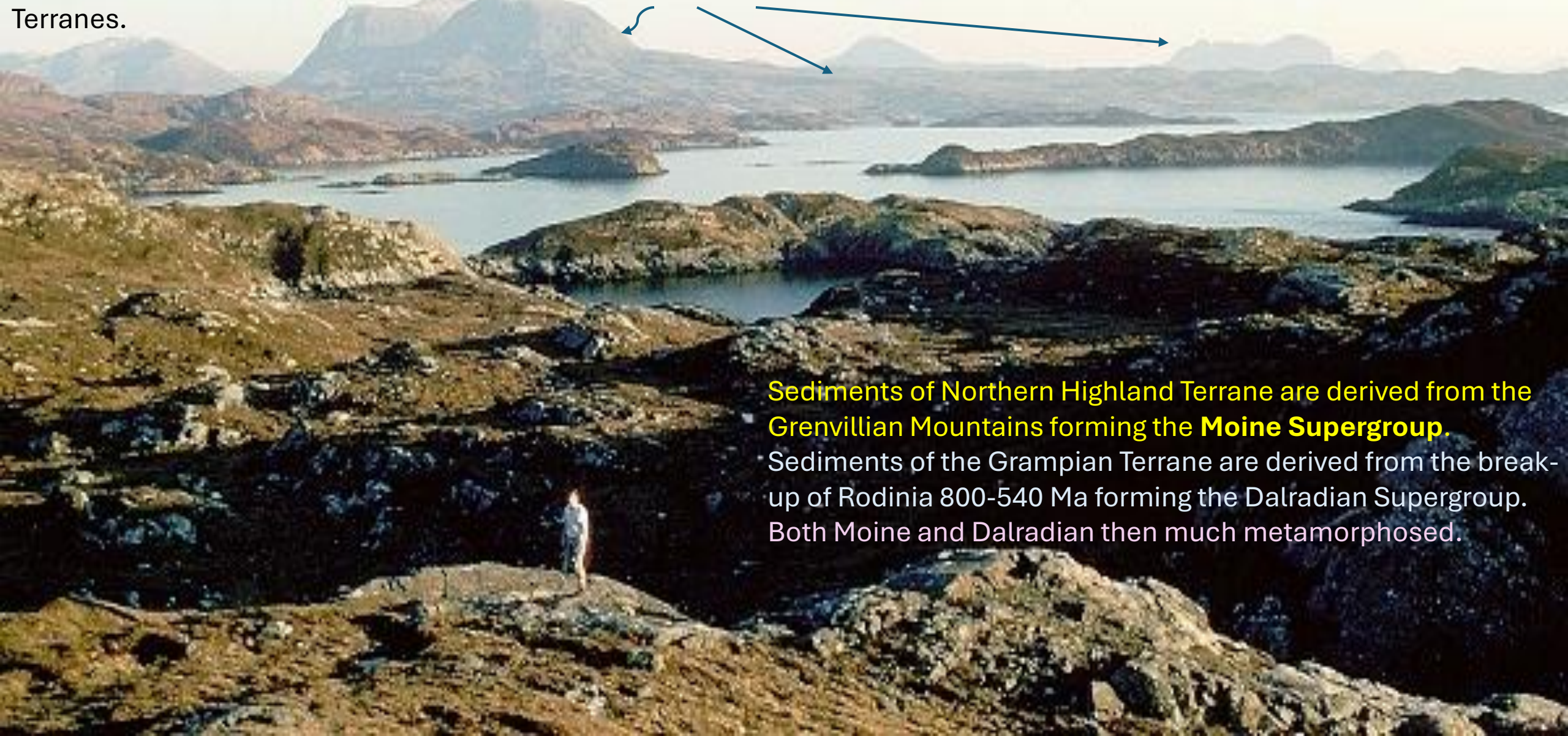


Rodinia!



The Lewisian Comes to the Surface

As Laurentia drifts towards the collisions that will form Rodinia, intensive continental erosion removes vast quantities of the continent > sediments deposited around the edges of the continent. The eroded surface is still there... The eroded sediments now form the Torridonian Supergroup and the mass of the Northern Highland and Grampian Terranes.



Sediments of Northern Highland Terrane are derived from the Grenvillian Mountains forming the **Moine Supergroup**.

Sediments of the Grampian Terrane are derived from the break-up of Rodinia 800-540 Ma forming the Dalradian Supergroup. Both Moine and Dalradian then much metamorphosed.

Depositing the Torridonian Supergroup in a series of depositional basins

Three groups, two older ones localised and distant from each other:
Stoer group (Stoer peninsula, north of Lochinver), 1.2Ga, 2 km thick
in a maze of canyons in the Lewisian surface..
Sleat group in SE Skye, 1.0-0.95 Ga, 3.5 km thick.

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

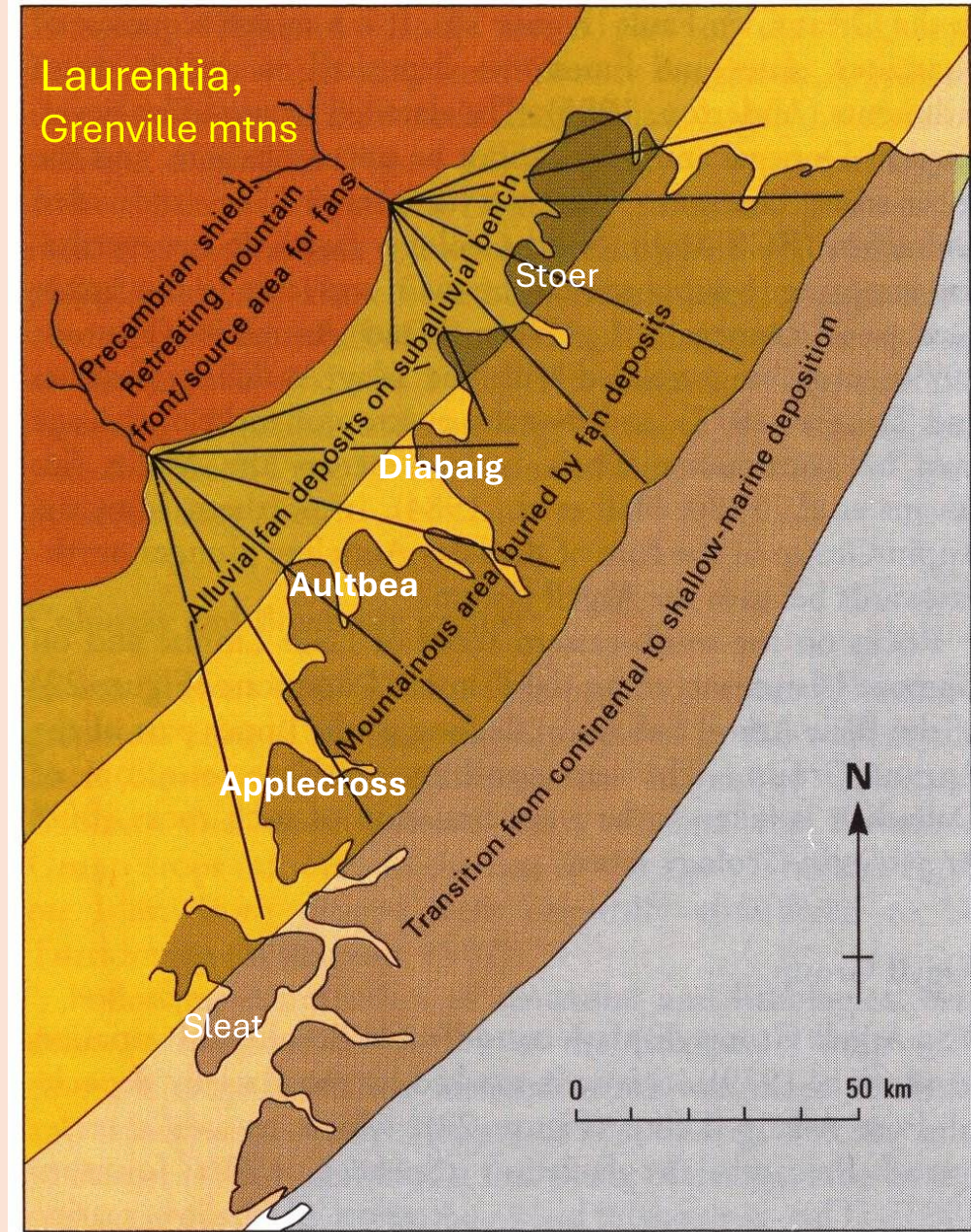
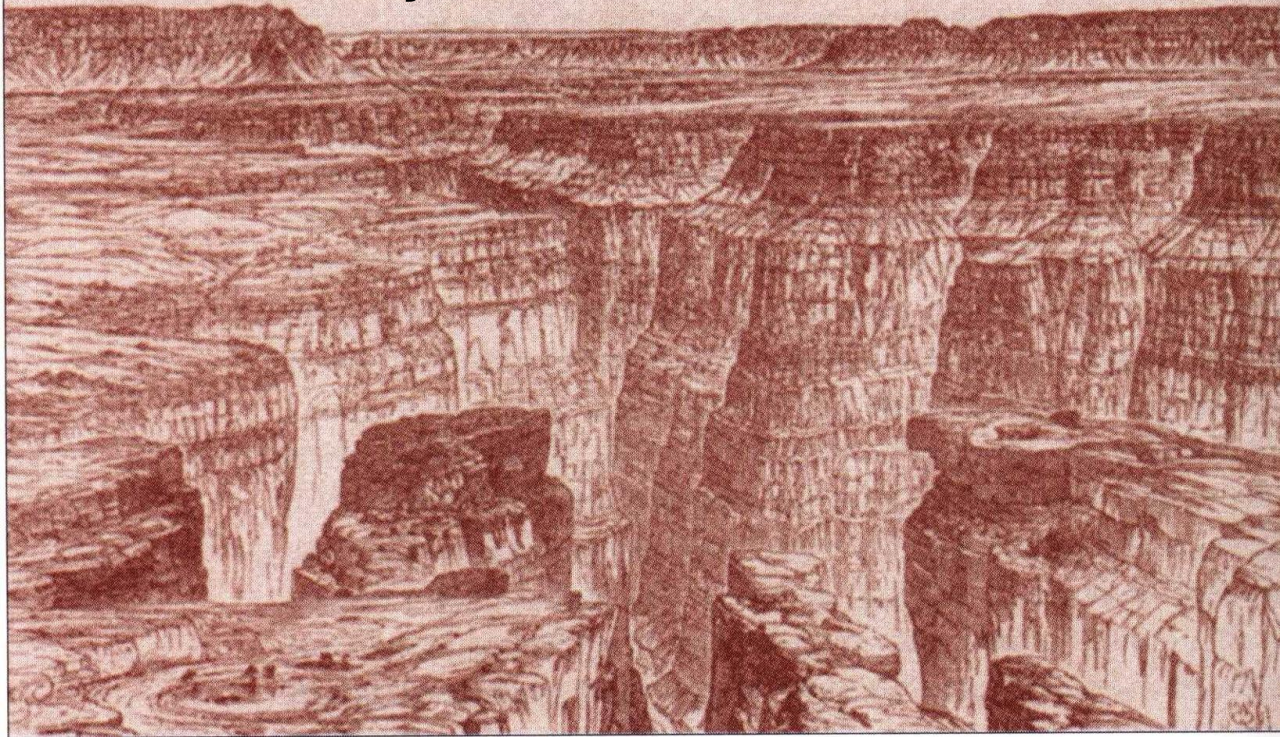


Figure 21 Depositional environment of the Applecross and Aultbea formations. After Williams (1969).

So to the Torridon Group with a 150 Myr time gap after Stoer Group, resting conformably on the Sleat Group (so continuity) but resting unconformably on the highly eroded Stoer Group (discontinuity).
However most rests directly on Lewisian basement with a highly varied palaeo-topography; relief from 100 m near Cape Wrath to 600 m at Loch Maree





Torridon mountains in the Applecross and Aultbea formations

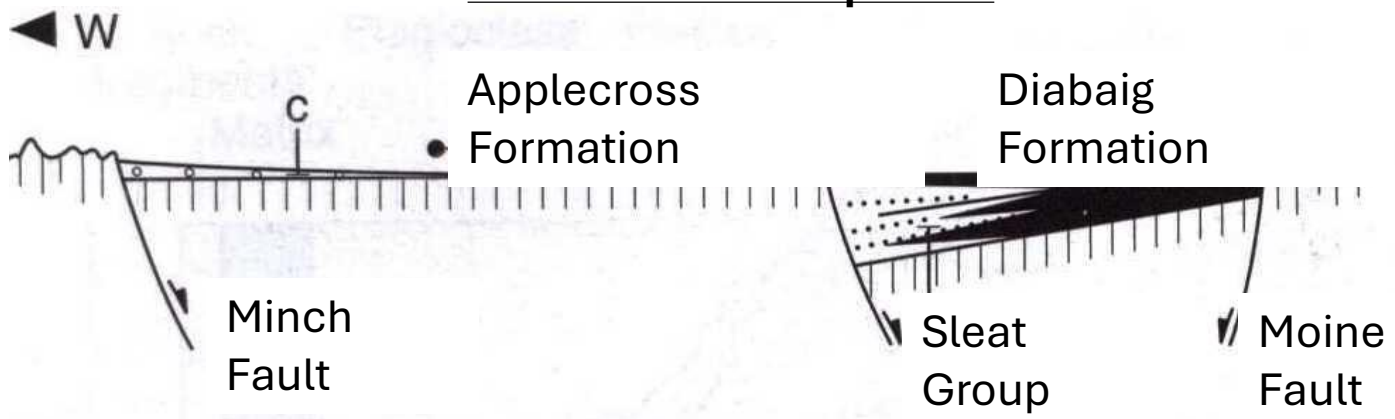


Note the lack of significant dip or folding – no evidence of metamorphism either.

Transverse profile - Sleat and Torridon Groups

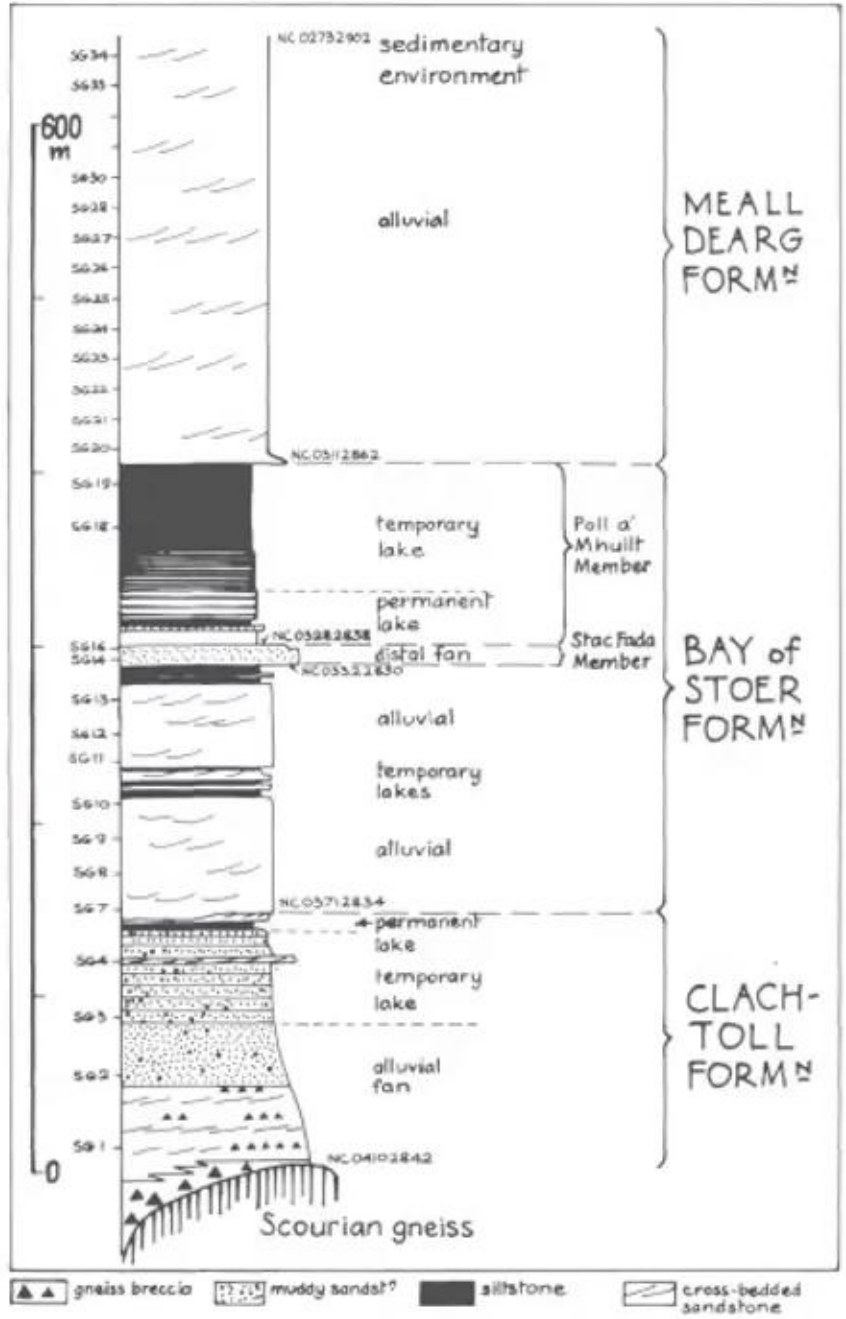
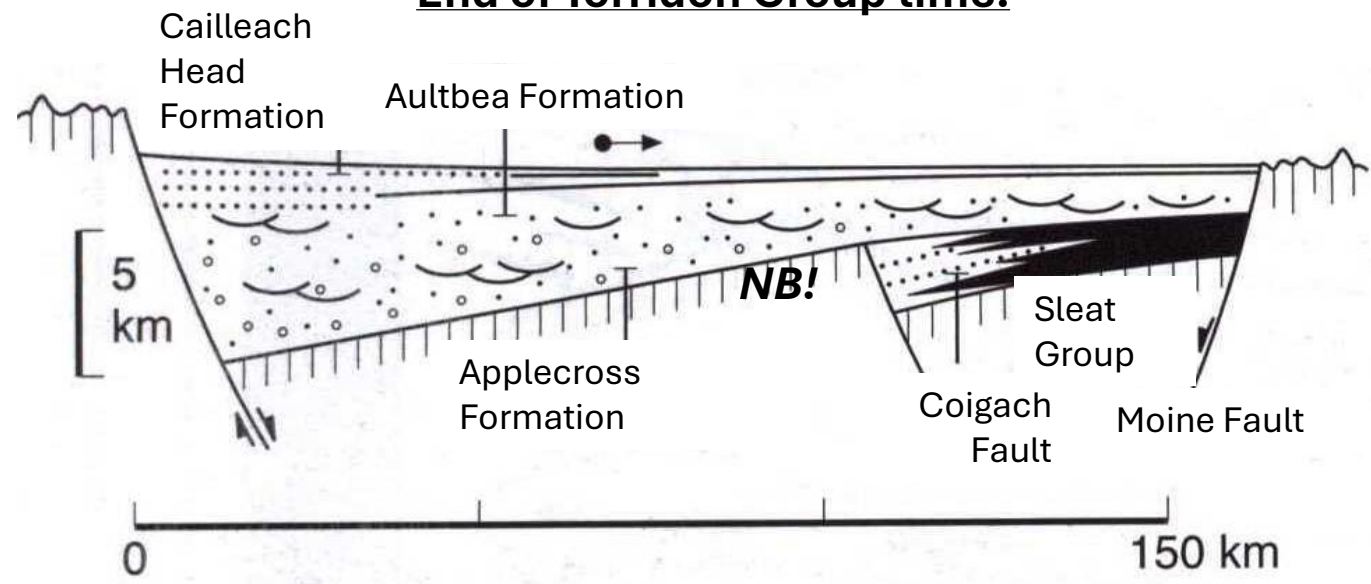
A. D. STEWART

End of Sleat Group time:



Profile across Torridonian at latitude of Skye

End of Torridon Group time:



The first 3 billion years!

The Hebridean Terrane has travelled a long way from its cratonic origins, from one supercontinent to another...

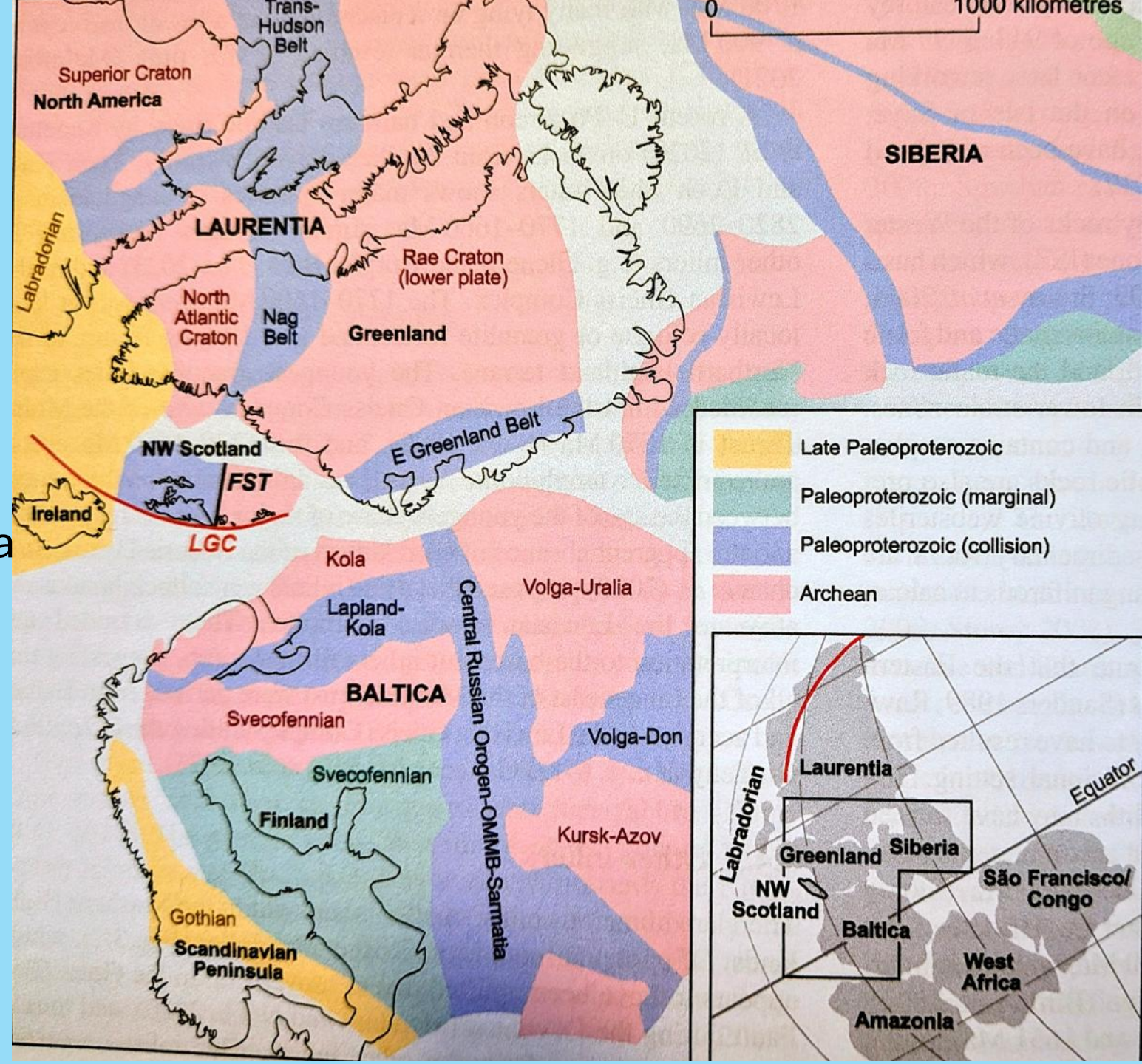
Vaalbara? 3.6 – 2.8 Ga

→ Ur? 3.0 – 2.8 Ga

→ Kenorland 2.7 – 2.1 Ga

→ Nena/Columbia 2.0 – 1.2 Ga

→ Rodinia 1.1 – 0.75 Ga



Rodinia 1.1 - 0.75 Ga

Grenvillian orogenic belt

Rifting caused the 'top' of Rodinia to break away to form the **Adamastor Ocean**.

Further south, rift valleys (*grabens*) opened across Laurentia. Erosion and transport filled these with vast quantities of sediment.

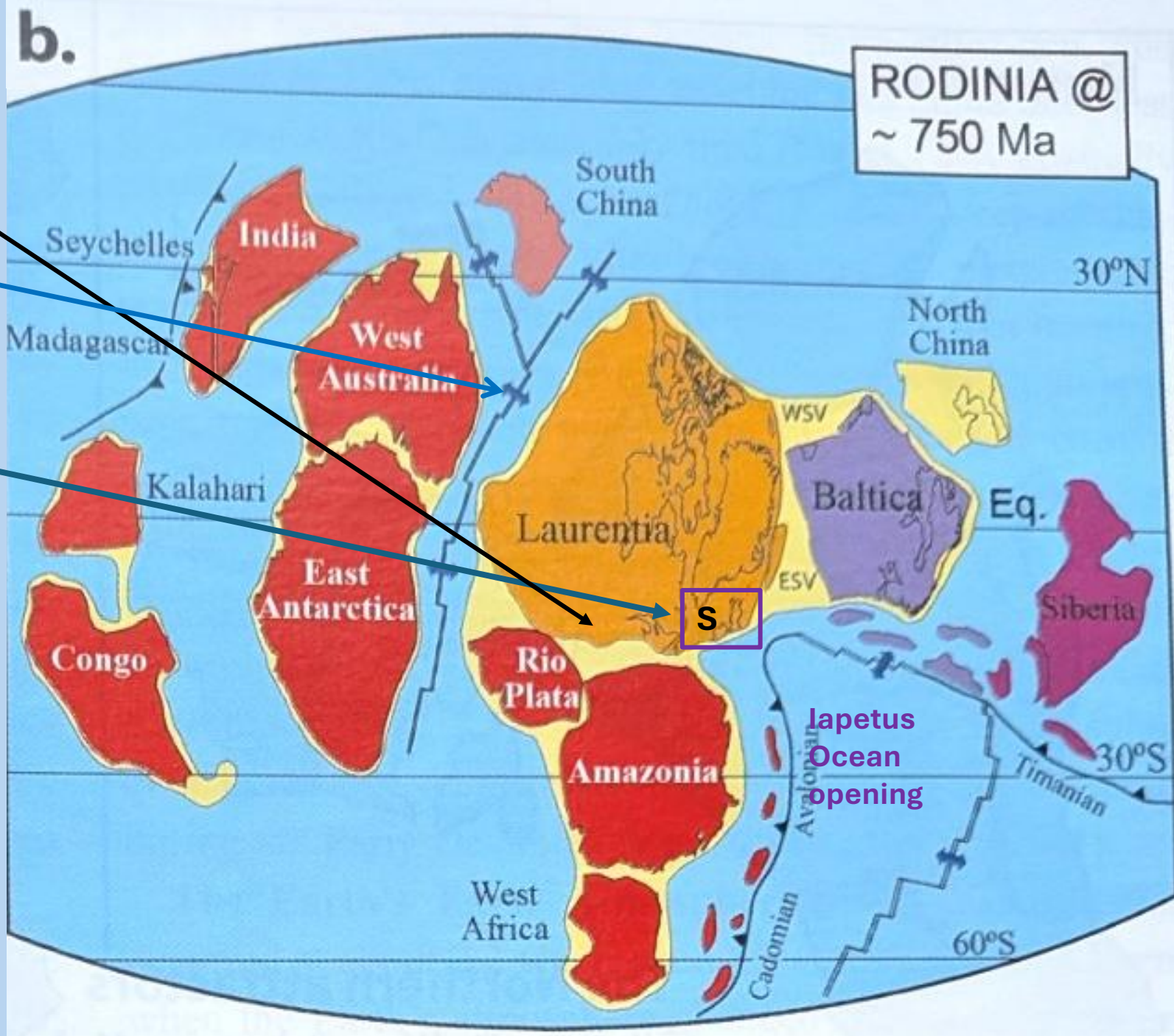
Palaeoclimate:

Latitude 10°-30° south

- Long hot dry summers
- Cool wet winters, up to 1m rainfall

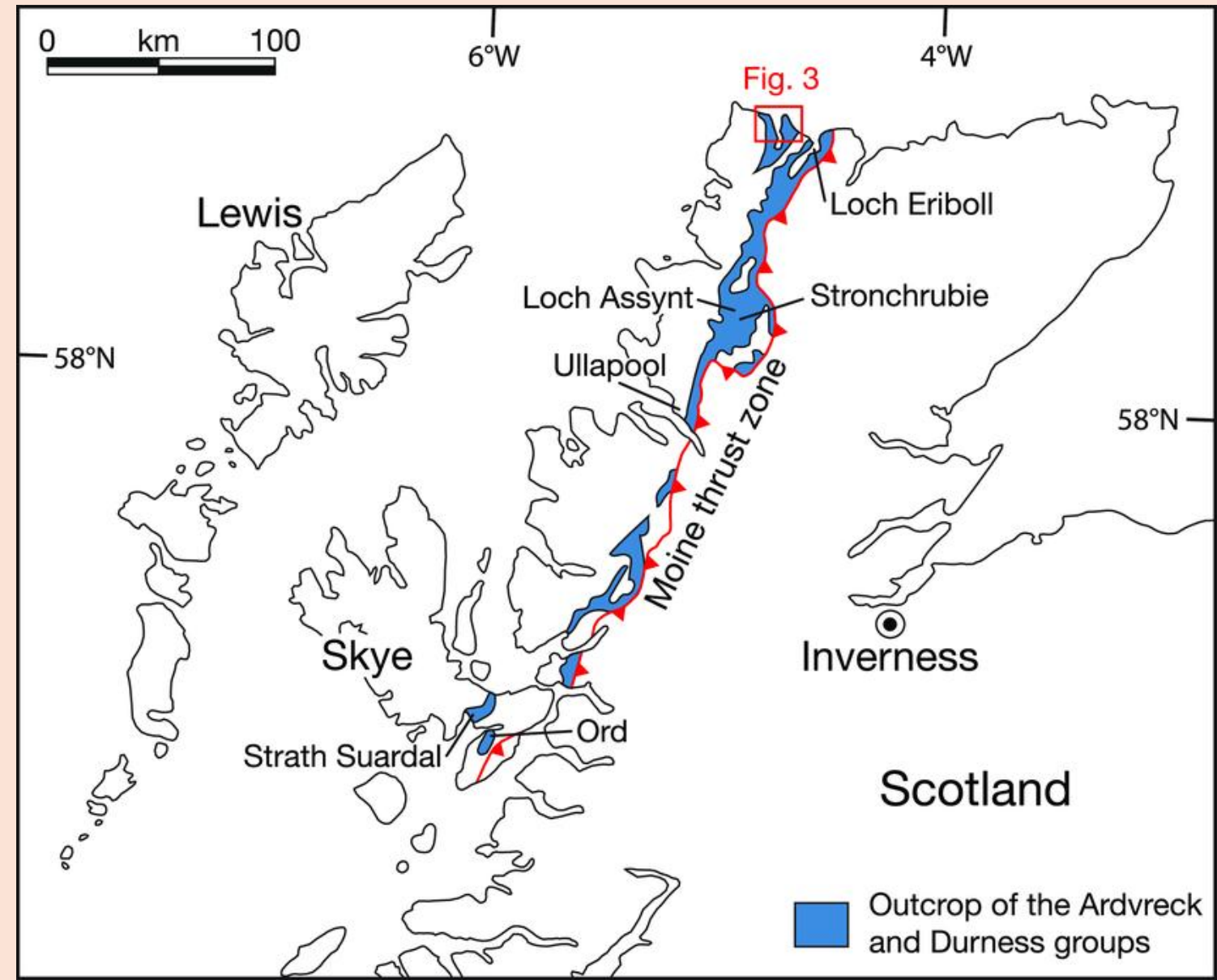
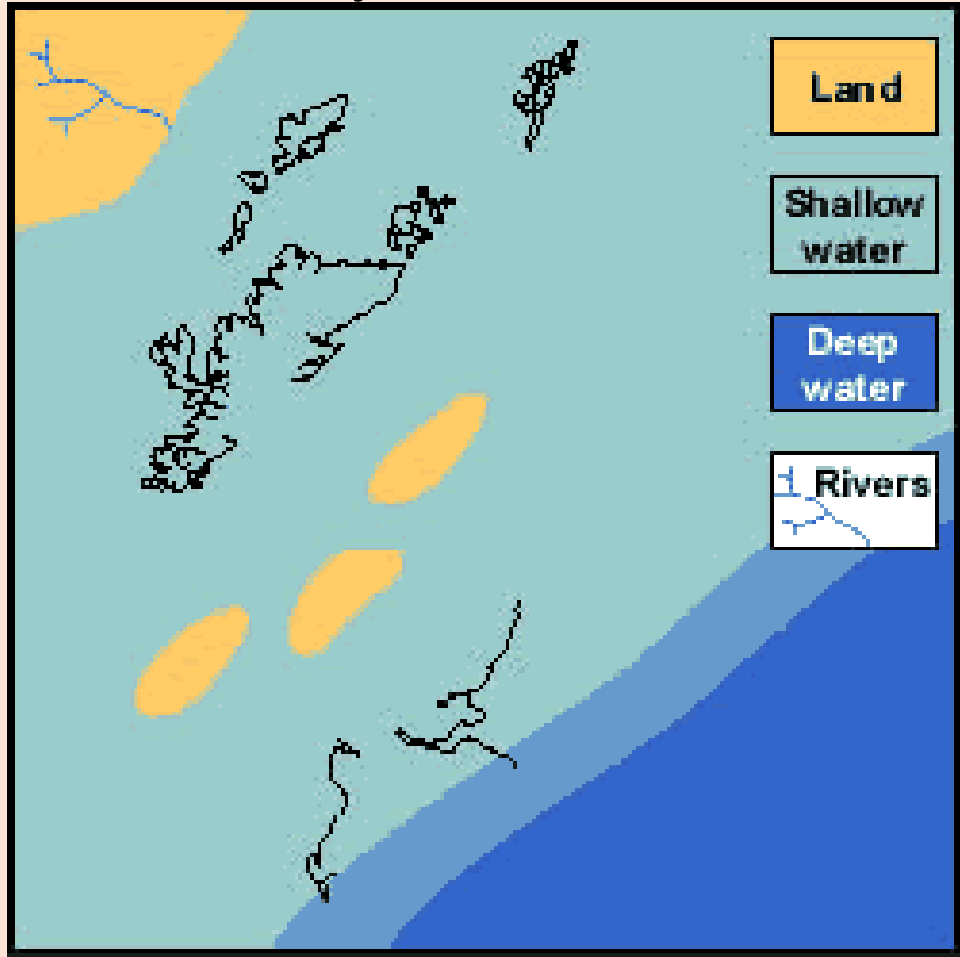
This produced the oldest sedimentary rock sequence in Scotland, essentially unmetamorphosed, the Torridonian.

And the first signs of life in Scotland!



The End of the Torridonian Era - the Cambrian period has begun!

530 Ma, the surface of the Torridon Group rocks is submerged beneath the sea, a highly eroded but remarkably level surface is ready to be buried by new sediments.





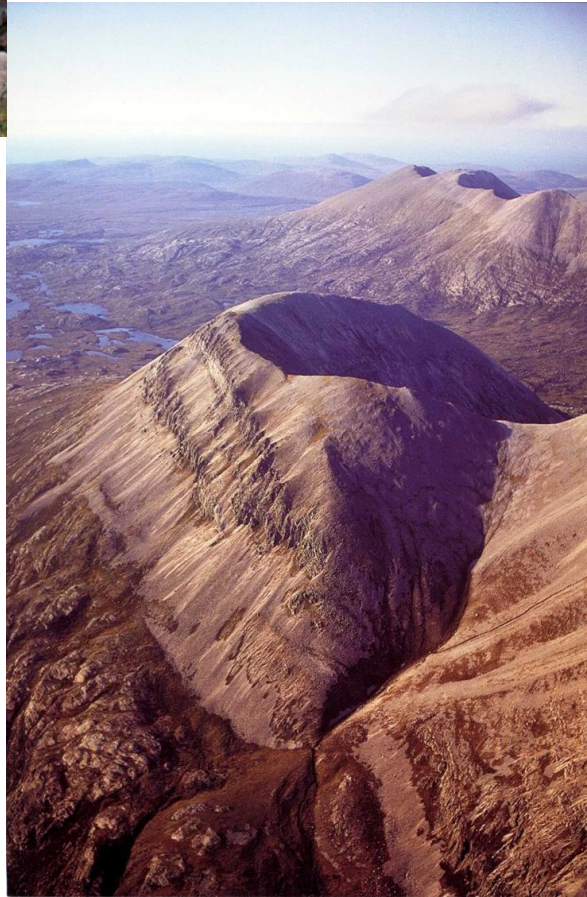
Sea level above the present Torridon Mountains!
The basal Cambrian quartzite deposits sit on top of the Torridon Mountains - a horizontal unconformity

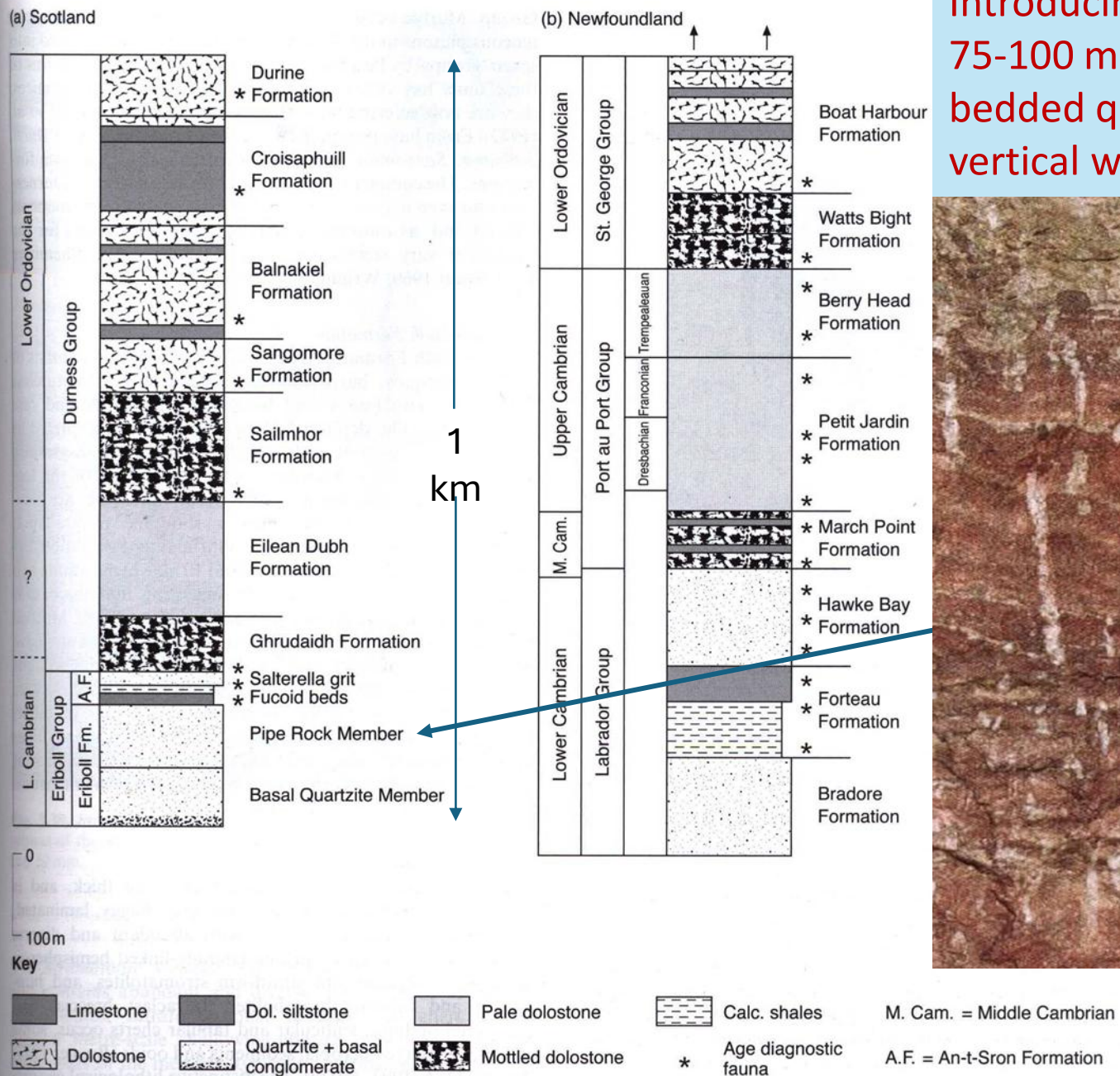
Torridon and Cambrian lie, one on top of the other. So a lot of erosion has happened since Cambrian times.

Deposition continues for about 70 Ma, producing a total thickness of sedimentary rock approaching 1 km.

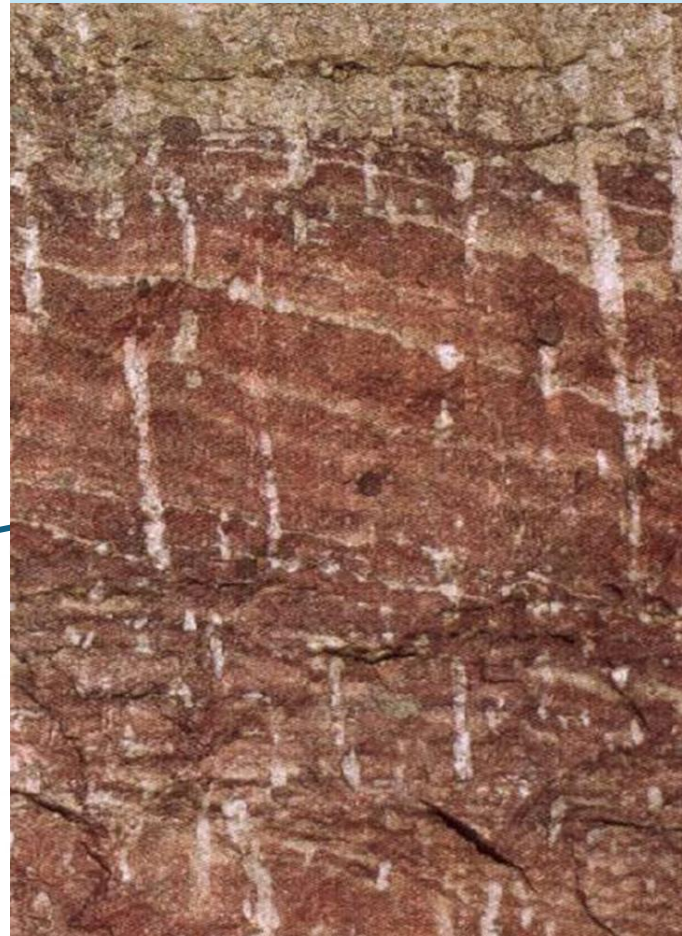
Similar to contemporary deposits found in Newfoundland.

And a new major player in sedimentary rocks emerges – **fossils** of multi-cellular organisms. **LIFE!**





Introducing the **Pipe Rock**, 75-100 m thick, a thinly bedded quartzite with vertical worm burrows...



Smoo Cave – Balnakiel Fm, typical feature of a limestone landscape



The Fucoid Beds, 12-27 m thick, with horizontal burrows



Fig. 3.35. Simplified stratigraphy of the Cambro-Ordovician of (a) Northwest Scotland and (b) western Newfoundland. Note similarity of lithofacies successions between biostratigraphic benchmarks of Lower Cambrian and Lower Ordovician strata.

Mineralisation

Mineral ores are found all over Scotland, and we need to include these deposits in discussing the geology.

Let us just whet the appetite! These are the locations of known **gold** deposits across Scotland. Note that there is a small scattering across the Hebridean and Northern Highland Terranes with one particular concentration in Strath Kildonan.

A future session on mineral deposits is pending – but first let's cover the rest of the terranes of Scotland.



3.13 MAP OF SCOTLAND WITH THE MAIN LOCATIONS FROM WHICH GOLD HAS BEEN OBTAINED (RED STARS) WITH THE MAJOR GEOLOGICAL FAULT ZONES (GREY LINES).

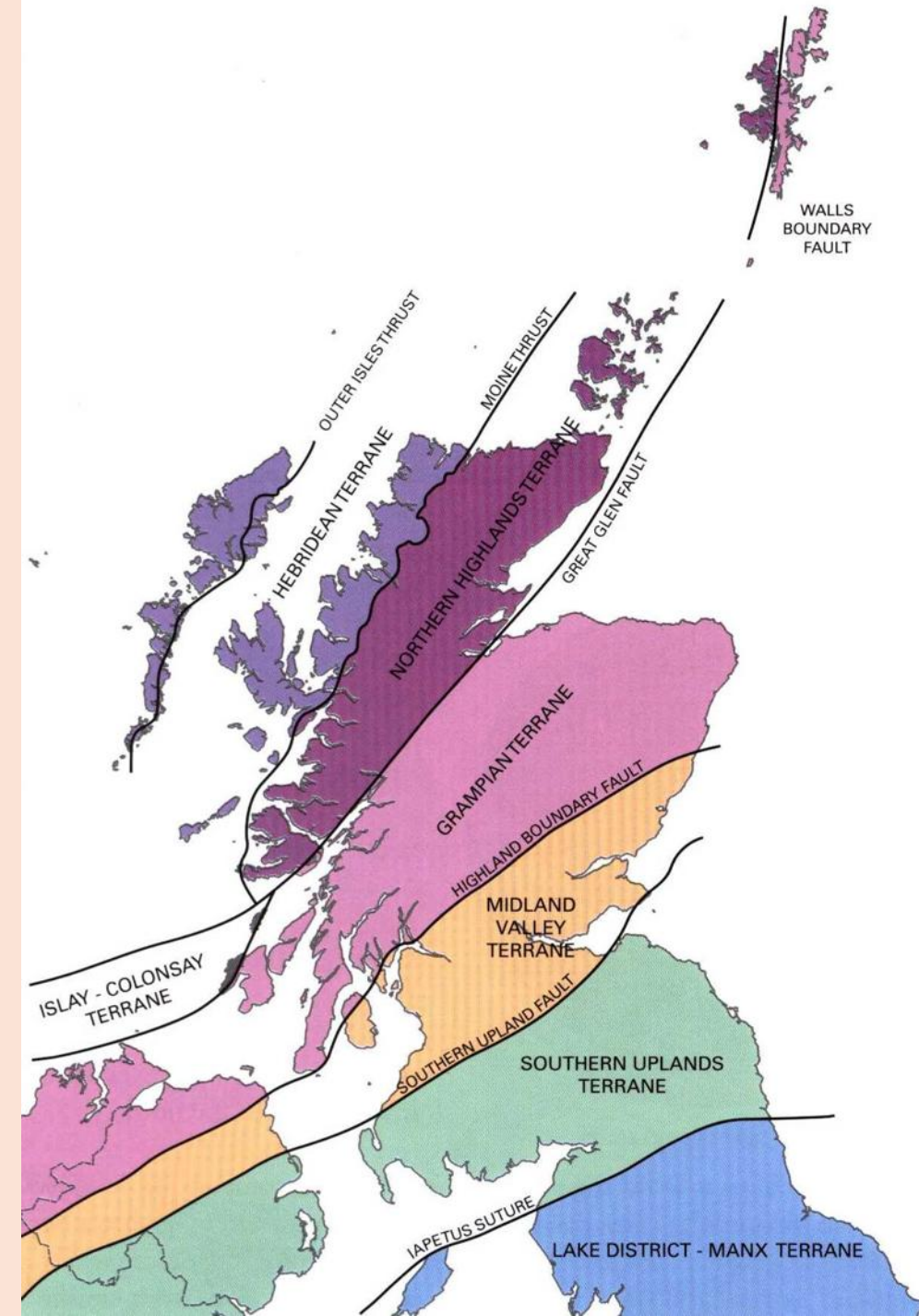
Next, across to the East: The Northern Highlands Terrane (The Moine)

Does it have a Basement? Perhaps an Archaean basement?

There are Archaean gneiss inliers in the Moine Terrane – but are they Lewisian?

Ages do not match! Geochemistry does not match!

So what are they? More later!



Northern Highlands Terrane (The Moine)

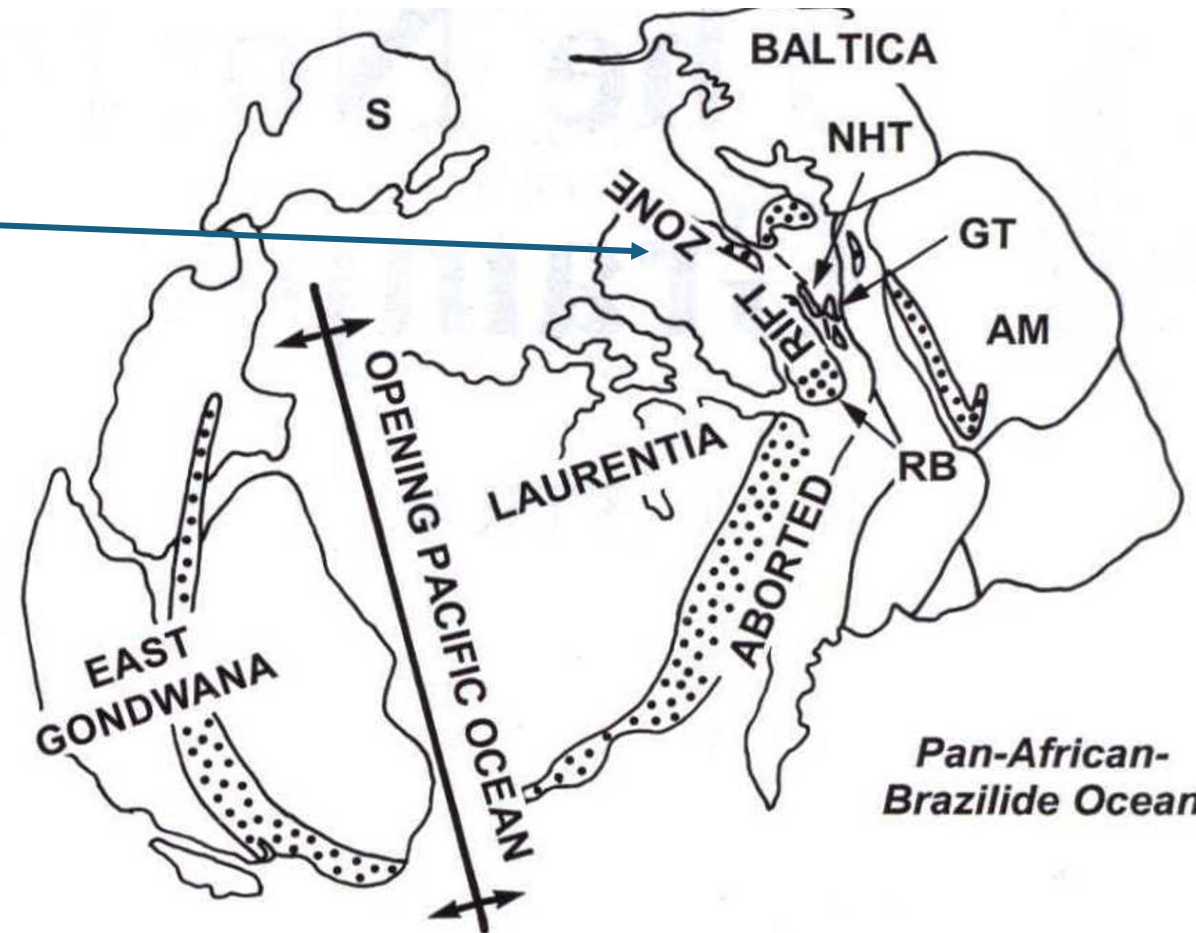
- Both Hebridean and Northern Highlands terranes derive from Laurentia, and close enough together to have become closely related terranes as Rodinia broke up.

Moine deposition happened c. **1.0 Ga** in an aborted ocean-opening rift event along east side of Laurentia providing basins for the Moine sediment deposition, so forming the **Wester Ross Supergroup**, 1000-950 Ma.

Then the Loch Ness Supergroup, 900-870 Ma.

Later still came the Grampian Terrane (GT) with the Dalradian sediments, 800 – 500 Ma.

Where were the depositional basins for the Moine sediments?



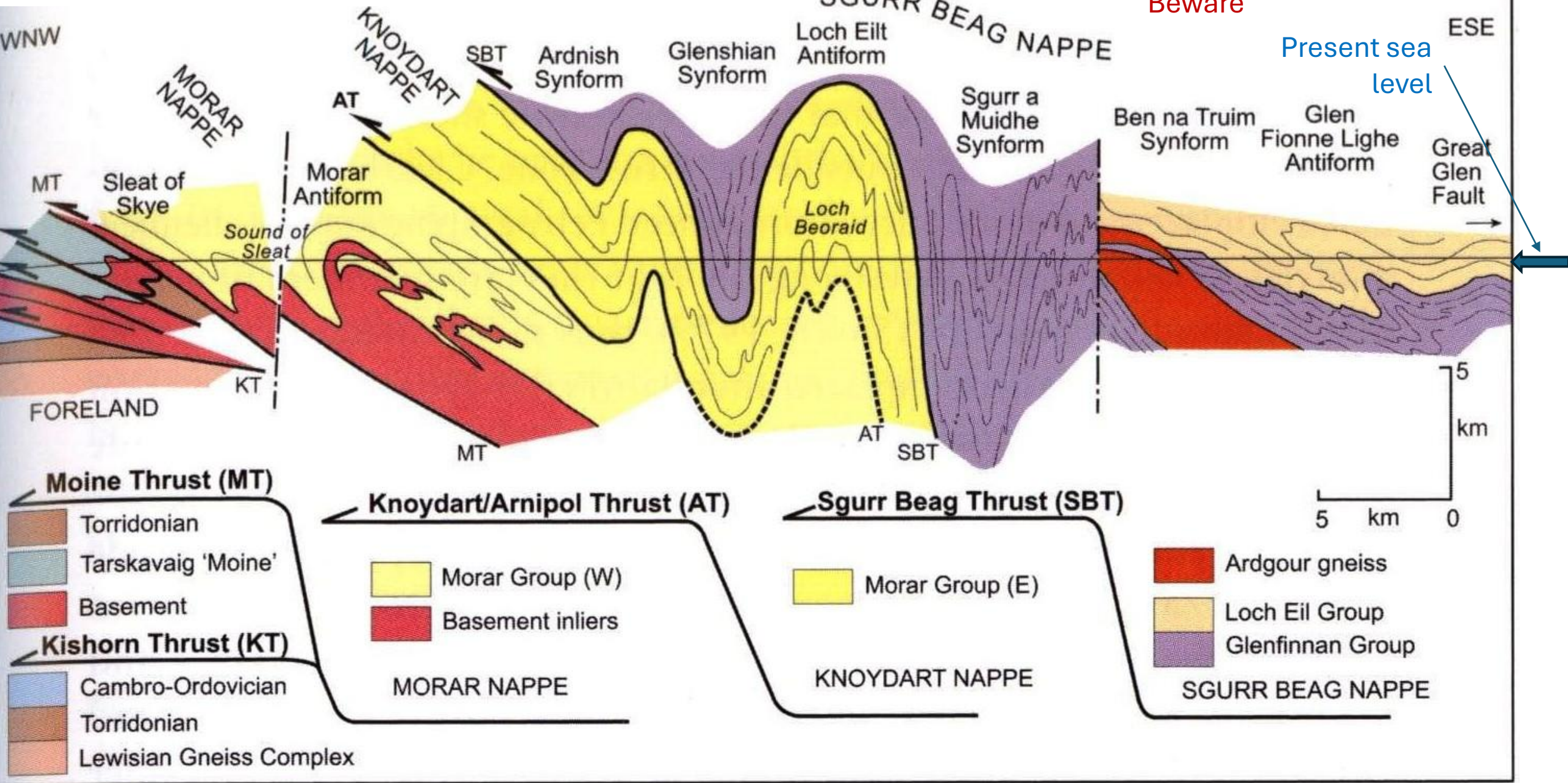
Cross-section of the Moine metasediments

Very contorted and faulted - why?

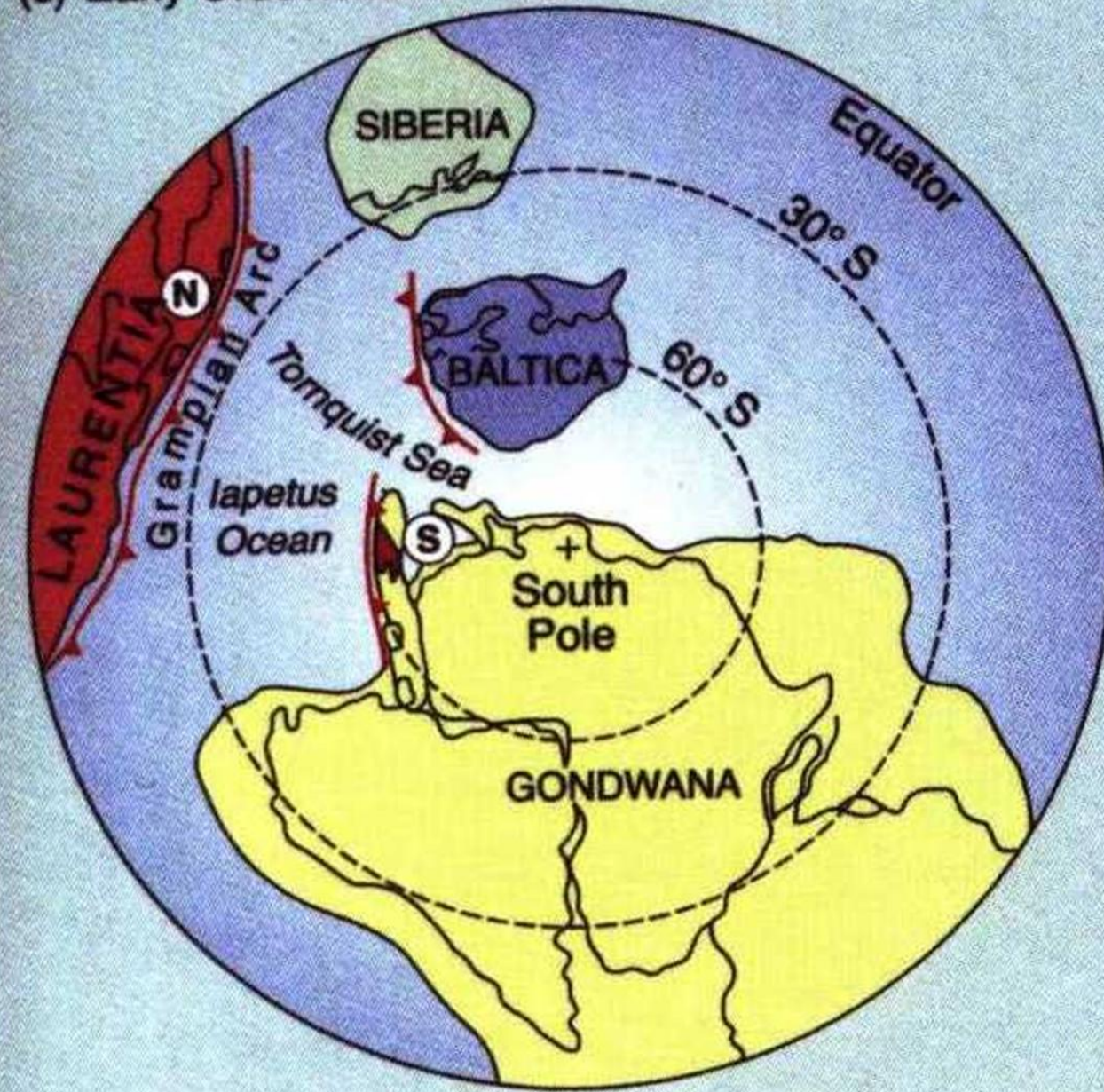
It is now 450 Ma

Avalonia is taking aim at the coast of Laurentia

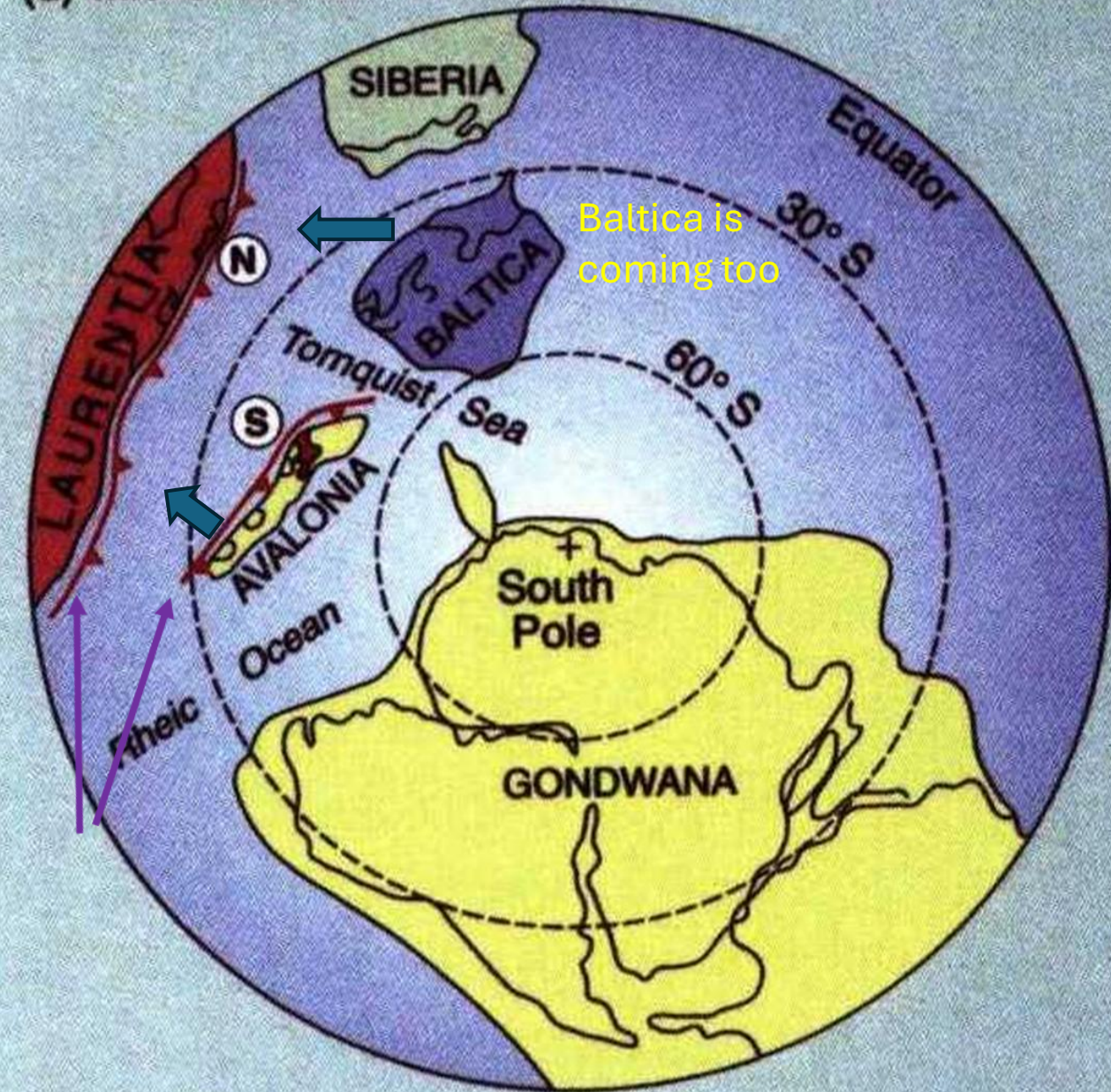
Beware



(c) Early Ordovician c. 490 Ma

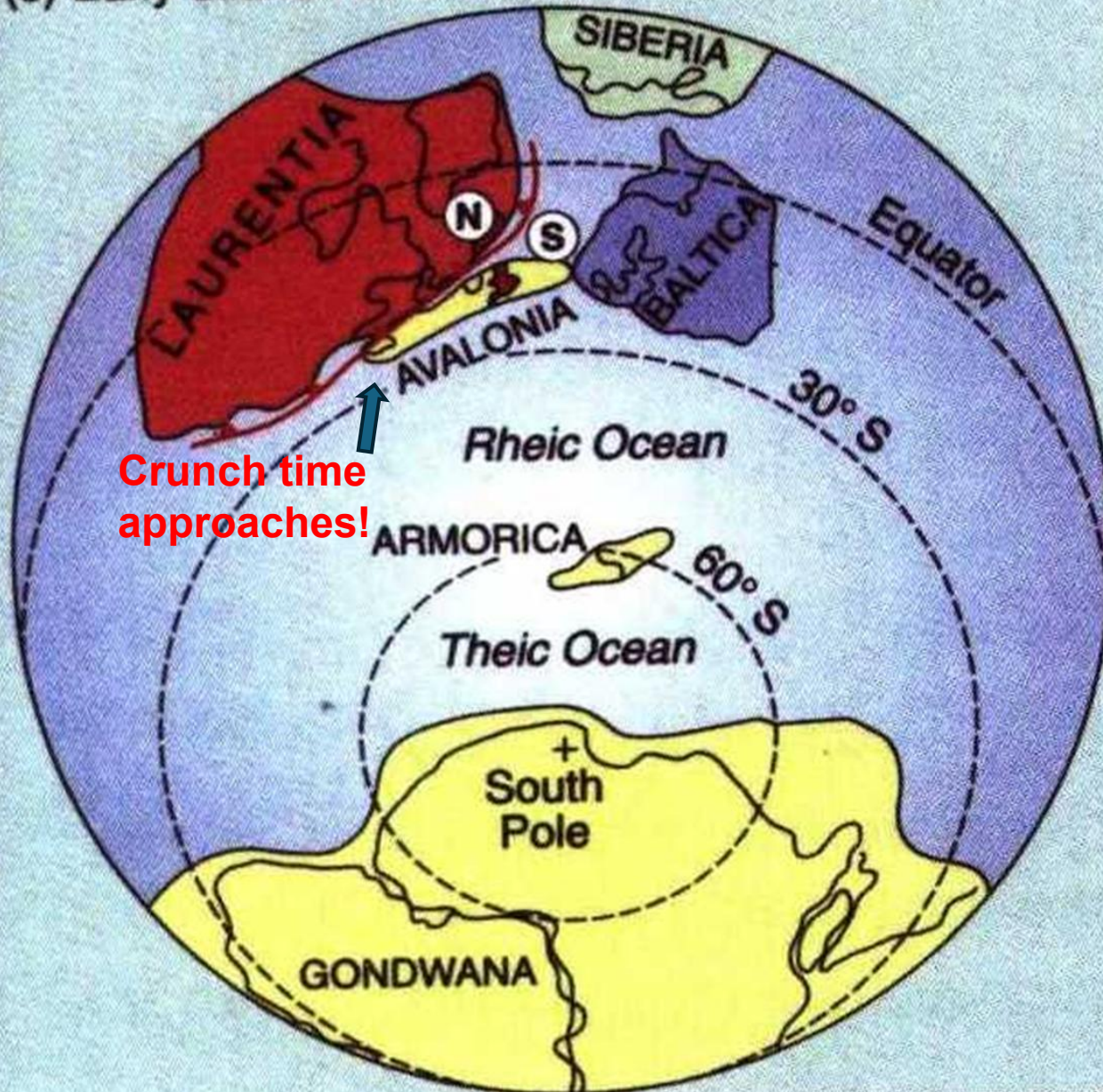


(d) Mid-Ordovician c. 470 Ma

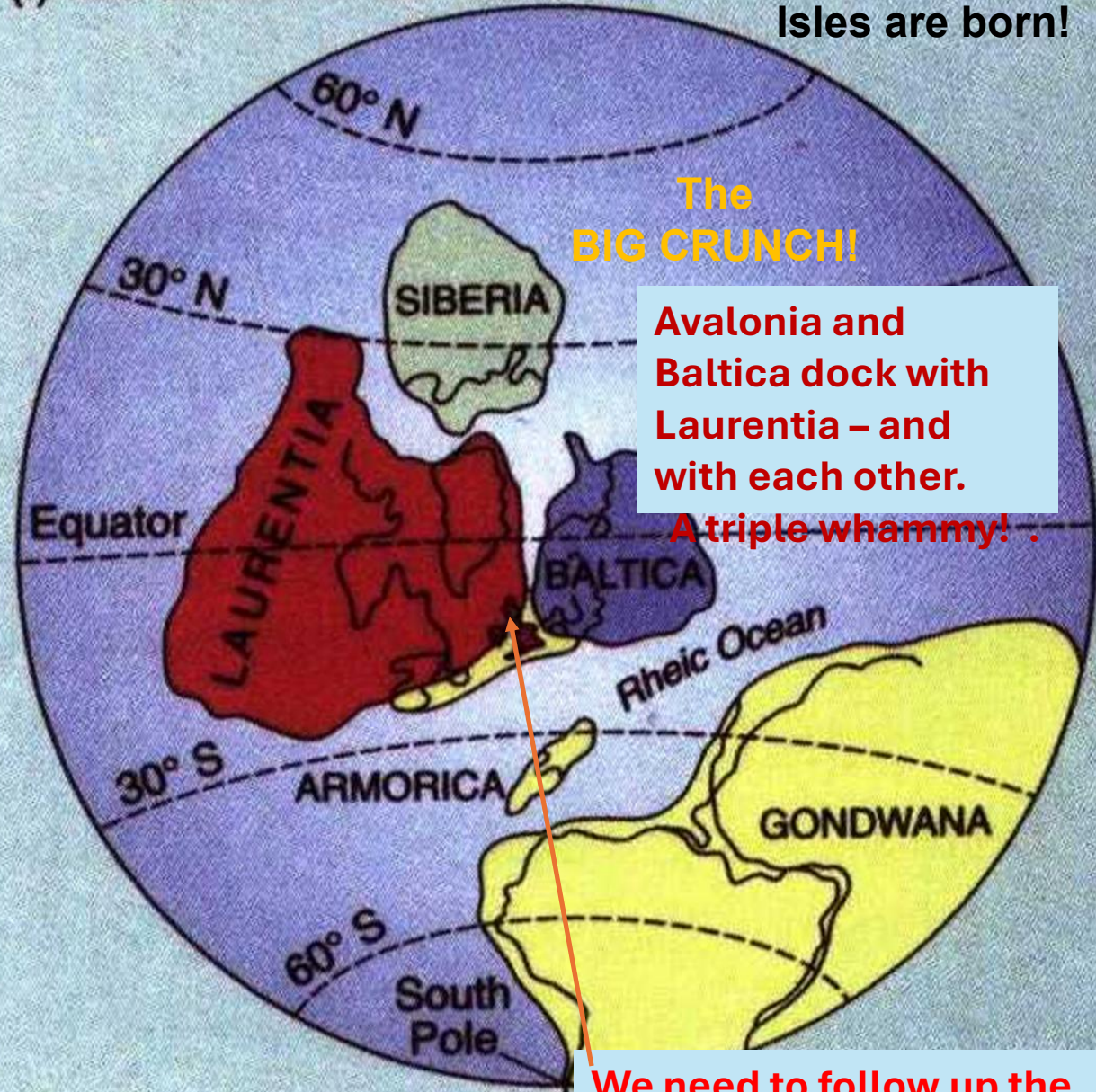


The Iapetus Ocean at 490 Ma is about the same width as the present North Atlantic, but closing after this.

(e) Early Silurian c. 440 Ma



(f) Mid-Silurian c. 425 Ma



The British Isles are born!

The BIG CRUNCH!

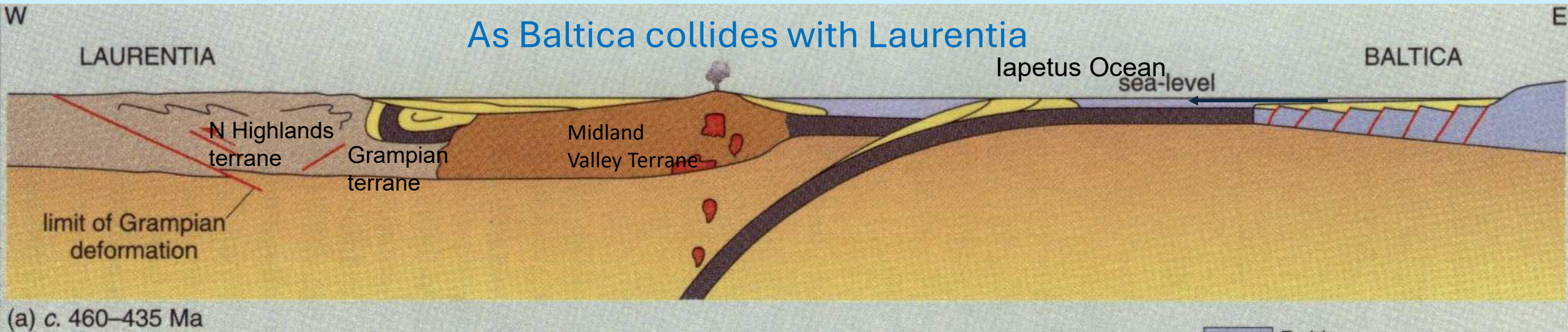
Avalonia and Baltica dock with Laurentia – and with each other.

A triple whammy! .

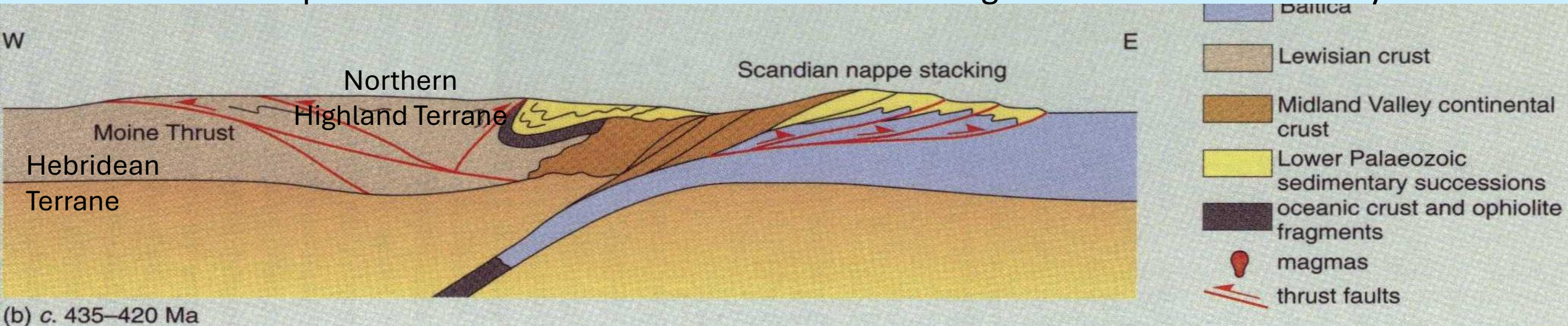
We need to follow up the consequences for the Hebridean Terrane

Avalonia has sped north to catch up with lumbering Laurentia! Baltica comes in from the side. The Iapetus Ocean closure is matched by the Rheic Ocean opening behind Avalonia.

The Cause of the damage: the Caledonian Orogeny – 1. the Scandian Phase

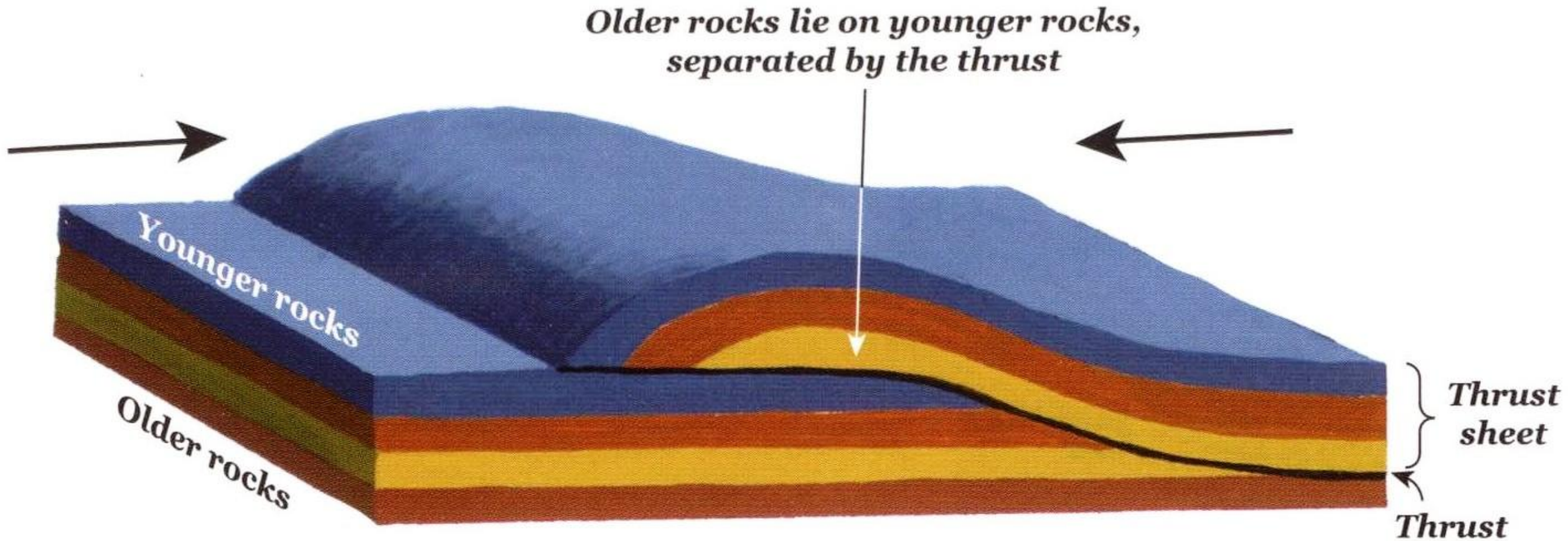


Northern arm of Iapetus Ocean subducts below Laurentia – magmatism in Midland Valley Terrane



Baltica thrusts under Laurentia – the N Highlands Terrane is thrust north-westwards over the Hebridean Terrane (Moine Thrust develops), also sliding along the Great Glen Fault south-westwards.

Thrust Tectonics



Knockan Crag

Moine rocks
(mylonites)
<1.0 Ga

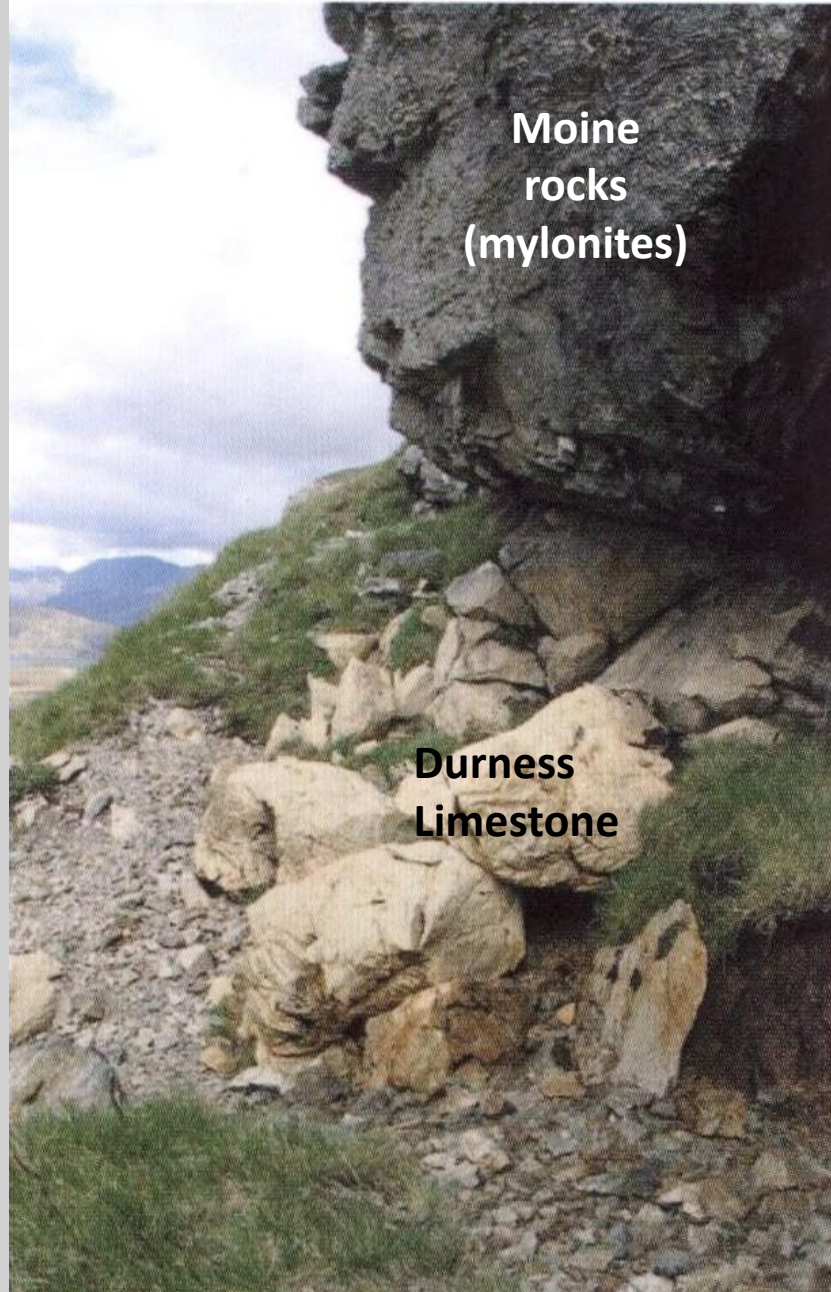
Hebridean Terrane
2.9 Ga

Cambrian rocks
c.530 Ma

Fucoid beds

**Basal
quartzite**

Dark Moine Rocks on top of creamy Durness Limestone, separated by the Moine Thrust

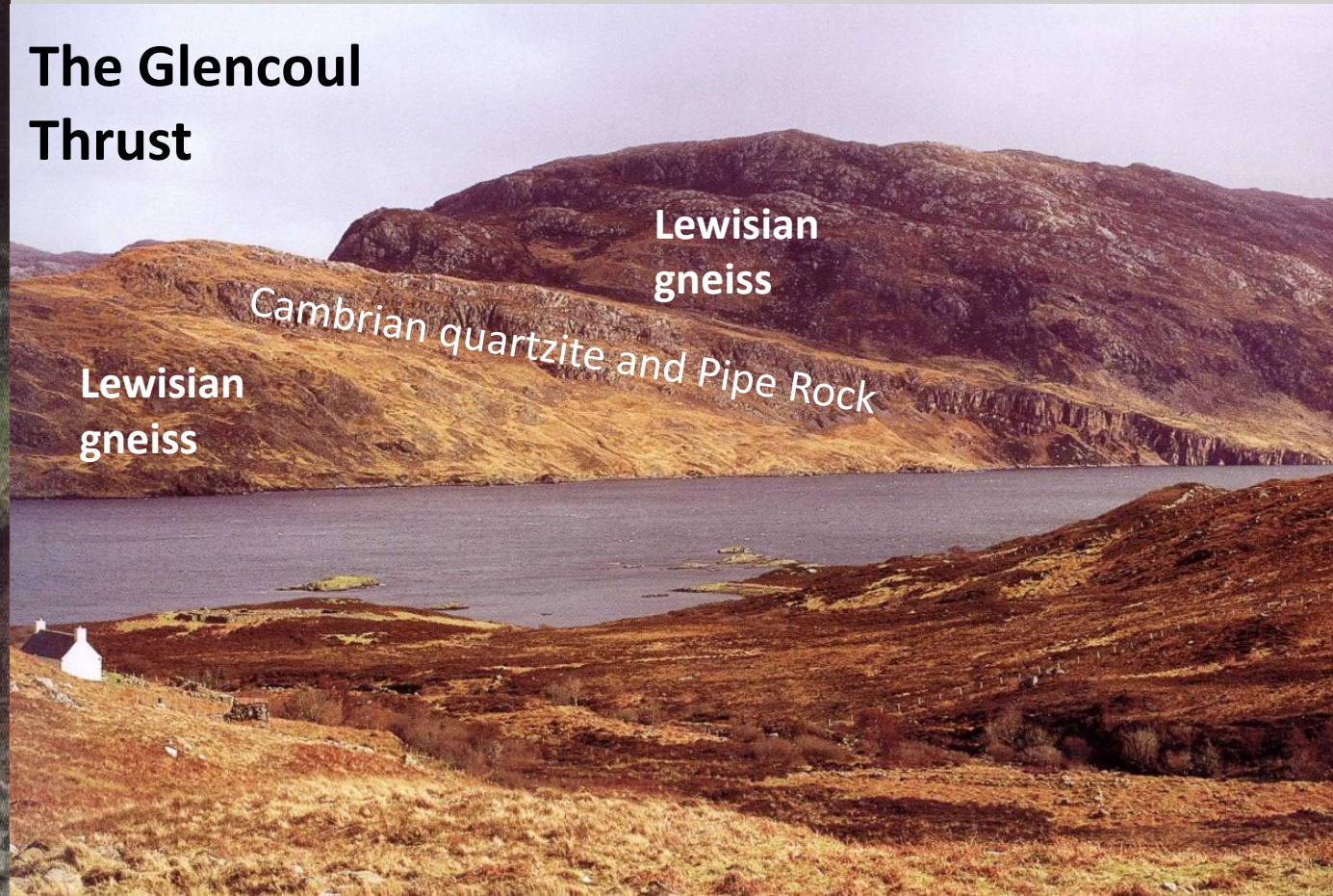


**Moine
rocks
(mylonites)**

**Durness
Limestone**

What you see.

The Glencoul Thrust

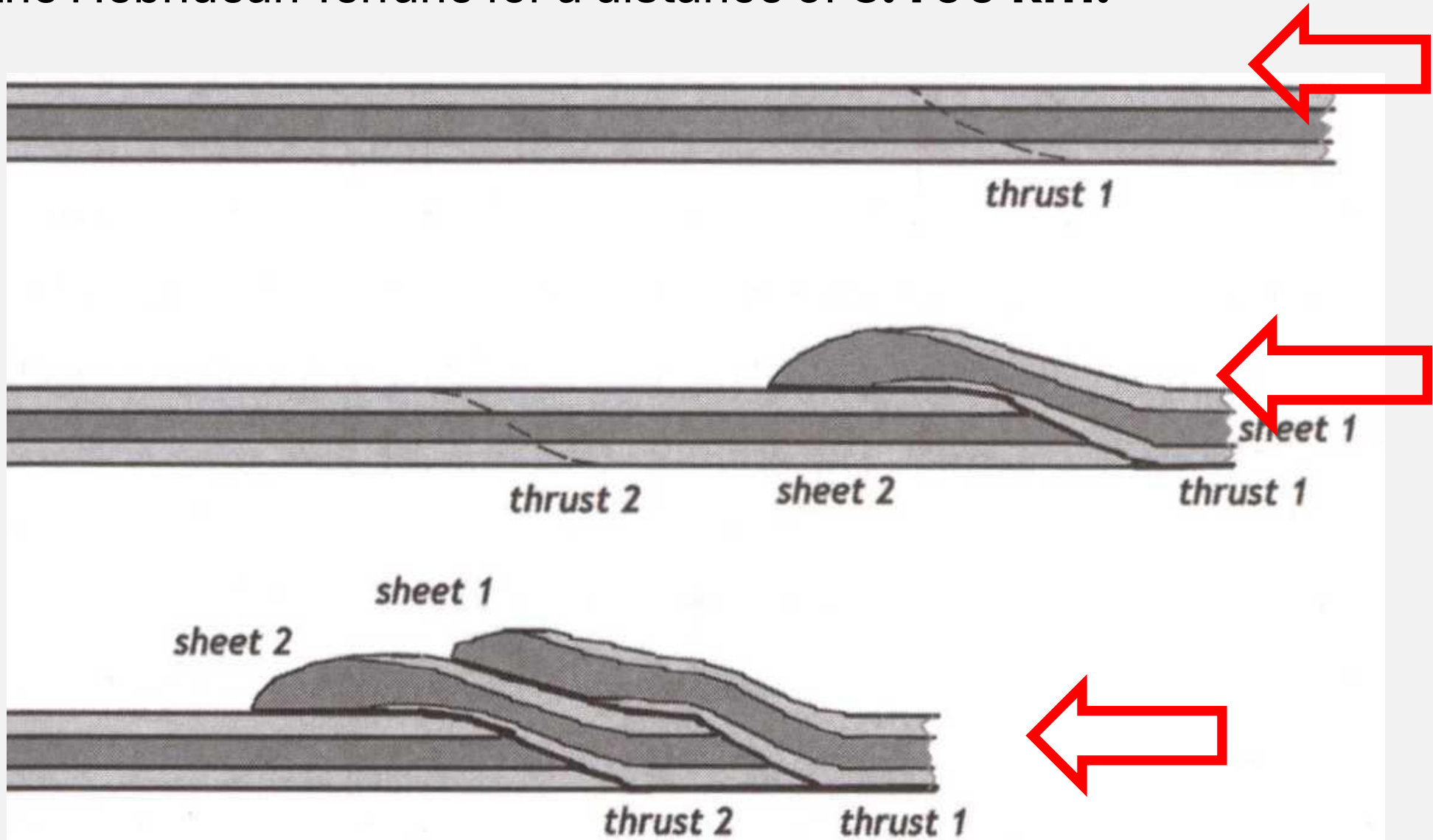


**Lewisian
gneiss**

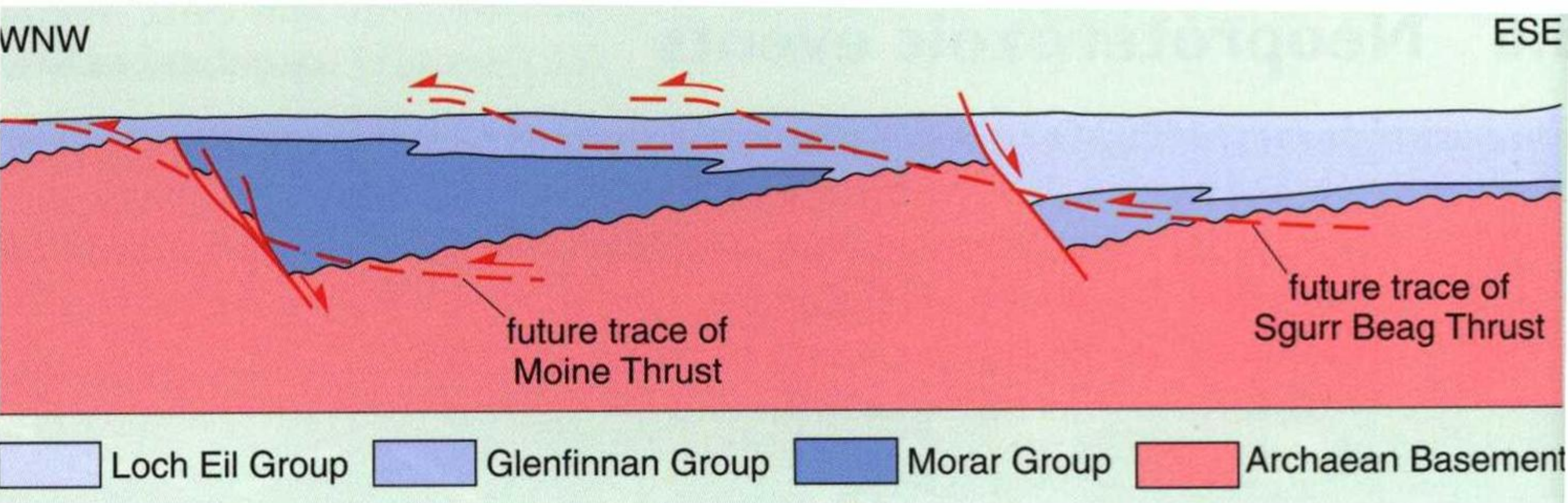
Cambrian quartzite and Pipe Rock

**Lewisian
gneiss**

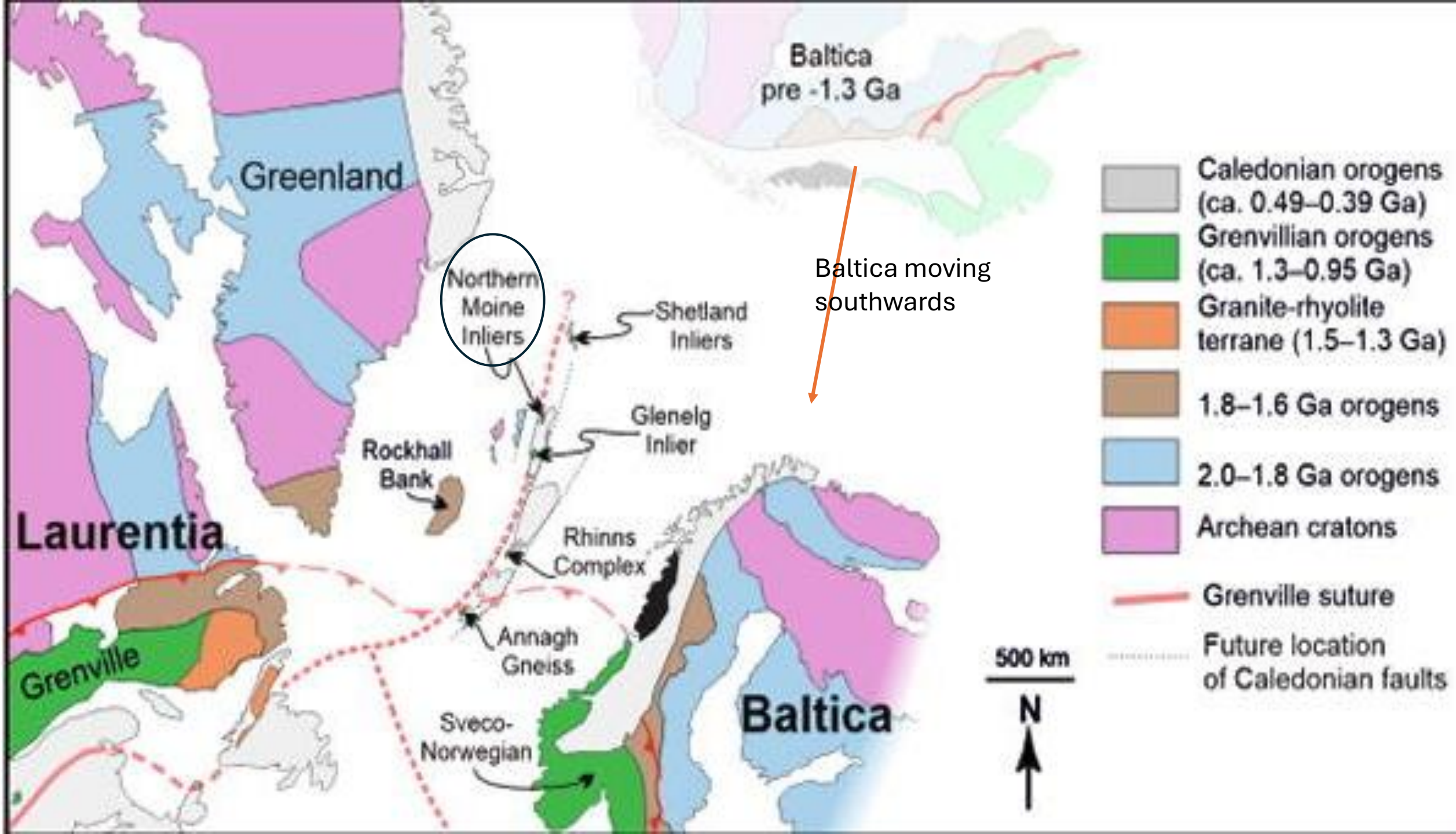
Moine Thrust Zone stretches from Shetland to Sound of Iona and across to Ireland. The MTZ represents an overthrust of the Moine rocks of the Northern Highland Terrane on top of the Hebridean Terrane for a distance of **c.100 km!**



Depositing the marine sediments of the Moine requires an extensional ocean basin, which creates faults such as the Moine Fault.

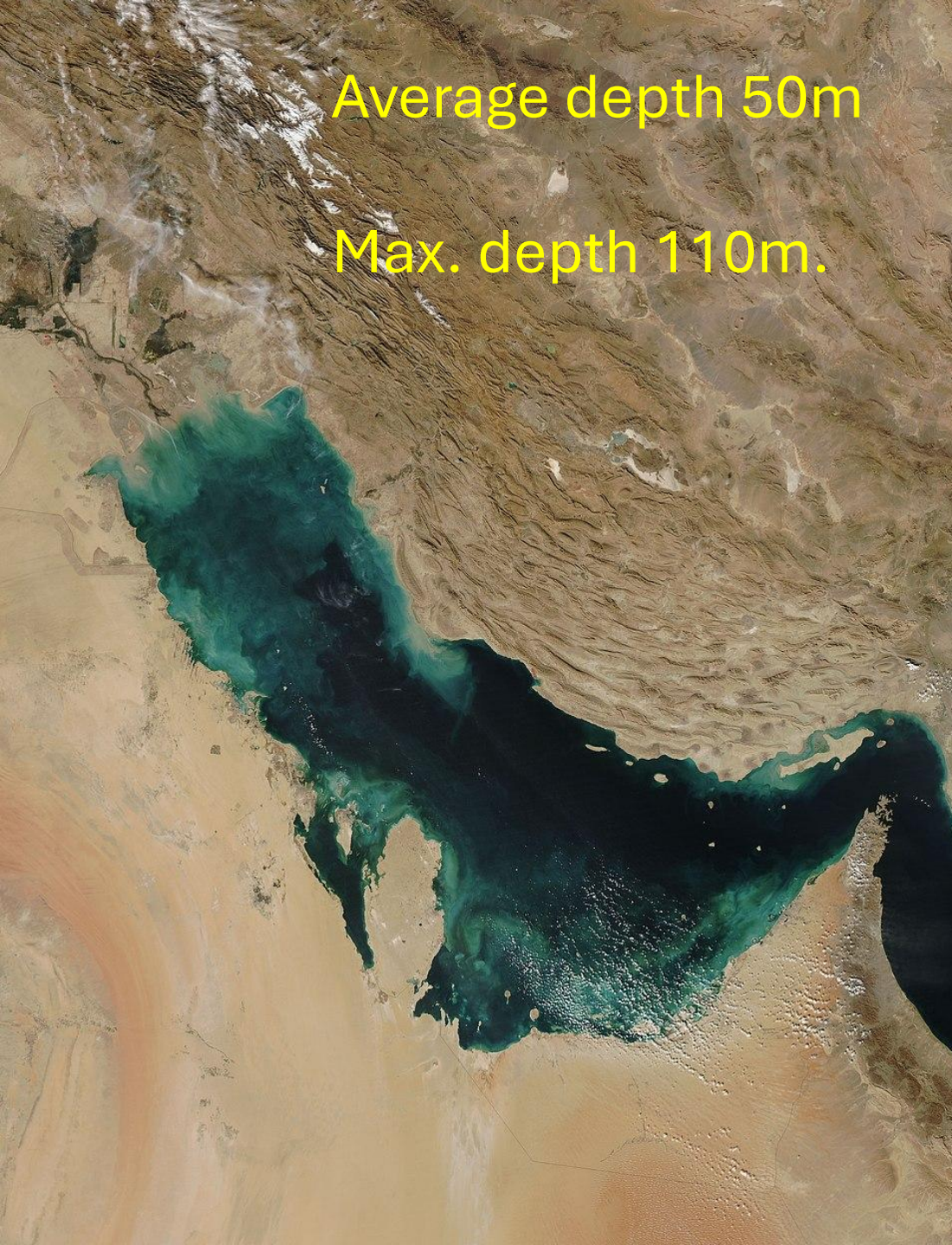


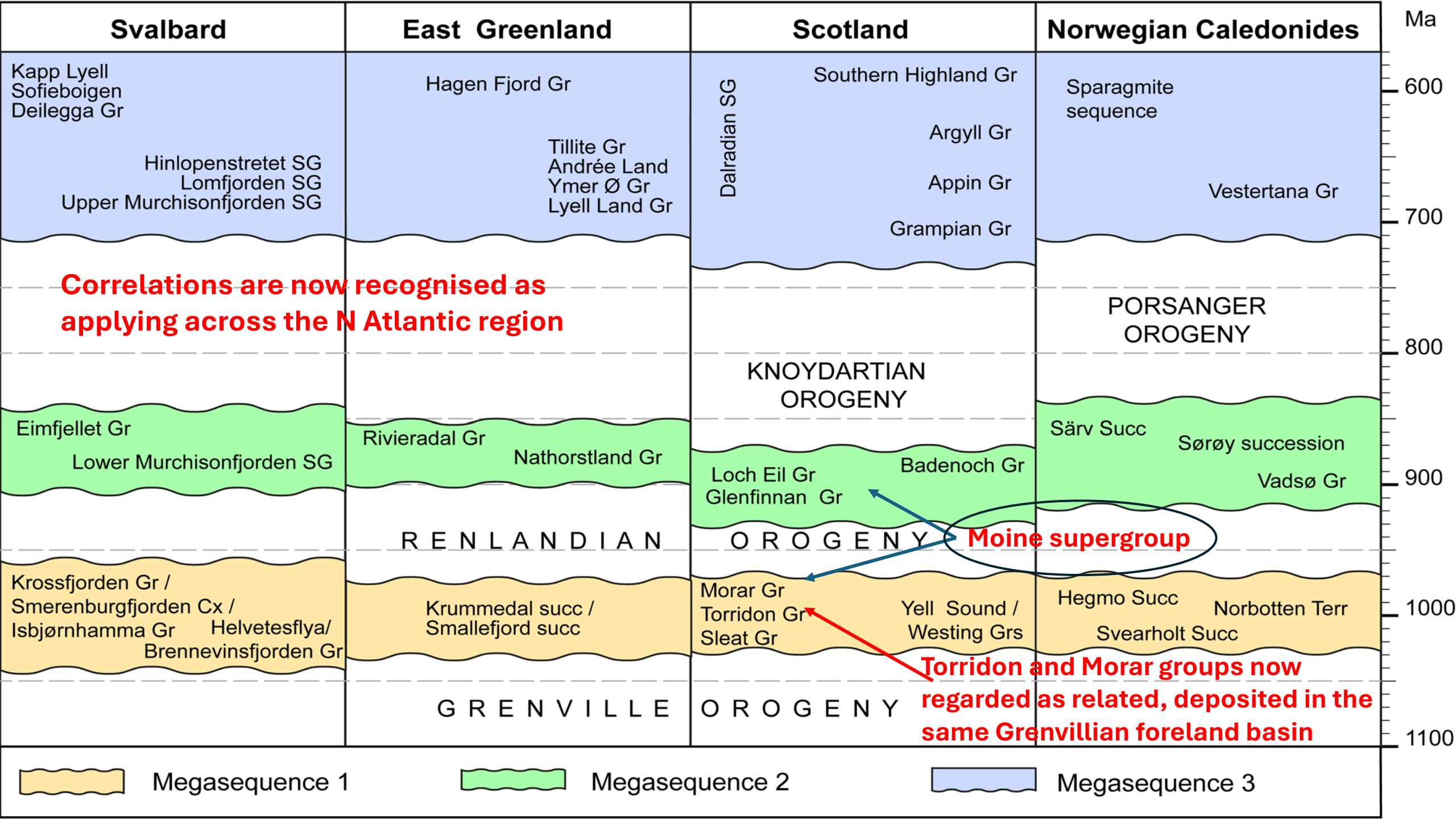
← extensional rifting →
Early break-up of Rodinia beginning – new ocean opening – sediments
flooding into the half-graben basins.
extensional-related magmatism > West Highland Granitic Gneisses



Average depth 50m

Max. depth 110m.



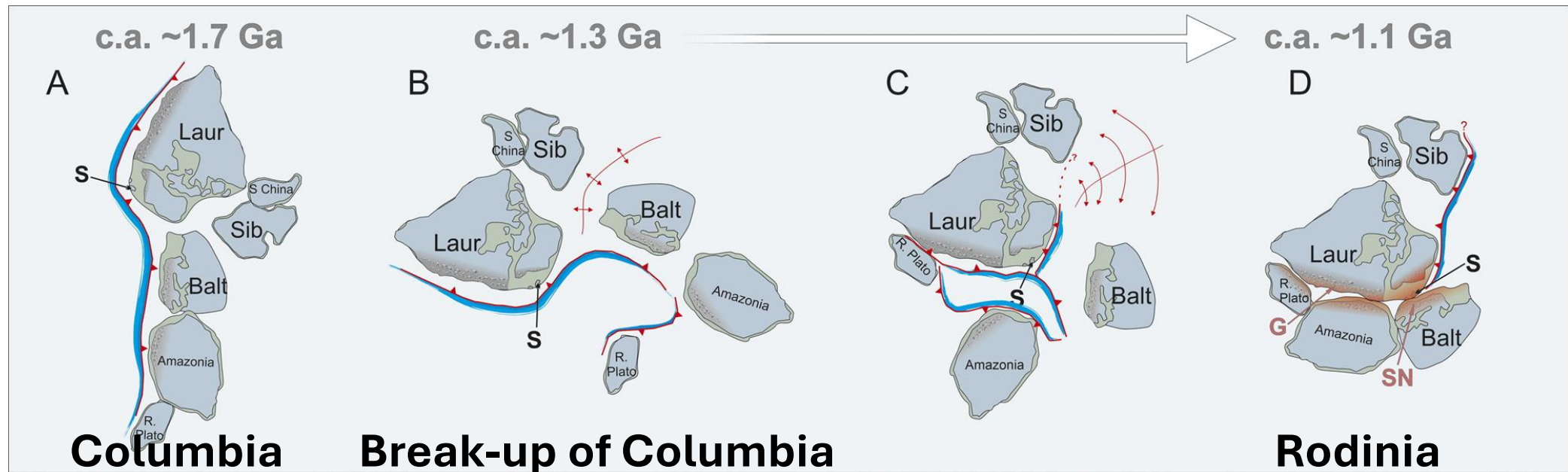


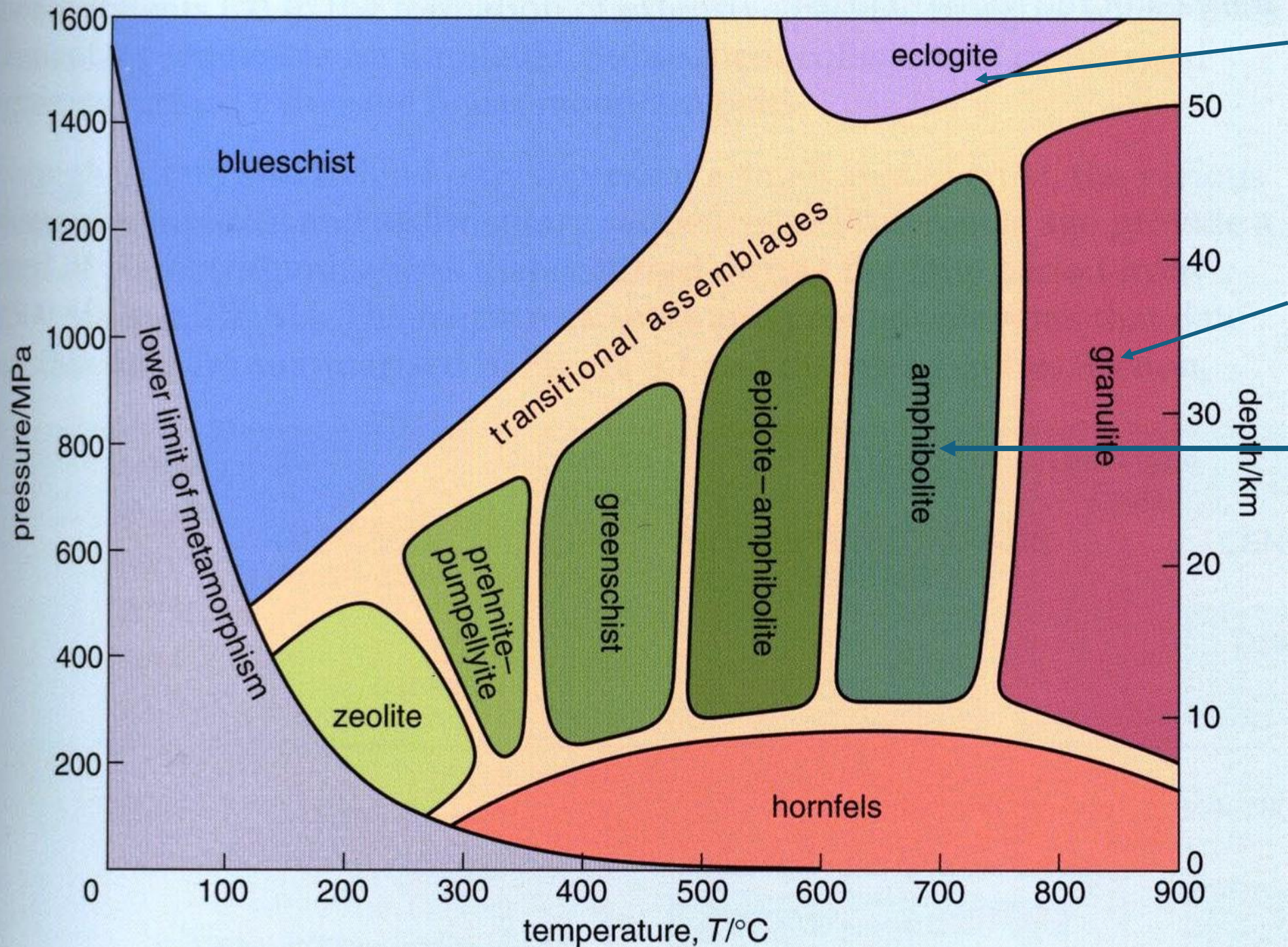
Summarising the latest conclusions from all the wider evidence across Laurentia:

- Youngest high grade metamorphic event in Laurentian Lewisian Gneiss was c.1850 Ma
- But Northern Highlands (NHT) basement was only affected by later high grade metamorphic event(s) 1700-1650 Ma, which are not seen in Laurentian - not present in Laurentia.
- So the NHT basement was not part of the contemporaneous Laurentian basement, but from a separate plate or terrane.

Around 1265-1000 Ma Baltica rotated (opening the Asgard Sea as it did so), and finally closed the ocean basin(s) between Baltica and Laurentia, with consequent scraping up of the ocean floor sediments.

The NHT then represents the accreted ocean floor sediments. The suture between Laurentia and the NHT is presumed to lie within the 100+km buried beneath the Moine thrust as Baltica collided.





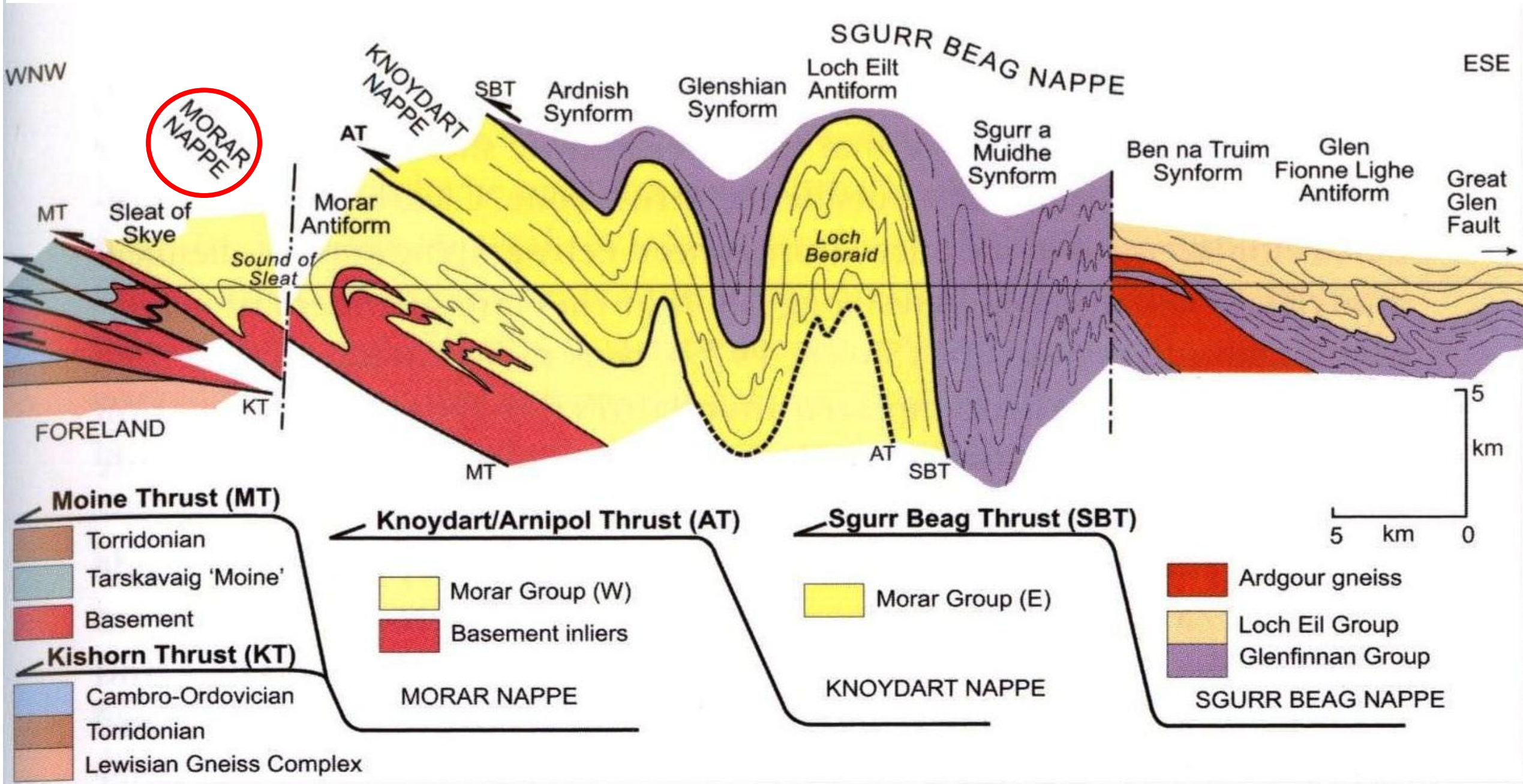
Key indicator of collisional orogenesis. Found in the Lewisianoid Eastern Glenelg basement inlier of the NHT.

Basalt of ocean floor metamorphosed to granulite facies.

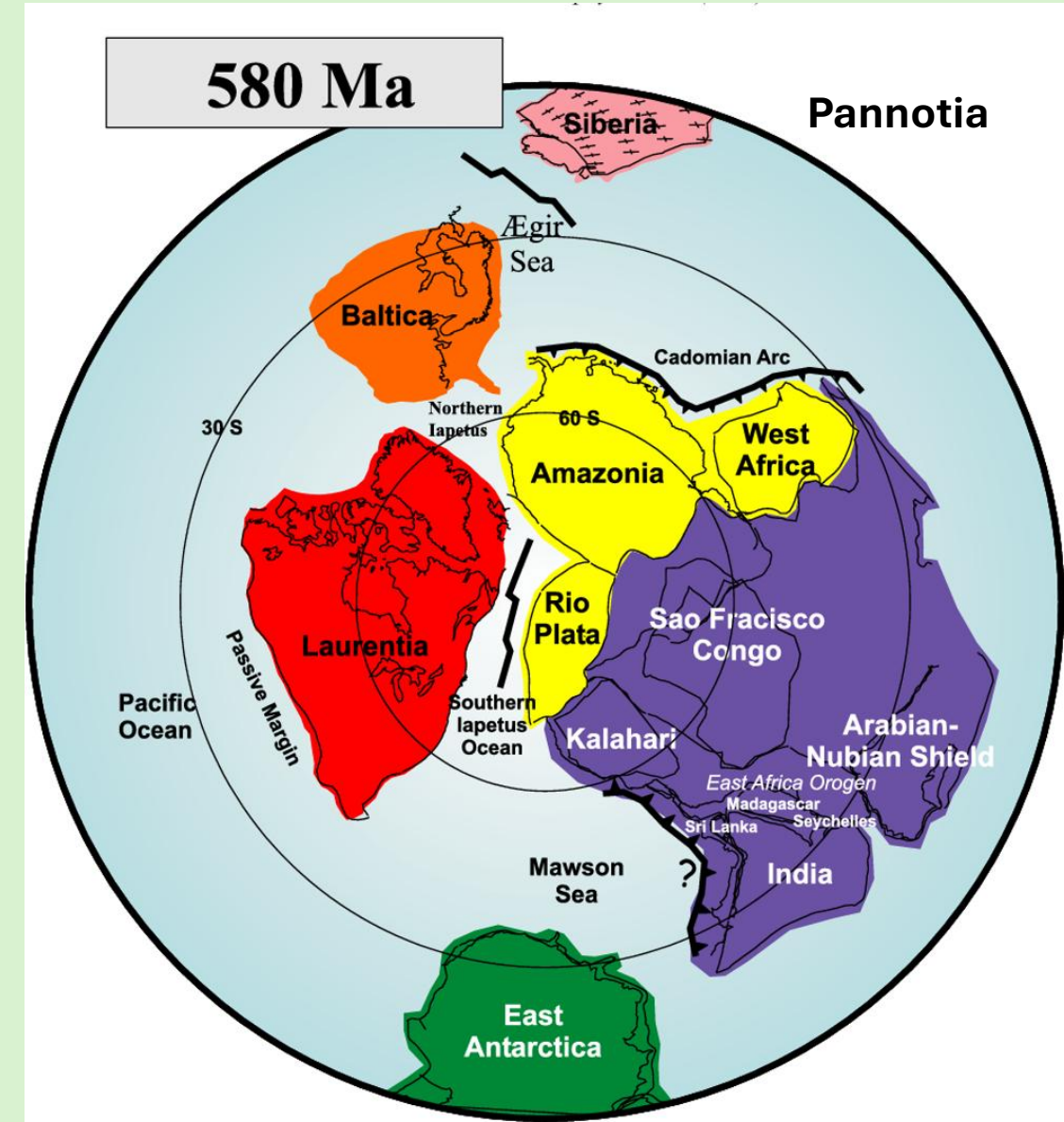
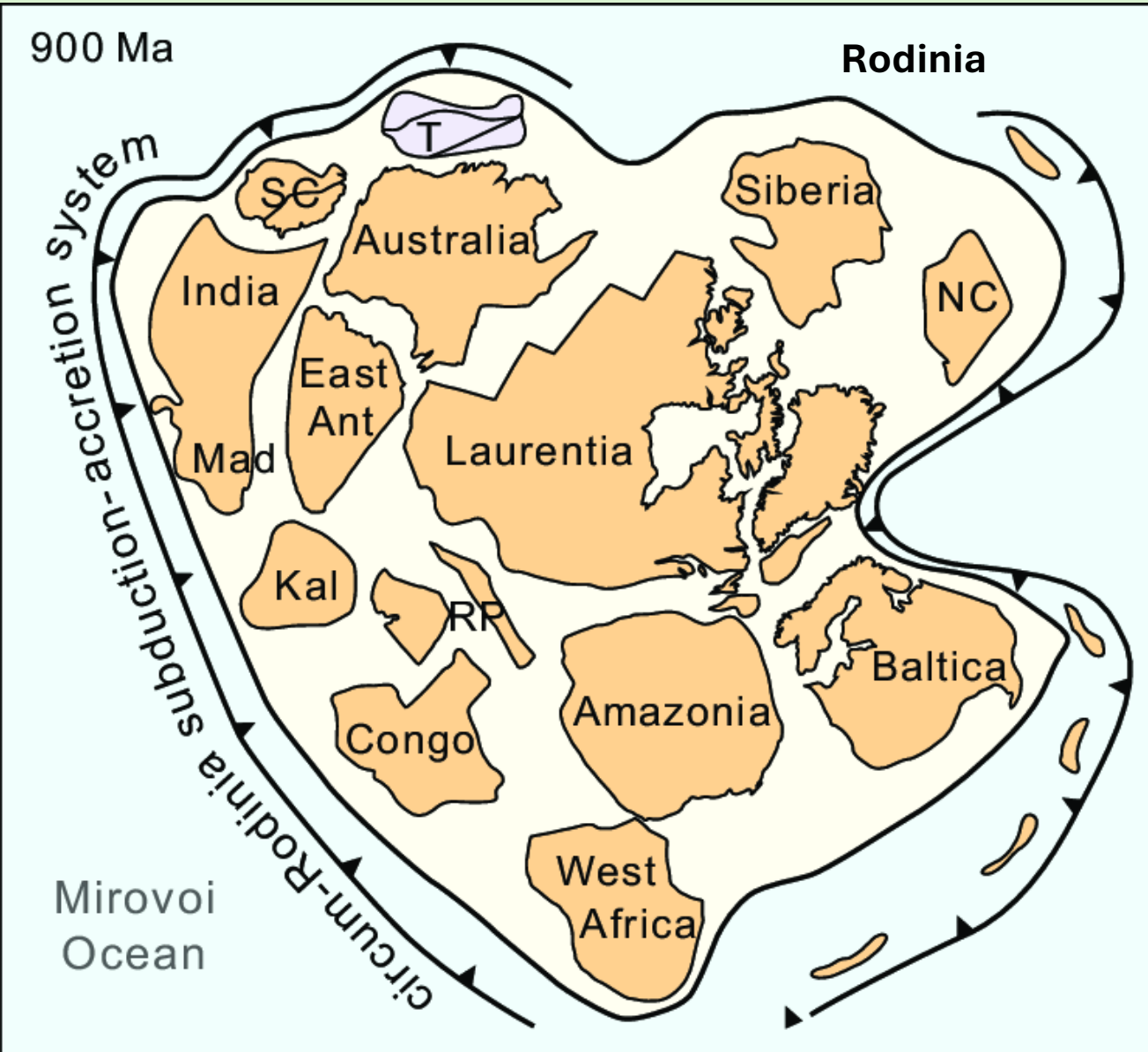
Marine sediments have been metamorphosed to amphibolite facies – schists – over most of the NHT.

Isotopic dating of the metasediment original deposition is based mainly on unchanged detrital rutile and zircon grains embedded in the muds.

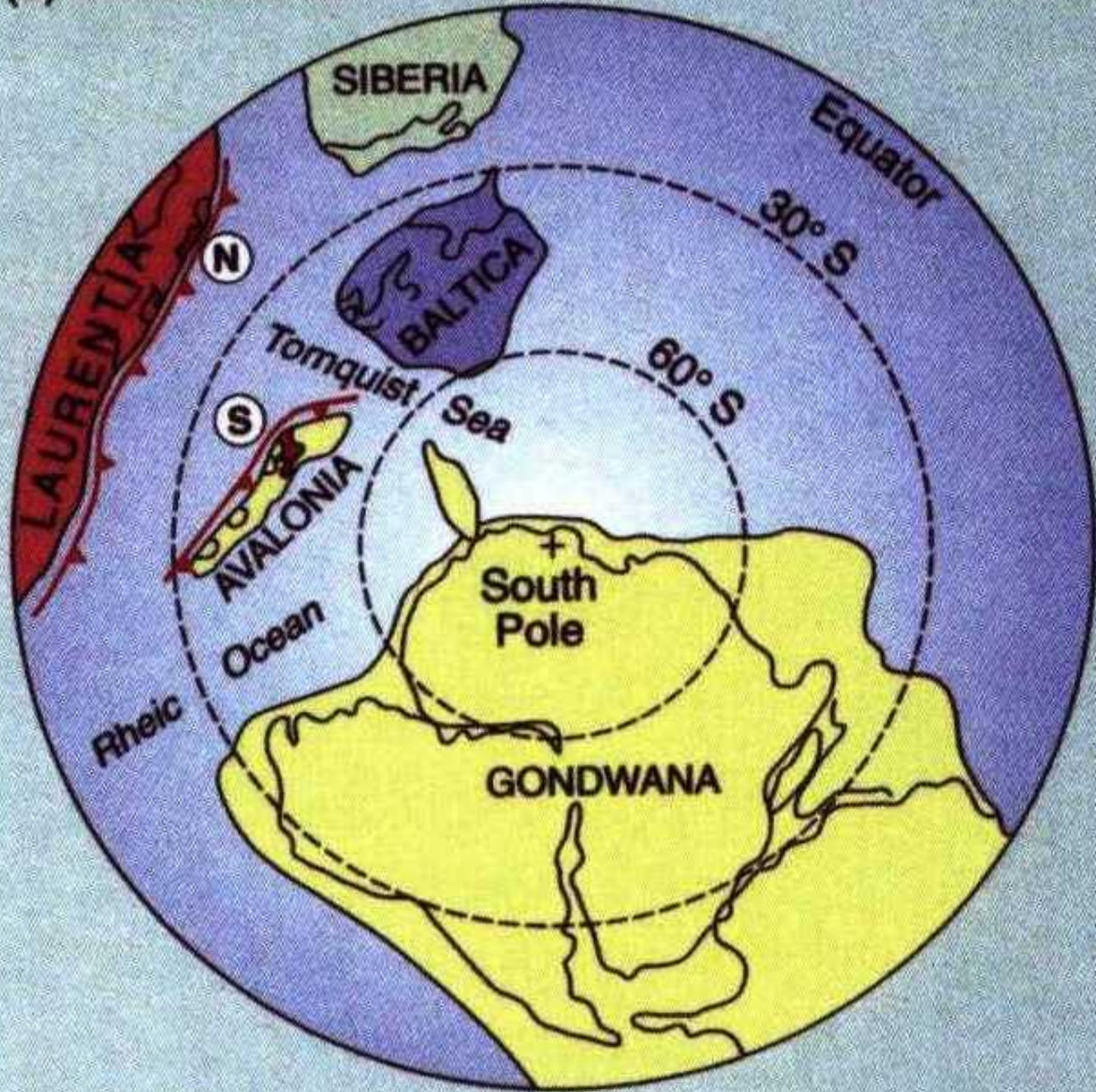
Deep burial is the first stage of why we have ended up with this mess!



So now at 1.0 Ga we are residents of Rodinia! But not for very long as Rodinia is short-lived and soon comes apart, the plates move around until at 580 Ma they form **Pannotia**:



(d) Mid-Ordovician c. 470 Ma



470 Ma

Pannotia soon broke up. Then the Avalonian microcontinent broken away from Gondwana and headed towards Laurentia.

Baltica came back as well!

A double collision approaching! And Baltica is much bigger than Avalonia

Note the subduction arcs (red lines with arrow heads) as the ocean plate goes down below the two continental plates, and the Iapetus Ocean closes, while behind Avalonia a new ocean opens – the Rheic Ocean.

The collision produced a major orogeny in two stages:

The Caledonian Orogeny

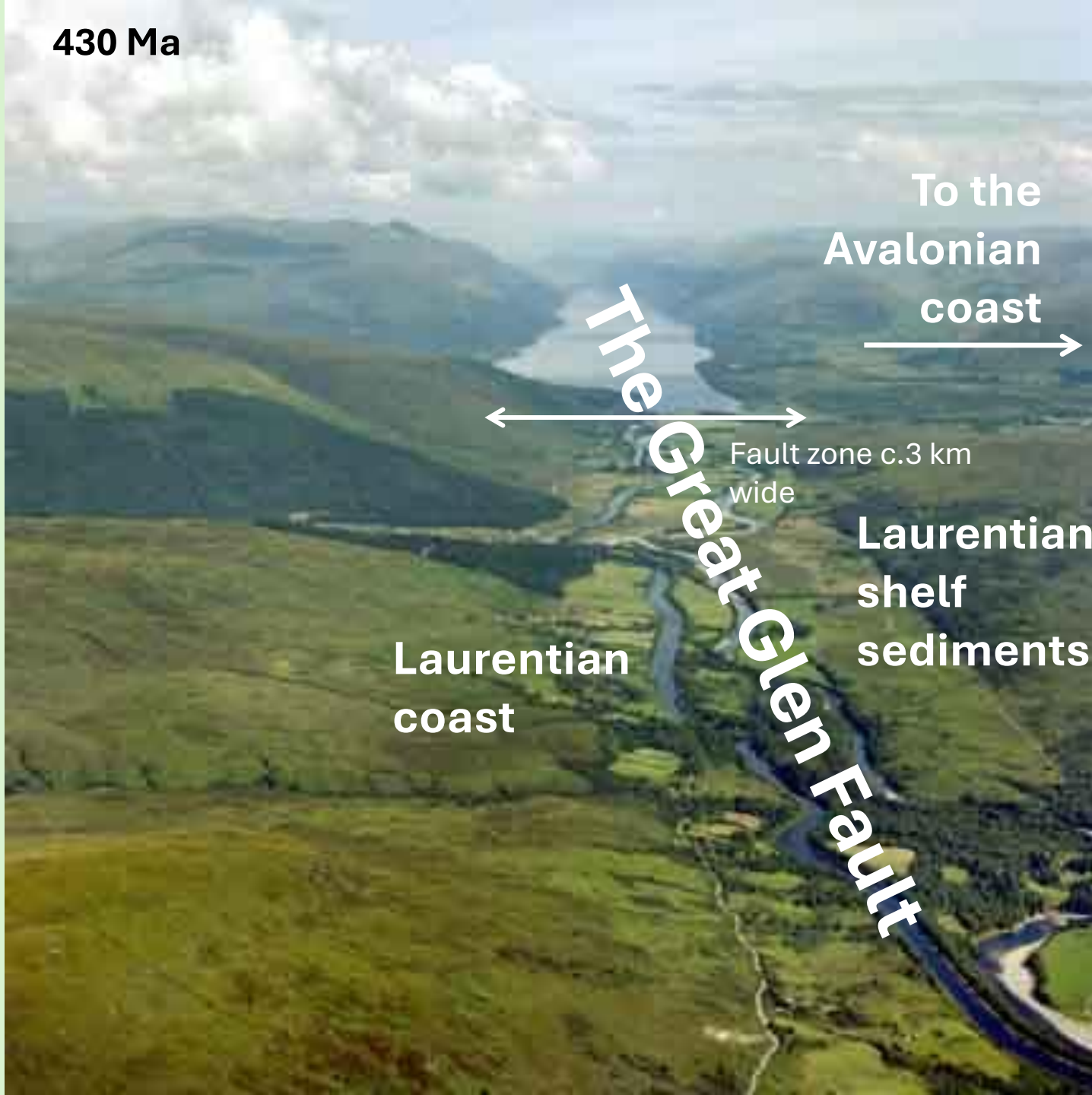
Grampian phase

- 470-460 Ma
- Affected Grampian, Midland Valley and S Uplands Terranes
- Little effect on NW Scotland
- Probably the result of the approach of Avalonia, carrying England & Wales
- Complicated story – the next chapter in our story!
- **We're trying to read this story now!**

Scandian phase

- 435-424 Ma
- Major effect on Northern Highlands Terrane
- Probably the result of Baltica as well as Avalonia colliding with Laurentia
- Probably the cause of the Moine Thrust and others in the NHT
- A simpler story!
- **We have read this story in the Moine thrust.**

430 Ma



The Great Glen Fault is formed at c.430 Ma, and movement continues as Avalonia with the Grampian Terrane (accreted shelf sediments) **scrape** their way first 'eastwards' then later 'westwards' along the Laurentian coast.

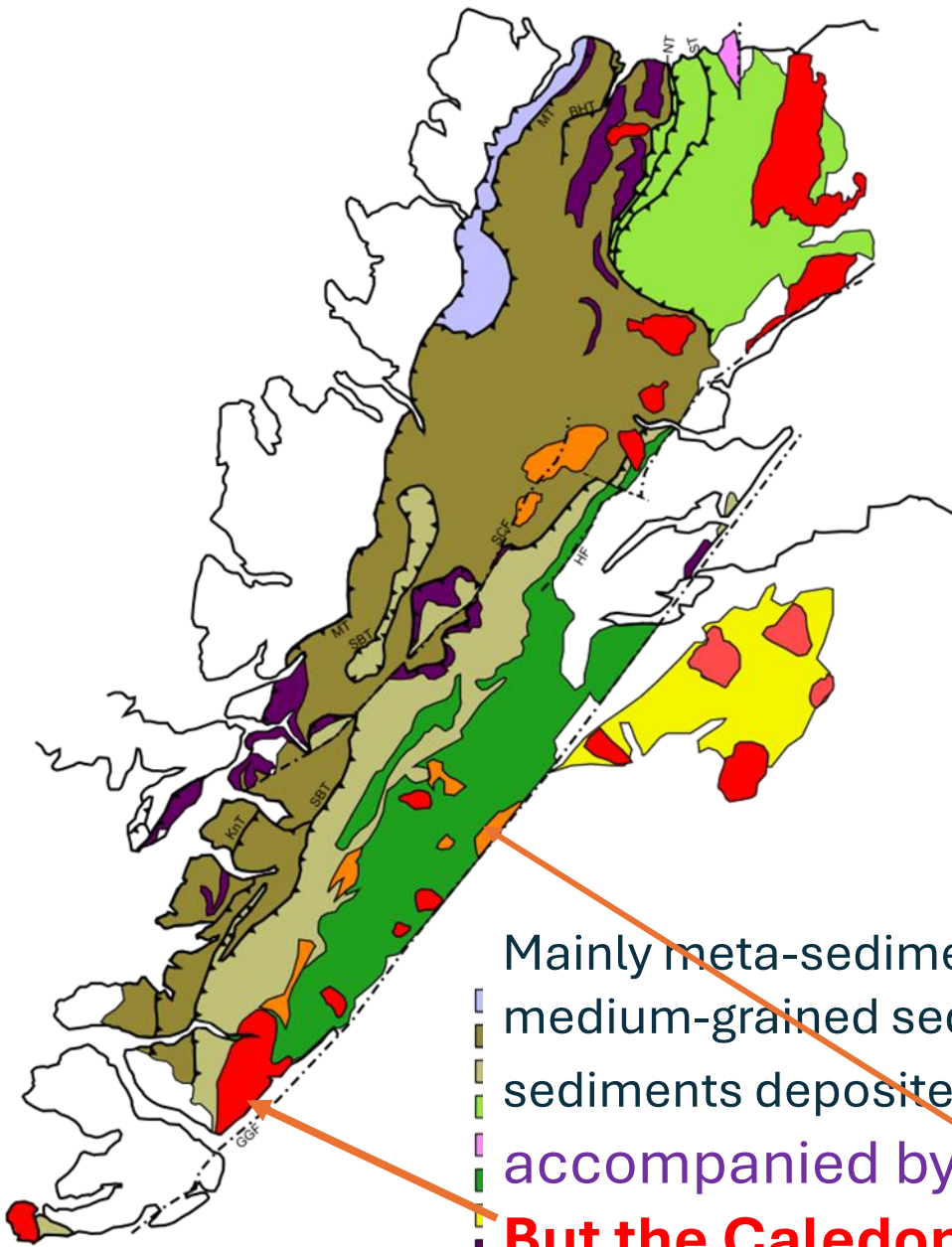
Major movement ceased c.400 Ma as Avalonia finally comes to rest, but minor movement continued until c. 60 Ma.

Total lateral displacement estimated at 104 km, but may be more. The fault continues across the North Channel and across Northern Ireland. It correlates with faults in Newfoundland and on into the Gulf of St. Lawrence. Also northwards through Shetland (Walls Fault) and away underneath later North Sea sediments.

Later ORS rocks (<400Ma) in the east of the fault zone show no strain.

The Moine Rocks of the Northern Highland Terrane

150 years of mapping!



Tectonostratigraphy

- Moine Thrust Zone
- Morar Group
- Glenfinnan Group
- East Sutherland Moine
- Strathy Complex
- Loch Eil Group
- Glen Bancher & Dava successions
- Lewisianoid basement

Pre-Caledonian intrusions

- Early granitic intrusions

Caledonian intrusions

- 'Older granites'
- 'Newer granites'

Structures

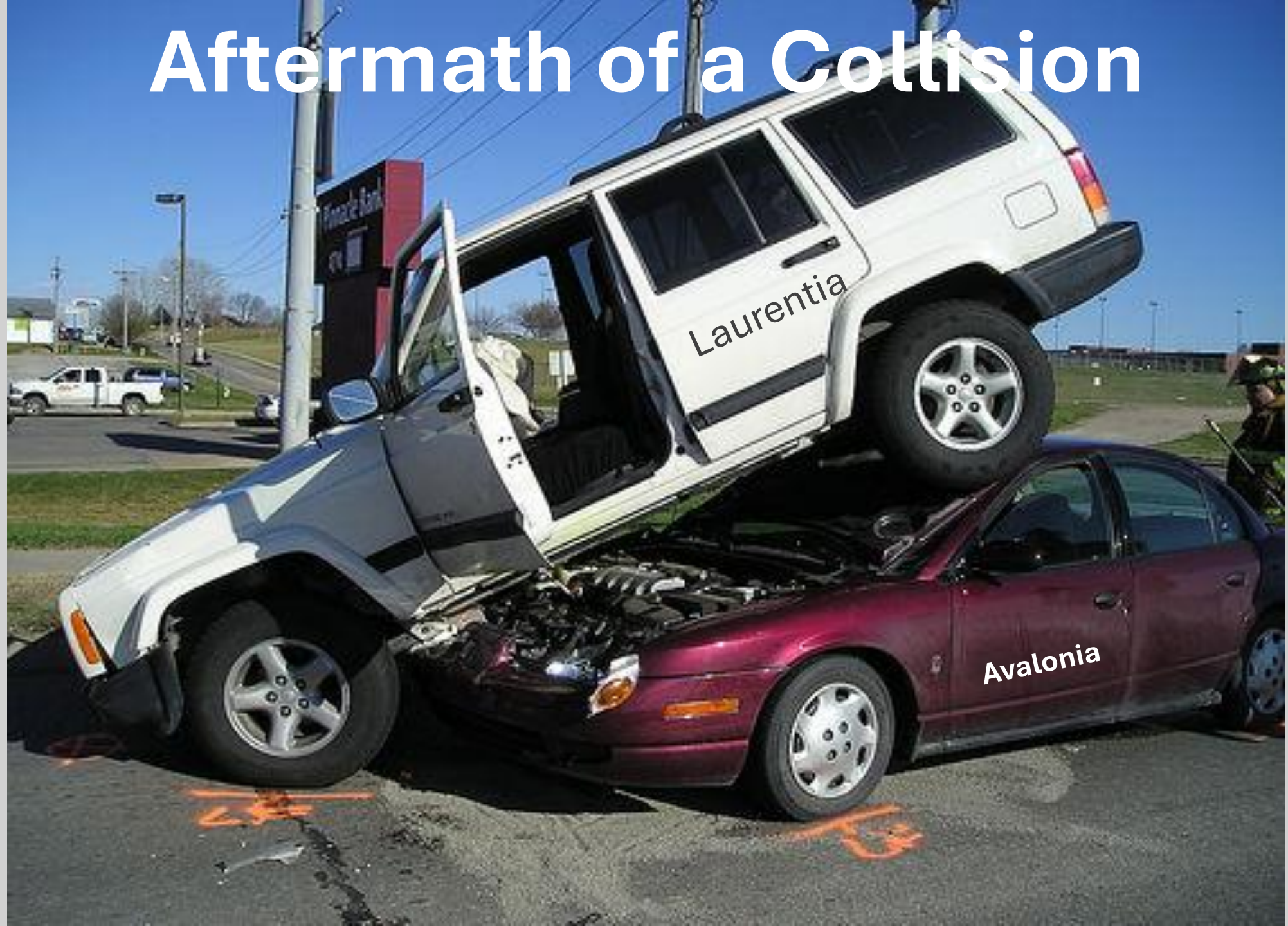
- Thrusts
- Normal & strike-slip faults

containing protoliths dated 2.9-2.7Ga & 1.8-1.7Ga

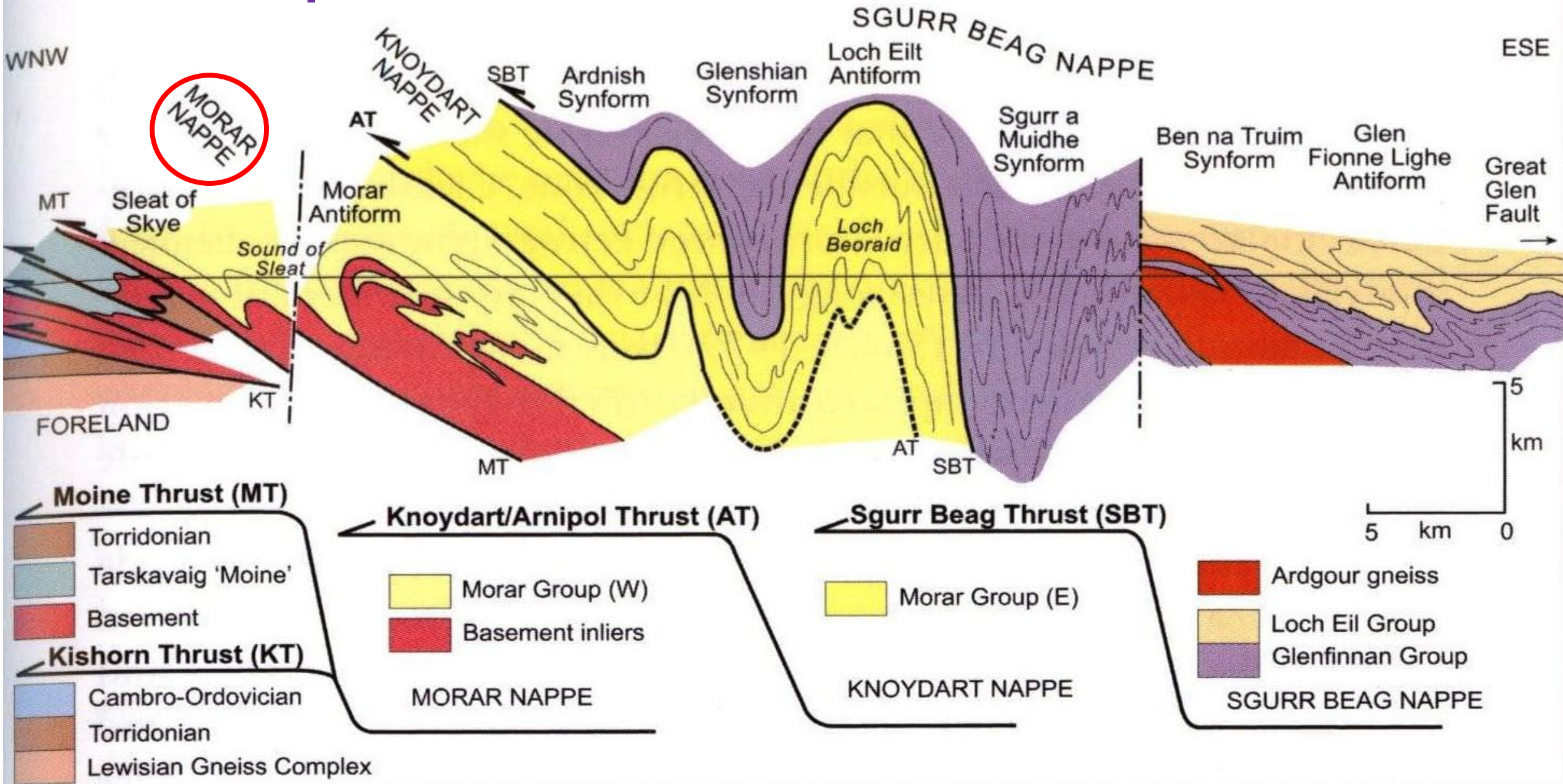
Mainly meta-sedimentary rocks: mica-schists and phyllites, derived from fine to medium-grained sediments: muds, shales, silts. These were continental shelf sediments deposited in offshore basins on a **Lewisianoid basement** and accompanied by **early granitic** intrusions (in orange).

But the Caledonian granite intrusions (red) post-date the collisions...

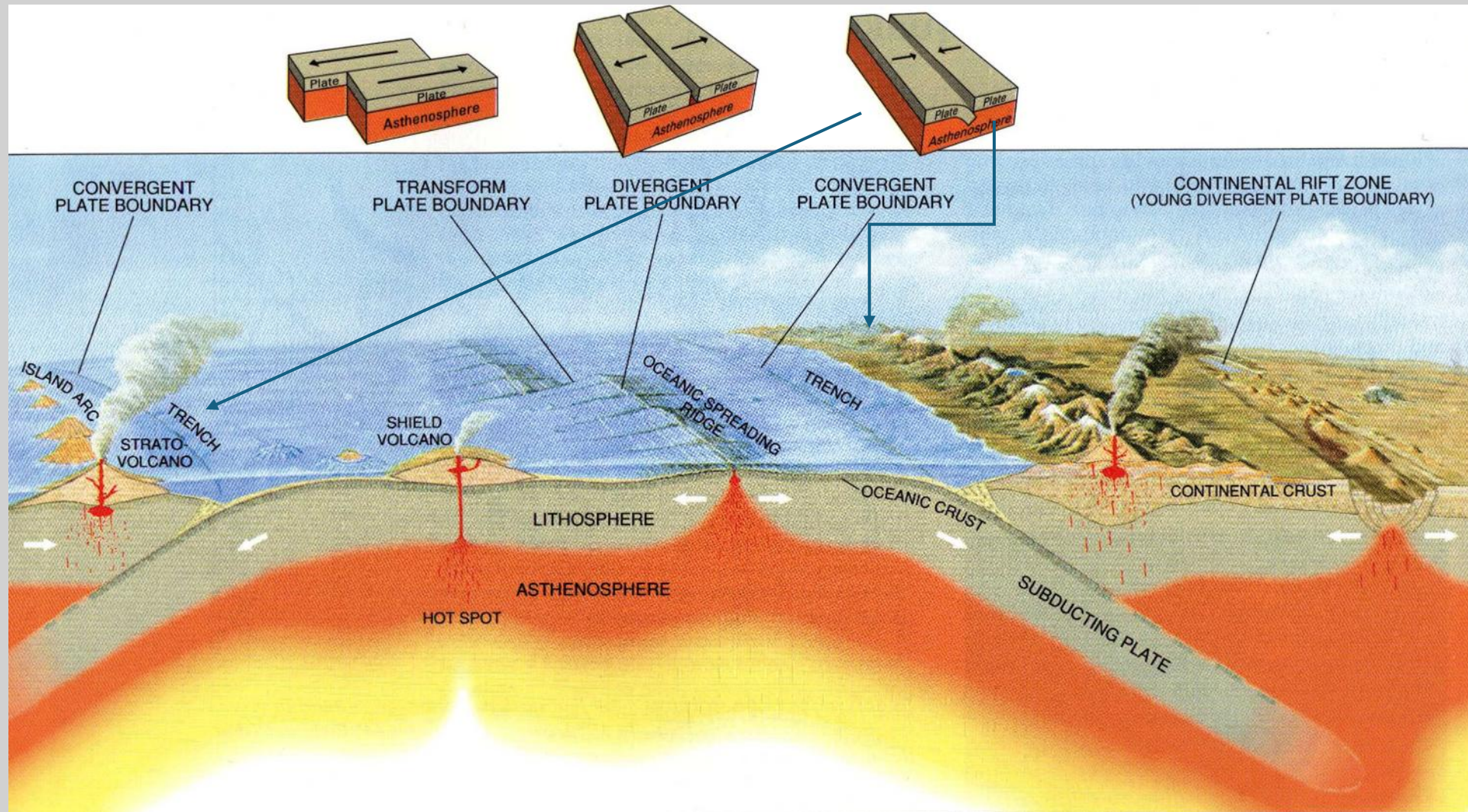
Aftermath of a Collision



The Crumple Zone



When Ocean Plate Meets Continental Plate



Guiding principle: more dense material sinks below less dense material.

Density of oceanic crust (basalt)

$\sim 3 \text{ g/cm}^3$

Density of continental crust (granite)

$\sim 2.7 \text{ g/cm}^3$

floor sediments

→ extraordinary phenomenon

volcanic arc

Ocean trench

Oceanic crust

Continental crust

Moho discontinuity

Solid uppermost mantle

Lithosphere

Asthenosphere

magma chamber

Hot basaltic oceanic crust and entrapped sea water under high pressure melt the lower-melting continental crust. This forms viscous granitic magma which rises.

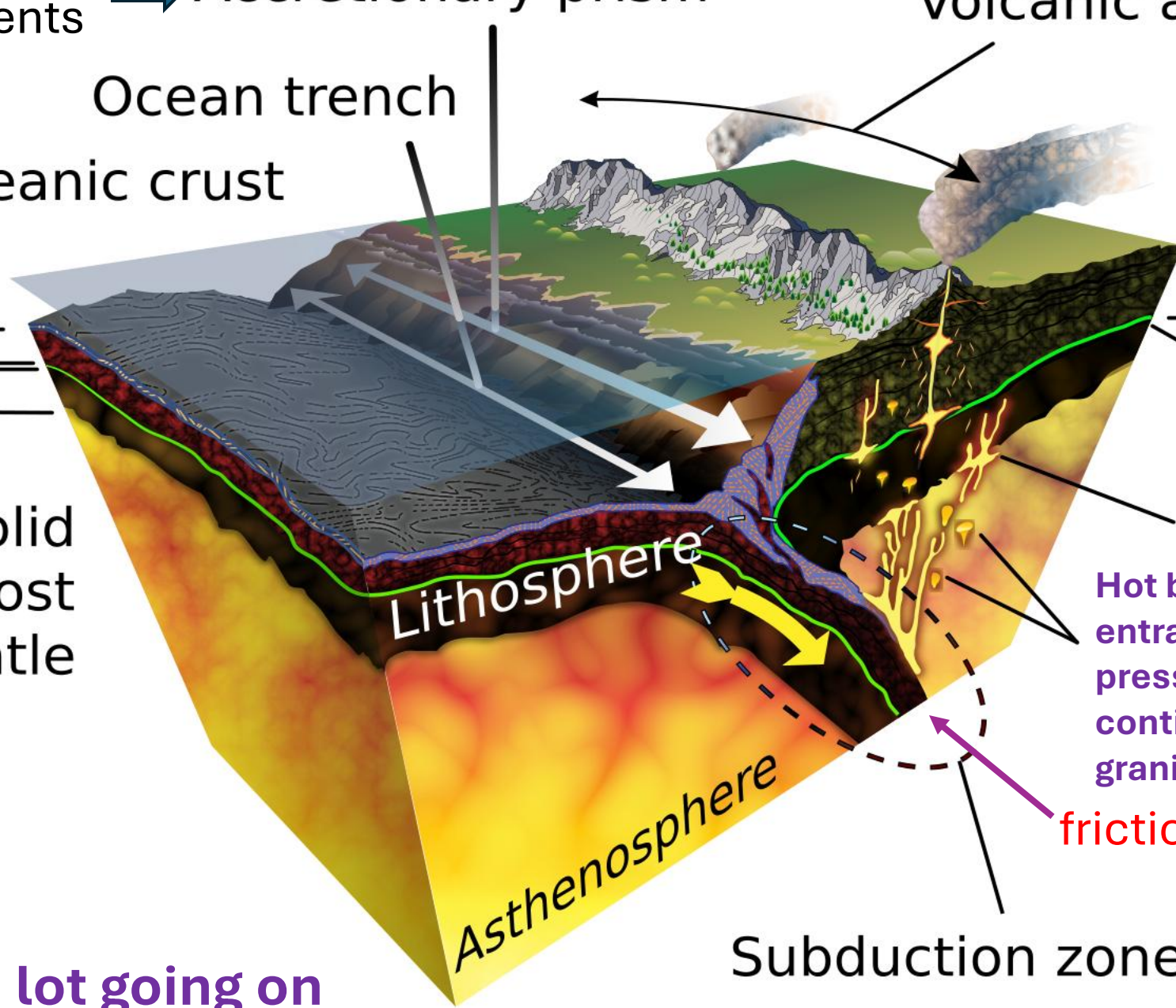
frictional heating

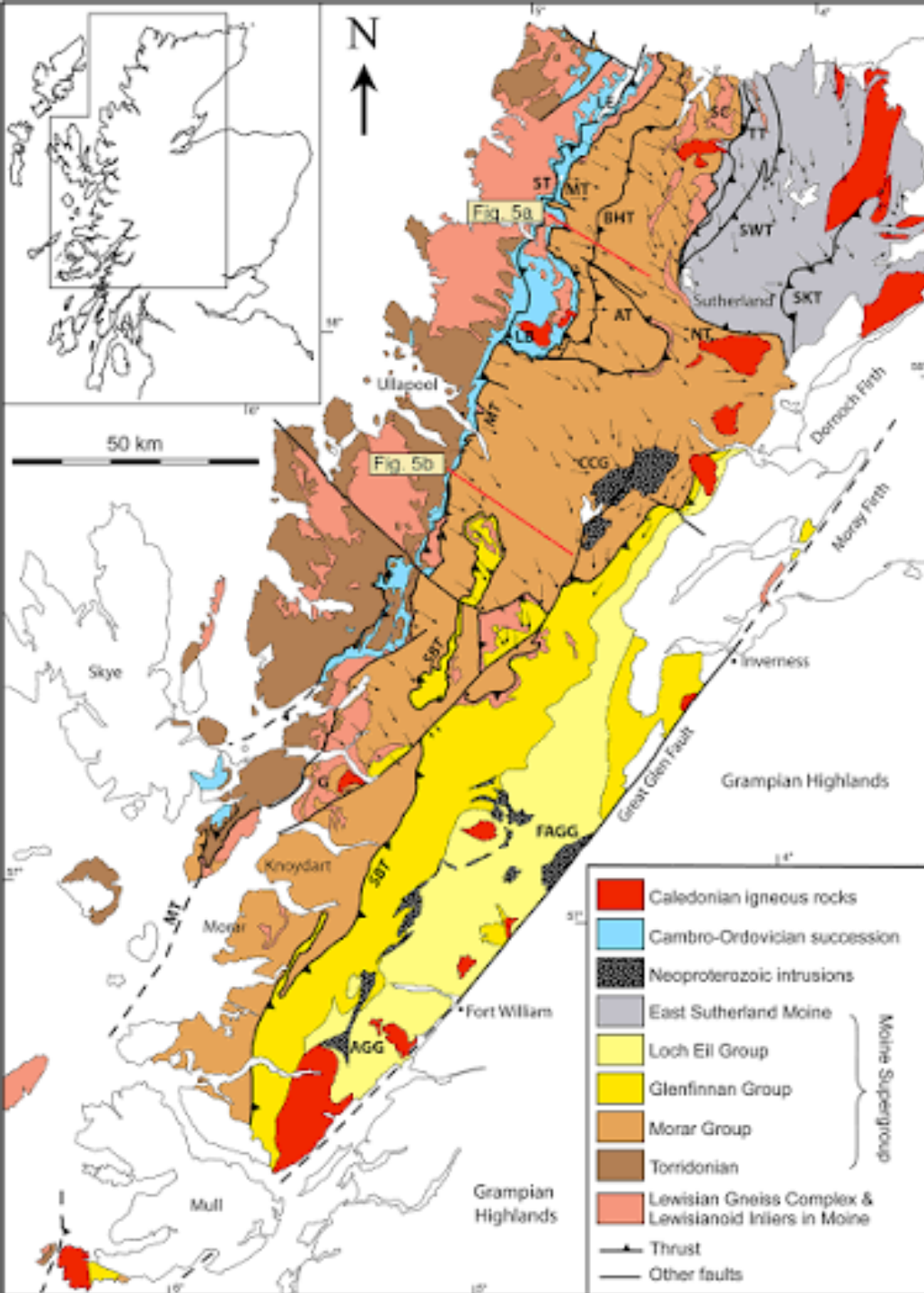
Subduction zone

And this is what was happening in the Caledonian collisions

There's a lot going on in a subduction event!

Ocean plate descends at an angle between 25° and 75°



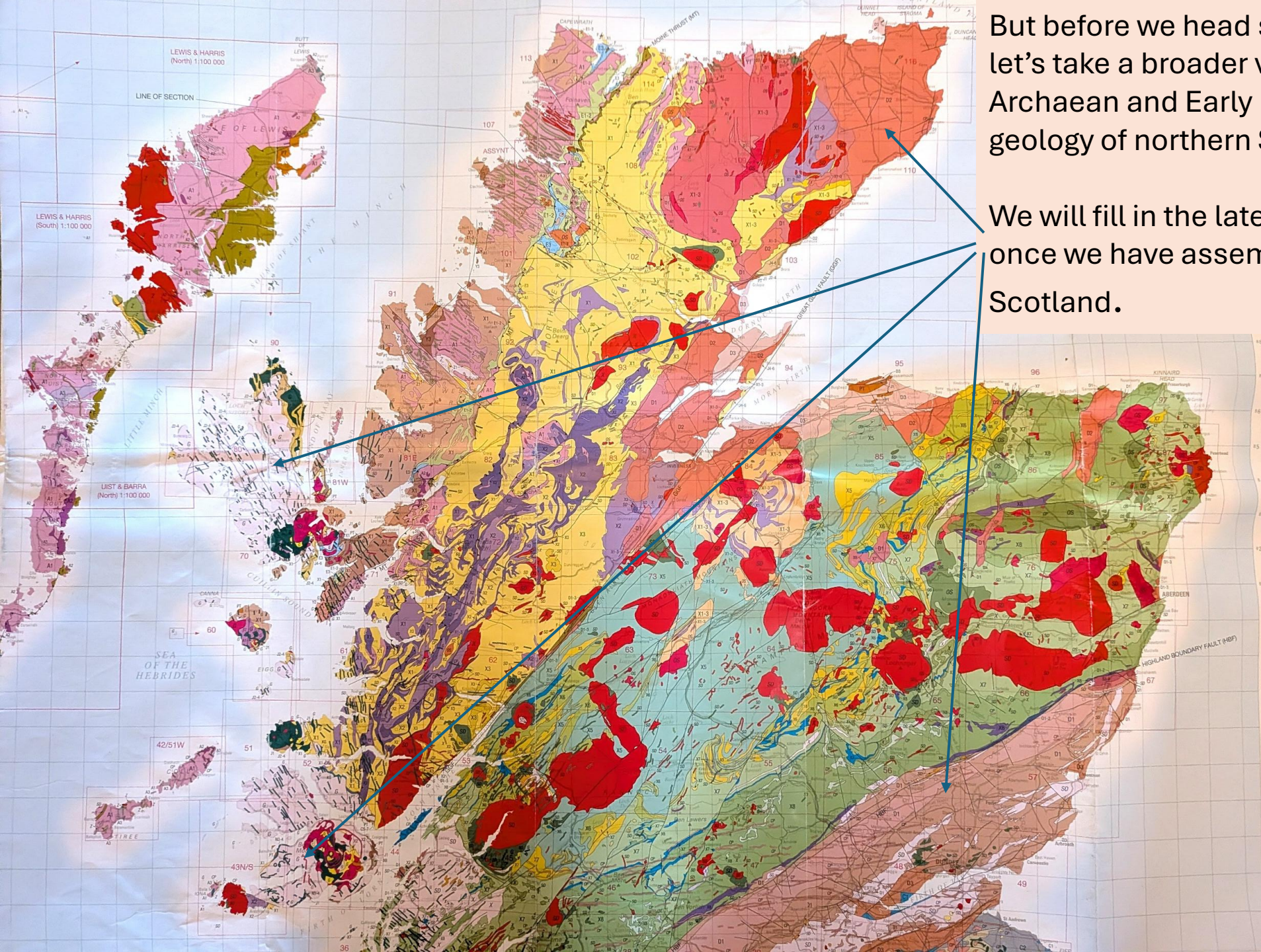


The Newer Caledonian granites of the Northern Highland Terrane – we will meet several more in the Grampian Terrane.

Note the Ross of Mull granite (50 km²), bottom left corner, and part of the Strontian complex (200 km²) sandwiched between the Moine Thrust zone and the Great Glen Fault. The Strontian pluton is the largest of the Newer Granite intrusions; **Glensanda quarry is worked in this intrusion.**

Dates of emplacement vary from 432 Ma to 400 Ma, with peak emplacement 426-418 ma. Ross of Mull age is 420 Ma.

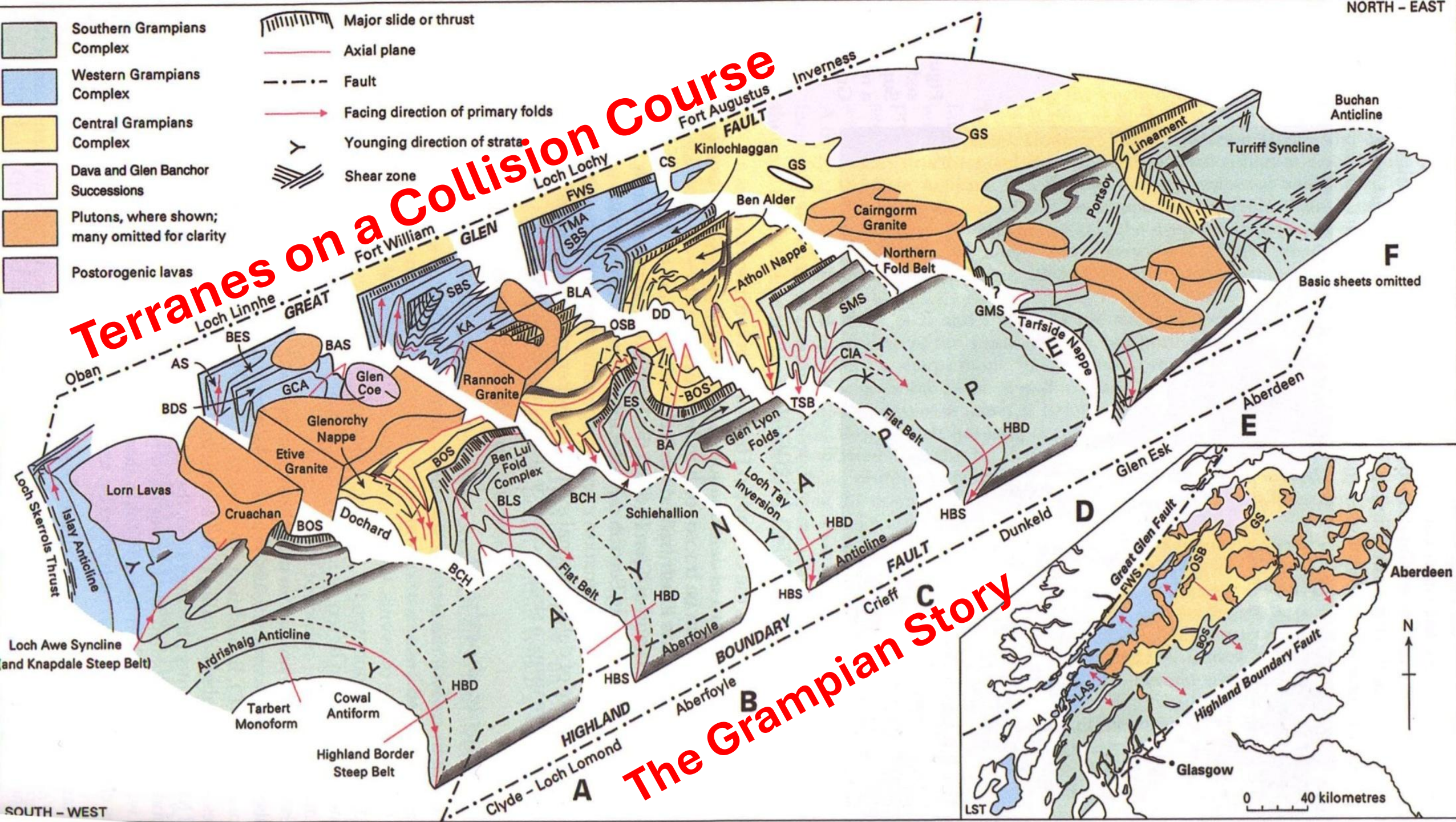
But we will have to venture south of the Great Glen Fault; so you thought the Northern Highland Terrane was complicated, just you wait!



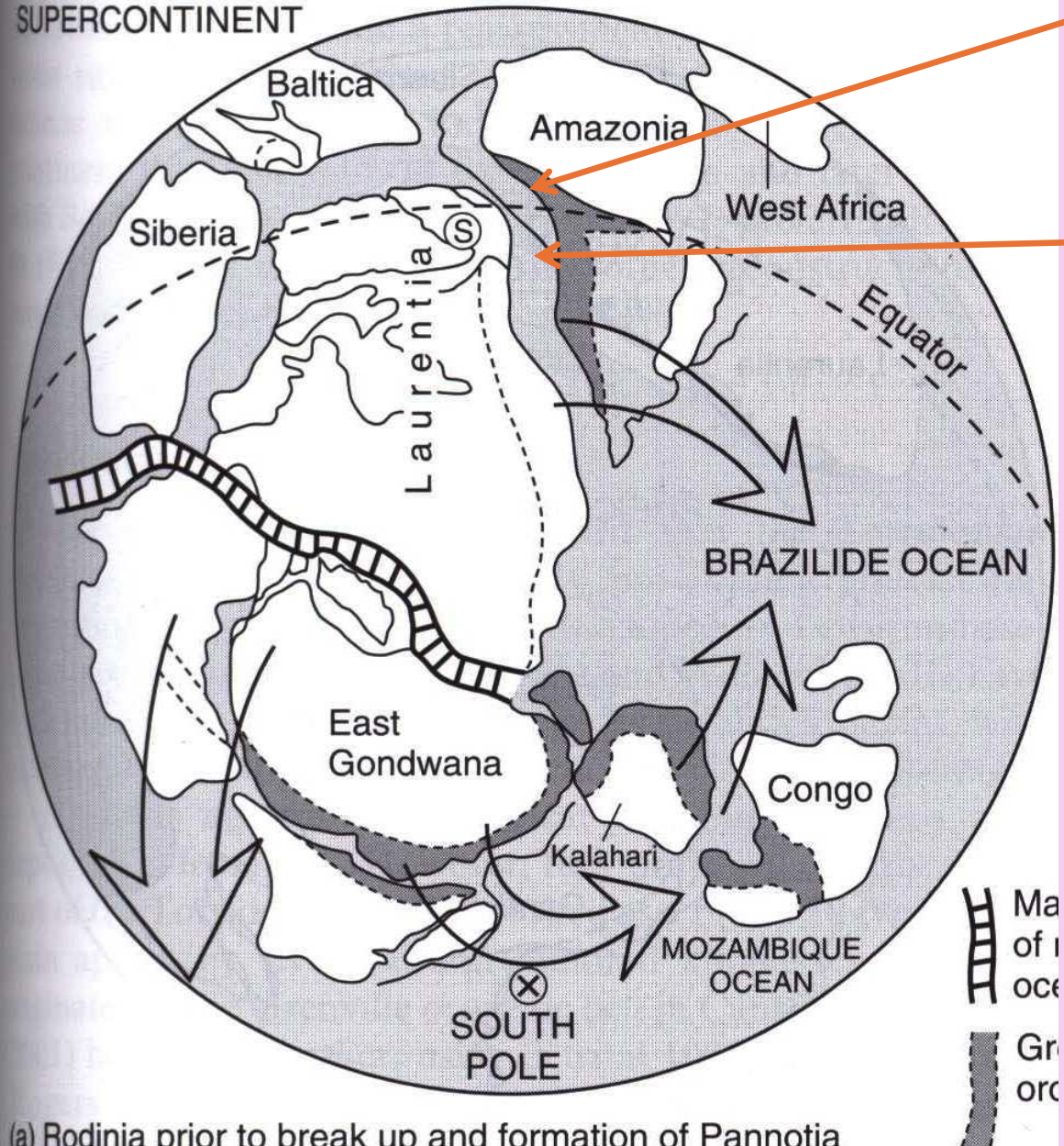
But before we head south,
let's take a broader view of the
Archaean and Early Palaeozoic
geology of northern Scotland.

We will fill in the later geology
once we have assembled all of
Scotland.





c. 750 Ma
RODINIA
SUPERCONTINENT



(a) Rodinia prior to break up and formation of Pannotia

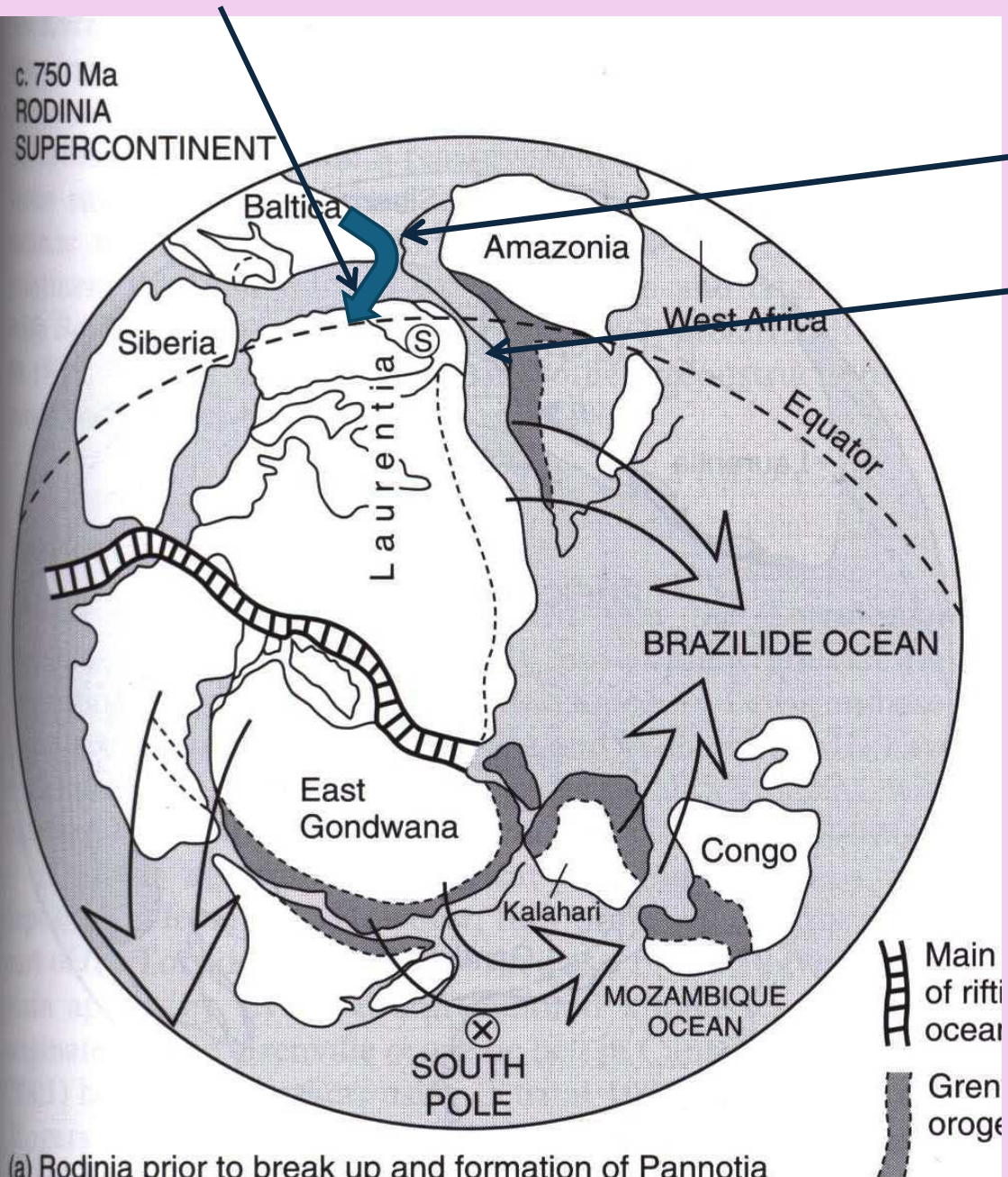
Iapetus
Ocean will
open here

The Grampian Terrane is
going to be formed from
the sea floor sediments of
the Iapetus Ocean,
somewhere around here!

Watch the
movements of Baltica
and Amazonia over
the next 400 million
years.

**We need to take a
closer look at the
events that led to
the plate collisions
and the Caledonian
Orogeny, starting
from the
disintegration of
Rodinia
800 – 700 Ma**

Asgard Sea opening



Break-up of Rodinia

Baltica rotates through 95°!

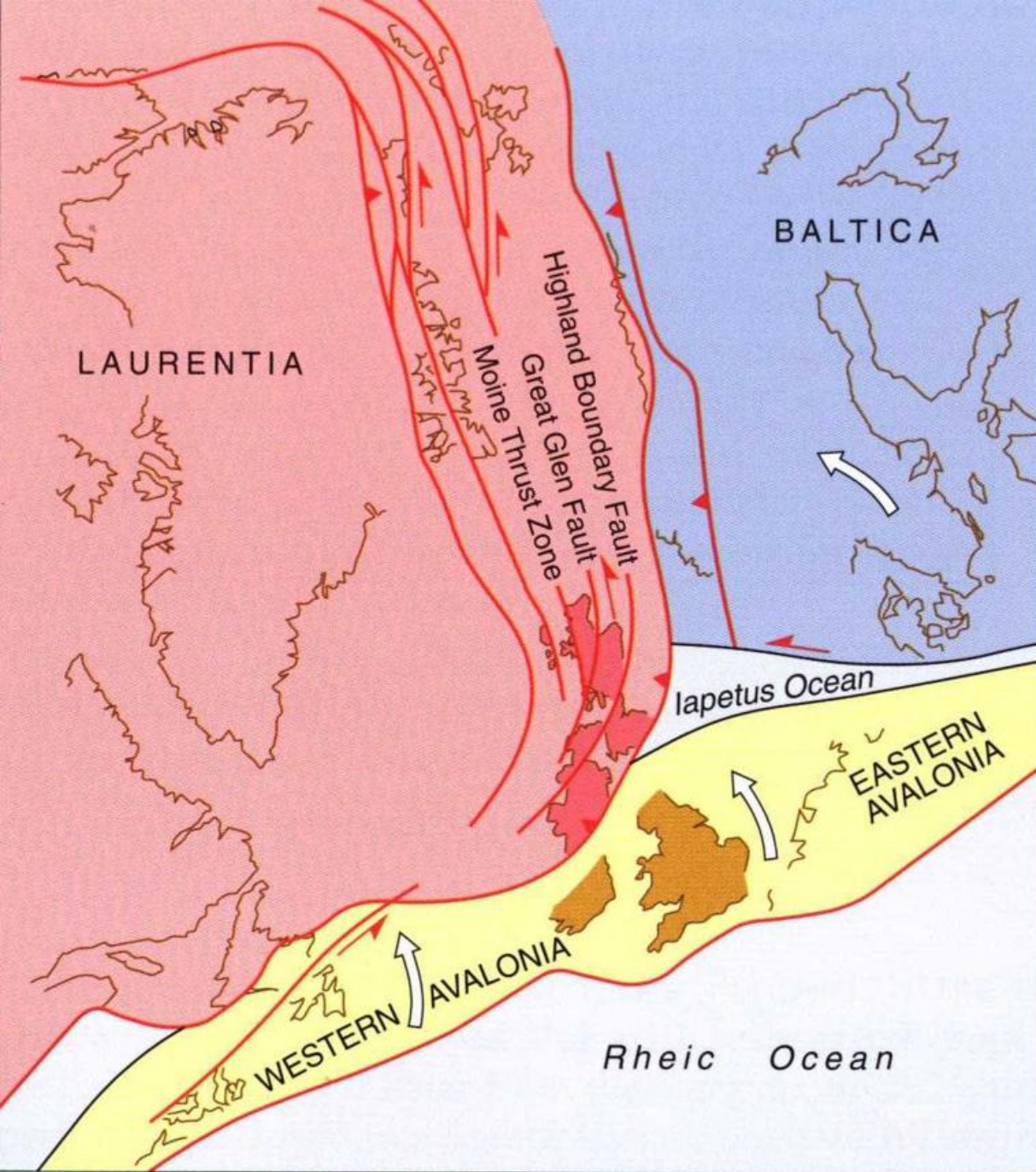
The Iapetus Ocean is about to open

The deepening basin of the Asgard Sea receives accumulating sediment in two cycles:

1030 – 980 Ma, followed by the Renlandian orogenic event as Baltica closes in, affecting parts of Laurentia.

910 – 870 Ma, followed by Knoydartian orogenic event, c. **800 Ma**, which affected the NHT.

In the ensuing 400 million years the Iapetus Ocean opened. Avalonia then broke off Amazonia and raced towards Laurentia and closed the Iapetus again. This created part of the Caledonian Orogeny.



(a) 420 Ma

The End of the Iapetus Ocean

and the development of the Grampian Terrane... next time (27th Oct).

But before that: Life Story continues on 13th Oct