The Variscan Orogeny; Causes and Consequences

Dorset Geologist's Association Group

22 April 2025

The Variscan is a complex orogen, resulting from closure of the **Rheic Ocean** - a key event in the consolidation of the Pangaea supercontinent

The focus of this talk will be on the Variscan Orogeny & it's influences in the southern UK

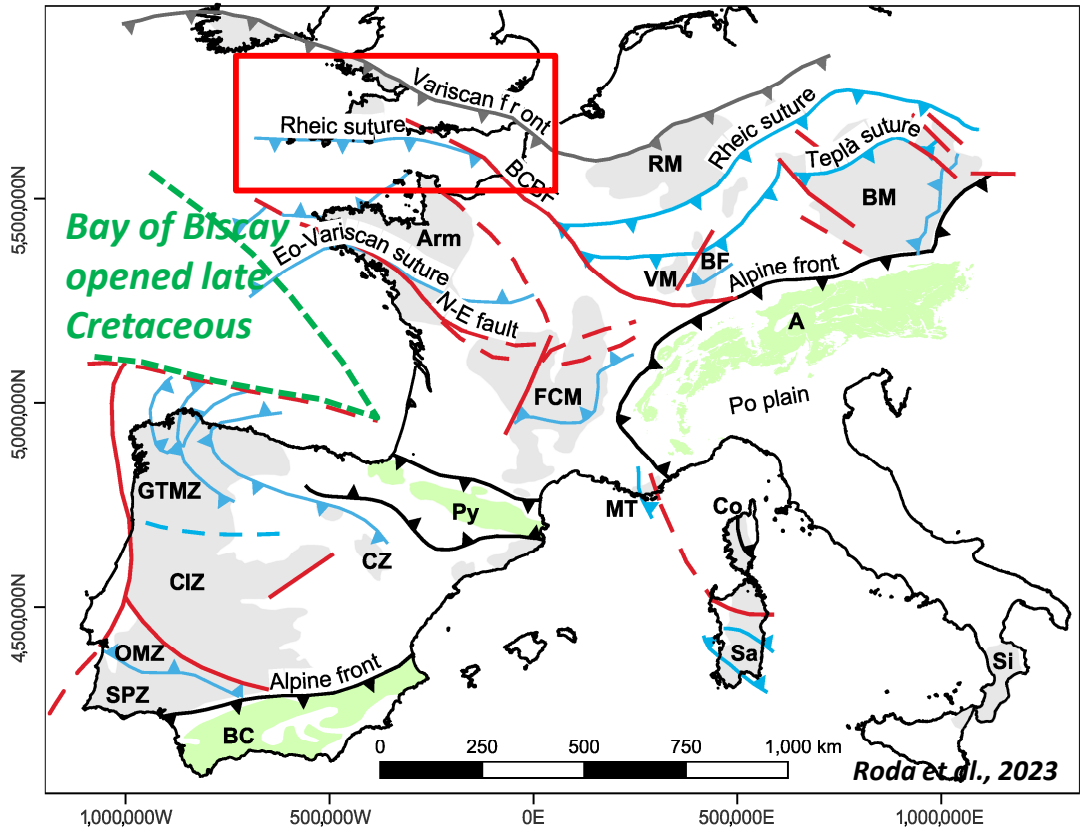
The main events we will discuss:

- **Early Ordovician to early Silurian -** opening of the Rheic Ocean (spreading phase)
- **Early Silurian to late Devonian -** ocean closure (subduction phase) - back-arc spreading - short-lived "Rhenohercynian Ocean" formed **early Devonian**
- **Latest Devonian & Carboniferous -** collision & deformation - the Variscan Orogeny
- **Earliest Permian-** Post-orogenic extension - granites & hydrothermal mineralisation
- **Late Permian to early Cretaceous -** extension & rift basin development exploiting Variscan structures
- **Late Cretaceous & Tertiary -** Alpine compression & rift basin inversion - shear basins

And then minerals associated with & influenced by the Variscan orogeny:

- Coal, oil & gas
- Tin & lithium
- China clay & ball clay
- Geothermal

Variscan structures & massifs



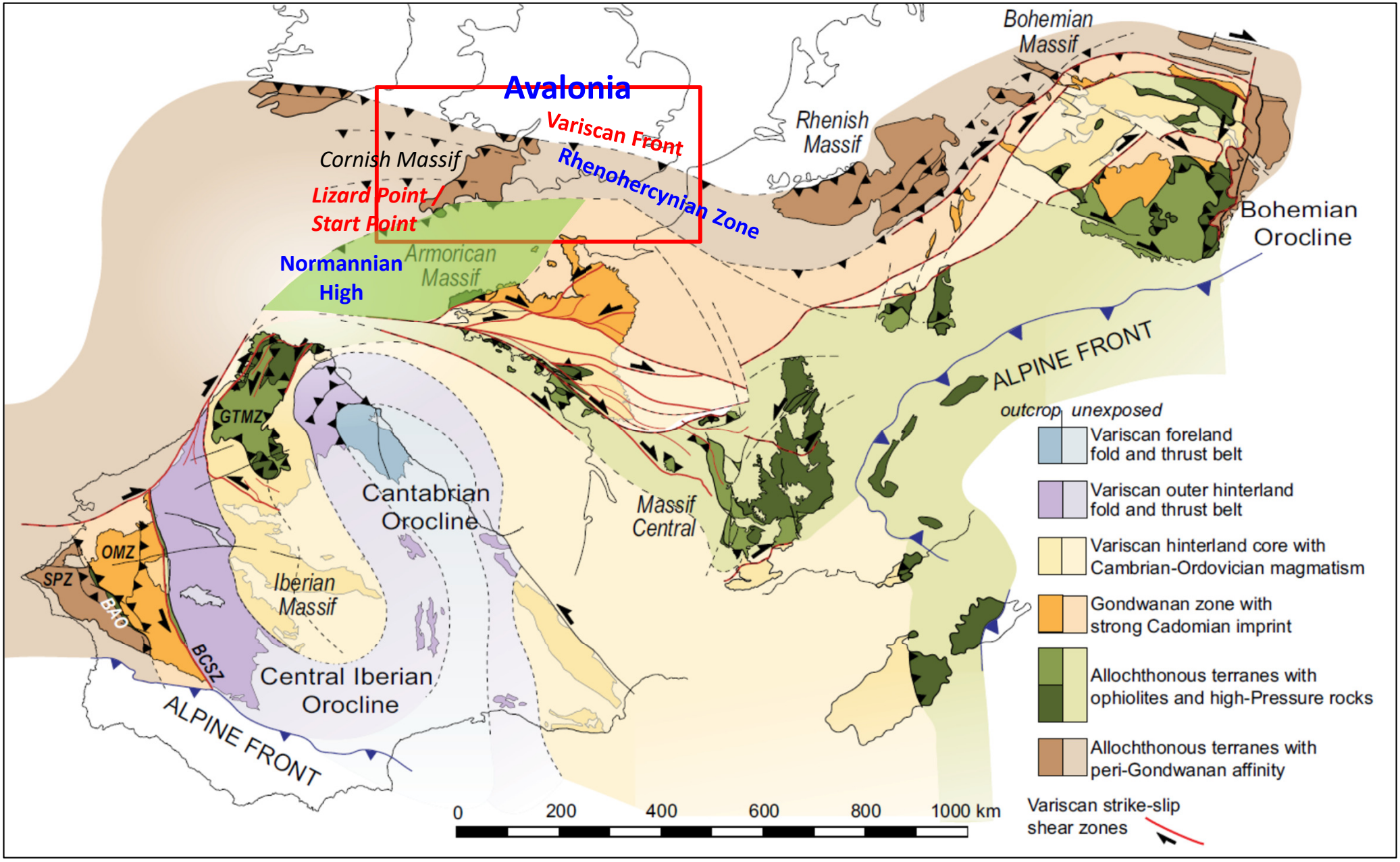
The Variscan Orogeny - the term "Variscan" was coined by Eduard Suess (1880) to describe a Palaeozoic NW-SE structural trend seen in the Upper Palaeozoic fold belt in Germany (from the Germanic Varisci tribe)

- "Hercynian" NW-SE trends originally described from the Hercynian Forest in Central Europe
- *The terms are now effectively considered synonymous*

Variscan massifs

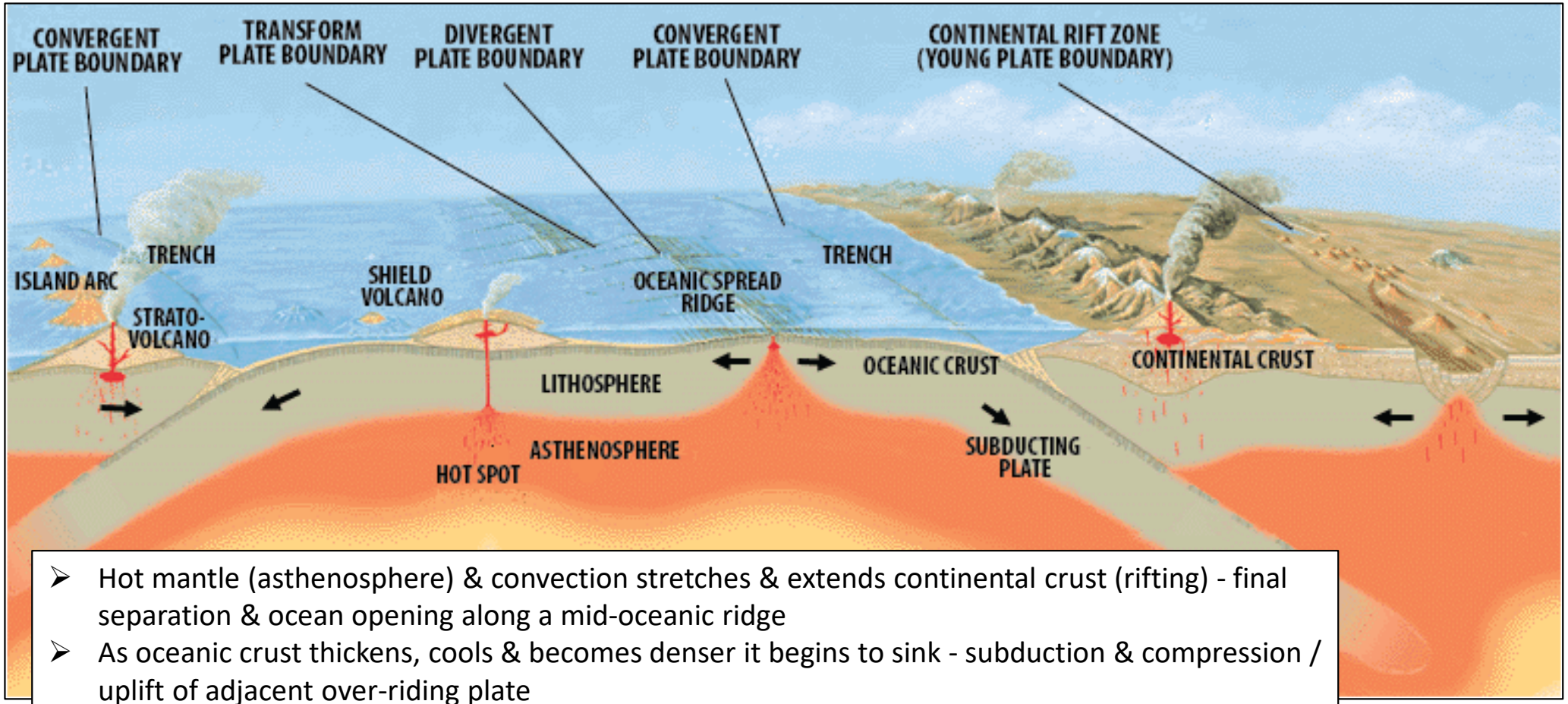
RM: Rhenish Massif
VM: Vosges massif
BF: Black Forest
BM: Bohemian Massif
Arm: Armorican Massif
FCM: Massif Central

The Variscan orogeny



Shaw & Johnston, 2016

Variscan structure & massifs (restored positions)



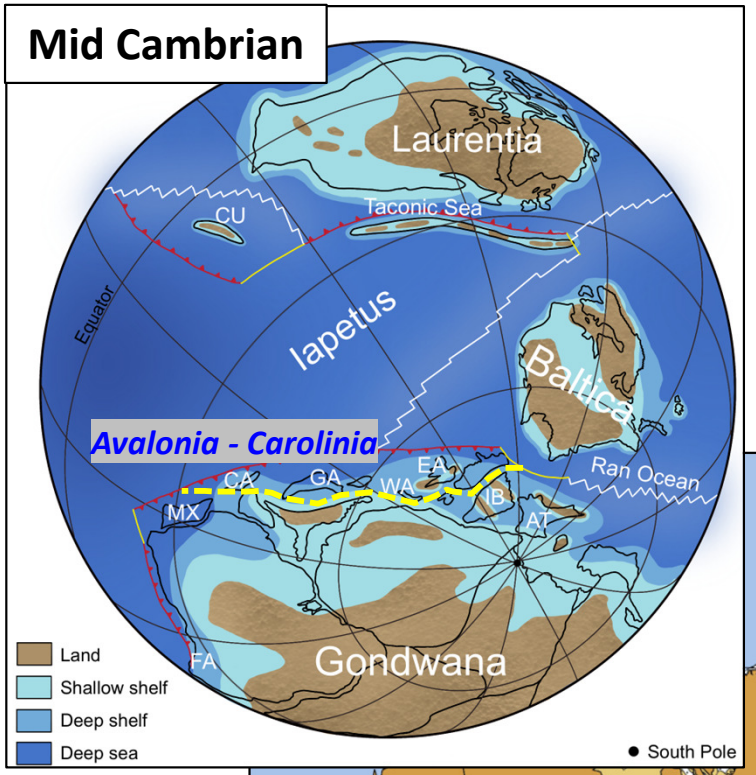
- Hot mantle (asthenosphere) & convection stretches & extends continental crust (rifting) - final separation & ocean opening along a mid-oceanic ridge
- As oceanic crust thickens, cools & becomes denser it begins to sink - subduction & compression / uplift of adjacent over-riding plate
- Partial melting of subducting slab - volcanic arcs on continental crust (e.g. Andes) & oceanic crust (e.g. Aleutian Islands)
- Final closure marked by continent / continent collision - orogenesis

In practice an orogeny is never simple - "microcontinents", oceanic islands (shield volcanoes developed over mantle hot spots - e.g. Canaries, Azores) & island arcs will collide at different times, basins formed by back-arc extension will close & invert (uplift) & closure is rarely orthogonal - these events all complicate the picture - with several, often discrete phases of orogeny

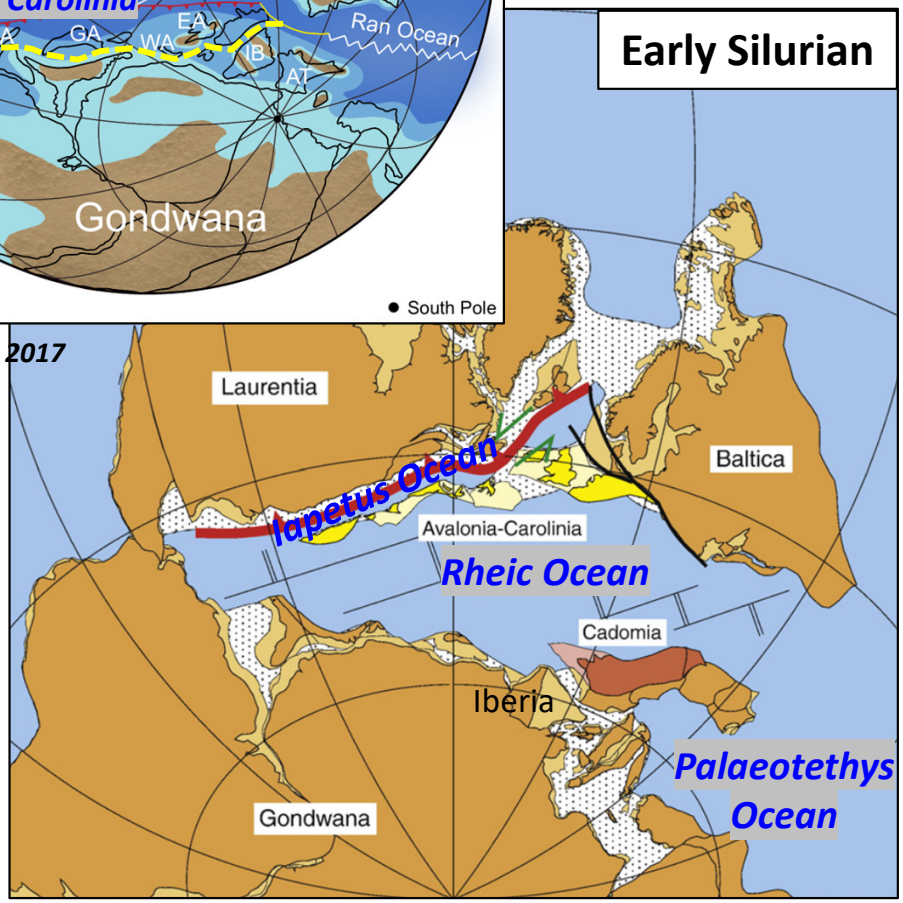
- *The Variscan is a good example of this*

But first: plate tectonics (the "standard" model)

- ***Late Ediacaran / early Cambrian:*** *opening of the Iapetus Ocean between Gondwana & Laurentia*
- **Mid-late Cambrian:** renewed extension & rifting along the northern margin of Gondwana
- **Early Ordovician:** the Rheic Ocean opens; splitting off late Precambrian island arc terranes - Avalonia (incl. southern UK), Carolinia
  - *Rapid ocean opening (8-10 cm / year) during Ordovician driven by subduction ("slab pull") in the Iapetus Ocean*
  - *Iberia & Cadomia (France / central Europe) remained close to Gondwana*
- **Early Silurian:** the Rheic Ocean reaches its maximum width (c. 4,000 km) as Iapetus closes
  - *Rheic subduction & closure commences*



After Torsvik et al., 2017 & Domeier, 2016

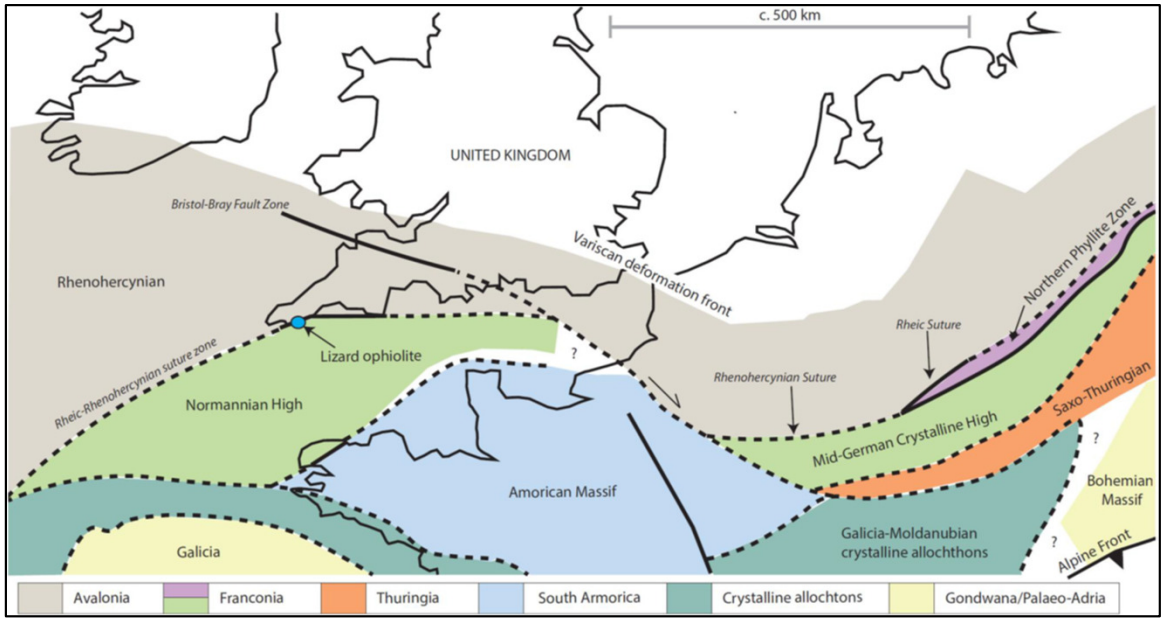


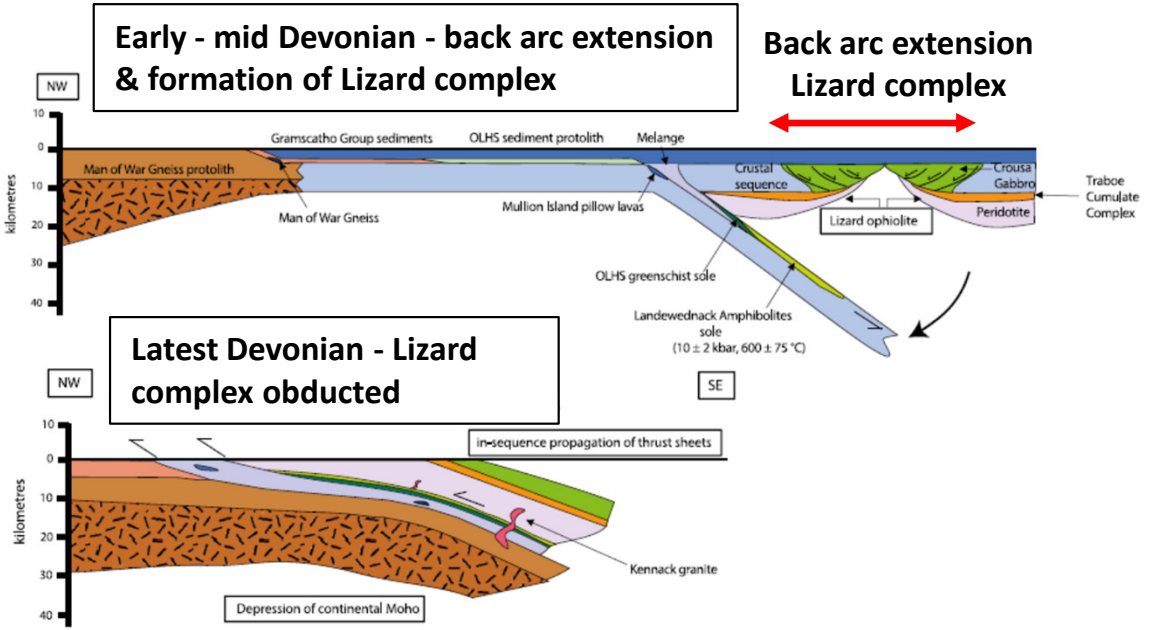
Nance et al., 2010 after Pickering & Smith, 1995

Opening of the Rheic Ocean

- **Latest Silurian:** Early subduction of the Rheic Ocean below the Avalonian margin
- **Early Devonian (Emsian):** A new spreading centre is formed over a south-dipping subduction zone within the Rheic Ocean to form the narrow "Rhenohercynian Ocean"
  Back-arc extension with "slab rollback"
- **Mid - late Devonian (from 380 Ma-Frasnian):** south-directed subduction of the Rhenohercynian Ocean with uplift of the Armorica margin (Cadomia) to form the Normannian High
  Sediments shed north into the Gramscatho foreland trough as deepwater flysch sandstone (c. 3.500 m)
- **Latest Devonian (late Famennian):** Devonian oceanic crust of the Lizard ophiolite over-thrusts late Cambrian Rheic oceanic crust & the Gramscatho Group

Closure of the Rhenohercynian Ocean effectively marks the commencement of the Variscan orogenic cycle



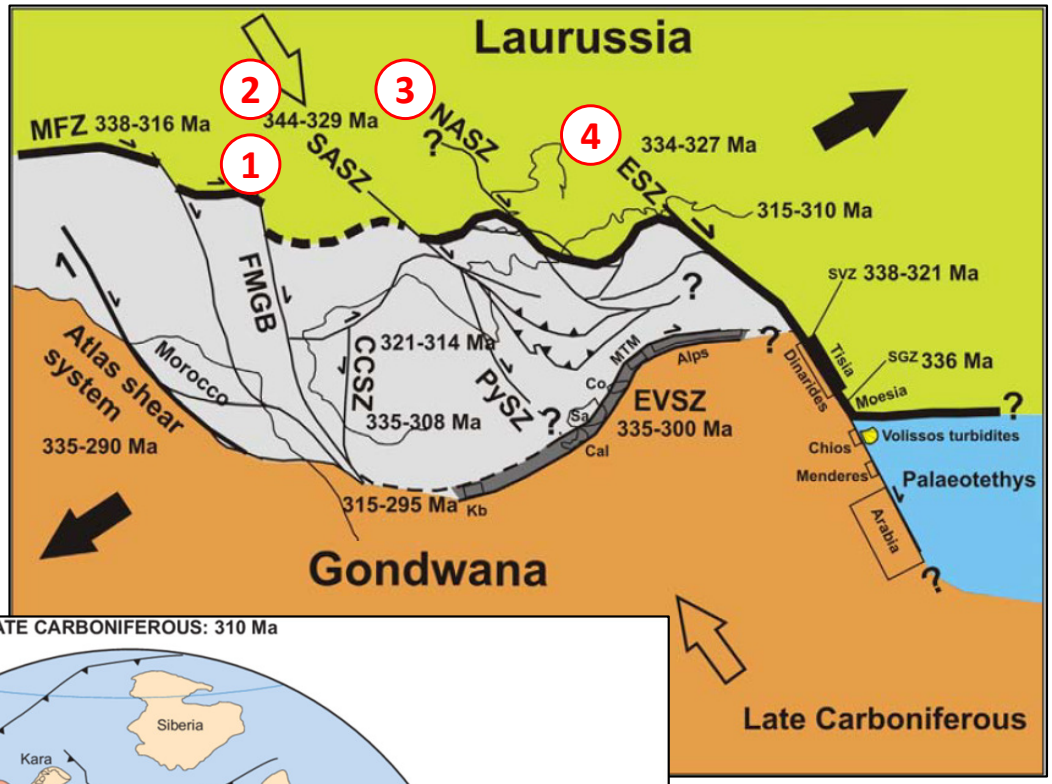


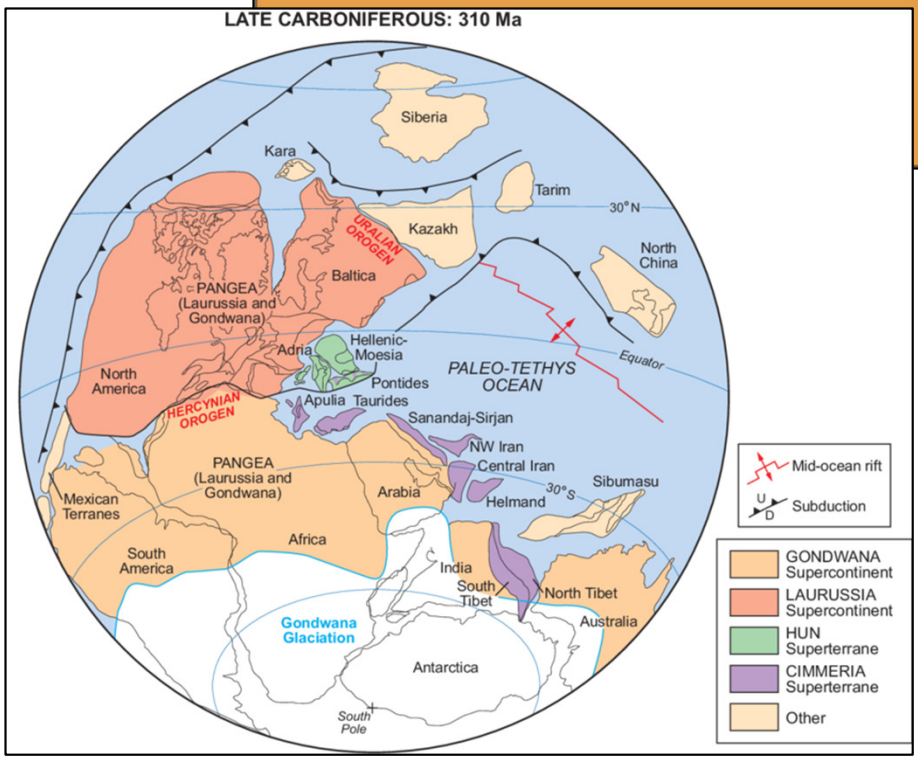
After Mackay-Champion et al., 2024

Closure of the Rheic Ocean & the Lizard ophiolite

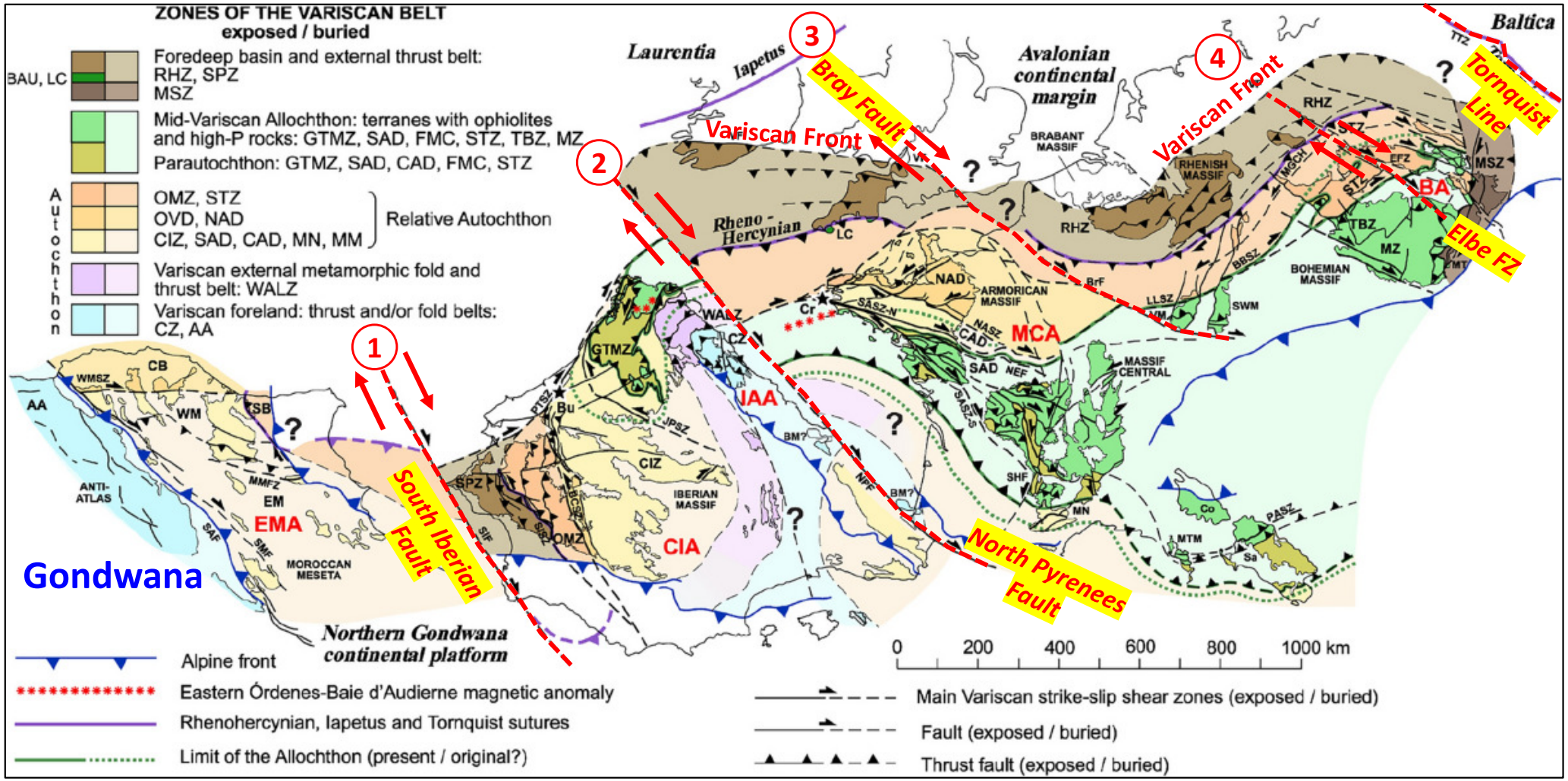
- Compressional tectonics dated as early as mid Devonian (uplift / erosion of the Normannian High)
- Compressional front & basin inversion spread northwards with time - *peaking in the late Carboniferous*
- NW-SE directed <u>oblique</u> closure & collision resulting in strong dextral shear - *peak 338-320 Ma (Visean - earliest Westphalian)*
- Late shear movement into *early Permian (290 Ma)*

Padovano et al., 2014





The Variscan Orogeny: mid Devonian - earliest Permian



Showing the significance of dextral shear fault with large displacement - e.g.:

- **The Bray fault** - reactivated during Mesozoic extension & by Alpine Inversion
- **The Noth Pyrenees Fault** - line of opening of the Bay of Biscay in the late Cretaceous

Final consolidation of the Variscan Orogen

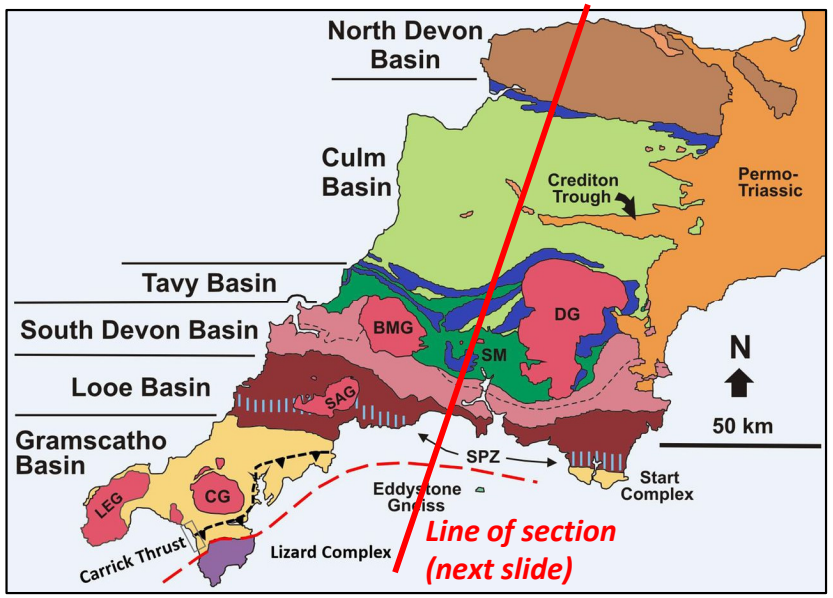
- **Early - late Devonian:** passive extensional rifted margin; mainly south-dipping half-grabens with shallow marine clastics & reef limestones north of flysch belt & deformation front

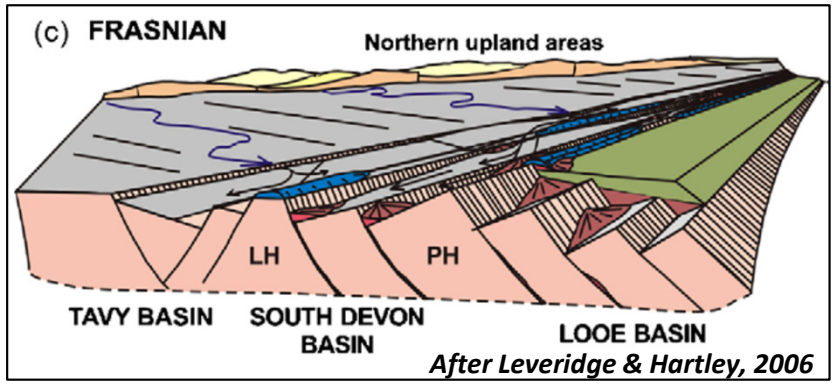
- **Mid Devonian - early Carboniferous (Tournaisian):** southern Gramscatho Basin inverted & thrust north over the passive margin
  - *Progressive uplift with Upper Devonian sediments displaced north-wards - four stacked gravity-driven nappes*

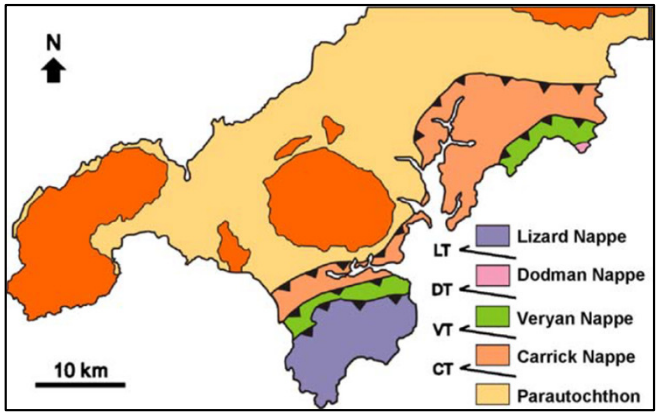
- **Namurian - Westphalian C:** The Culm Basin (a late Devonian rift) developed as a major trough north of the main deformation / inversion front

  The "Bristol Channel Landmass" developed to the north from the late Namurian - Devonian sediments thrust over basement & deformation along the Bray Fault dextral shear zone
  - *Major sediment source for the Culm Basin*
  - *The South Wales coal basin developed to north of this high*

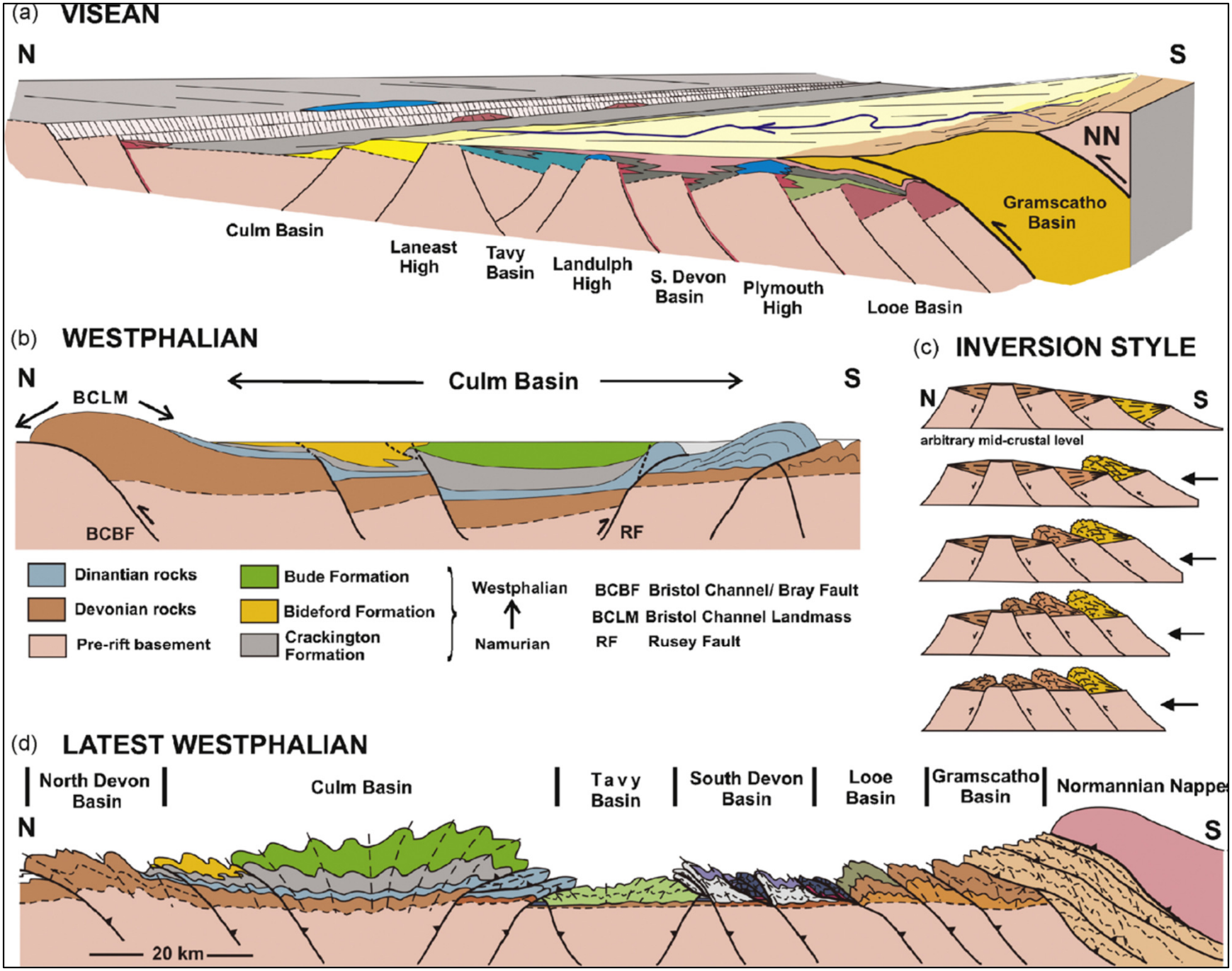
- **Latest Westphalian:** inversion of the Culm Basin with tight folding & north & south-directed over-thrusting







The Variscan orogeny in Cornwall



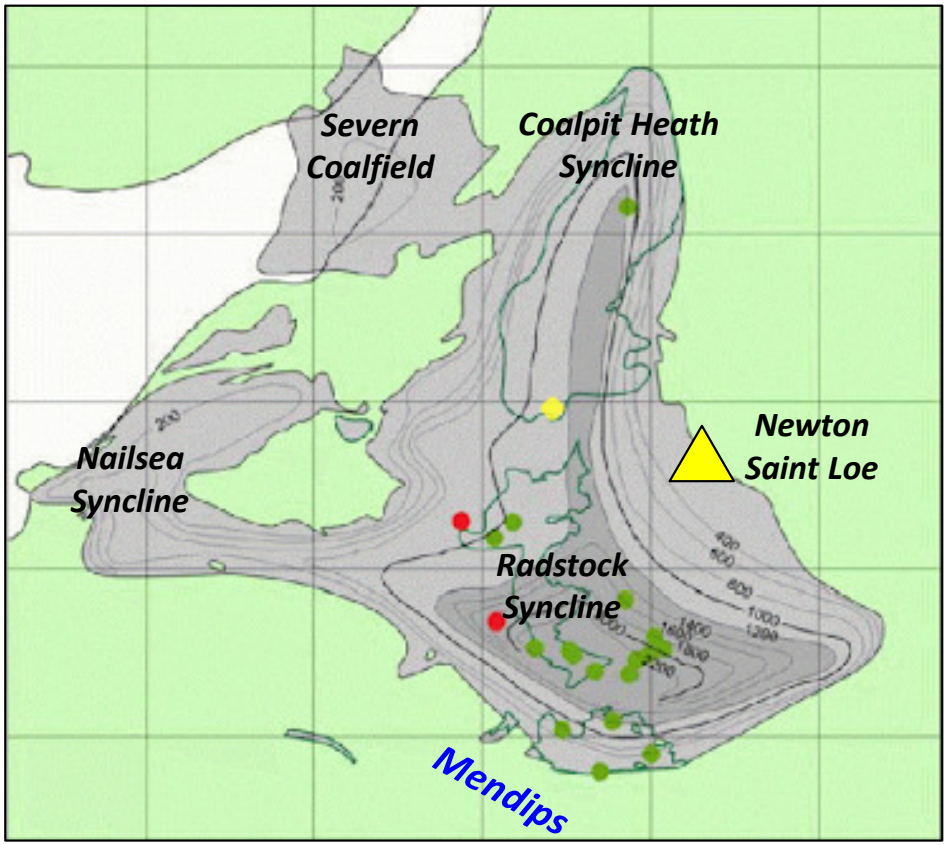
After Leveridge & Hartley, 2006

The Culm Basin & basin inversion

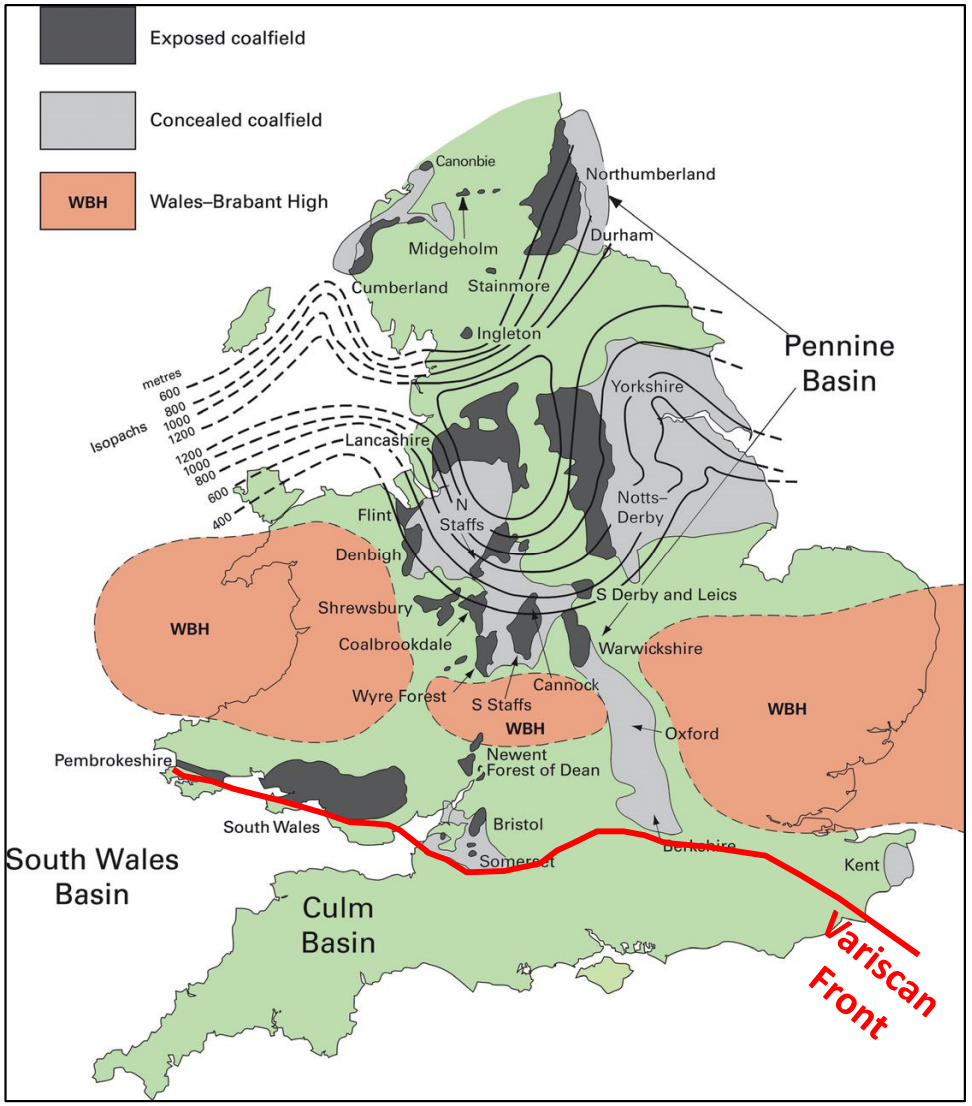
Variscan chevron folds - Millook Haven, north Cornwall

Late Carboniferous (Westphalian)

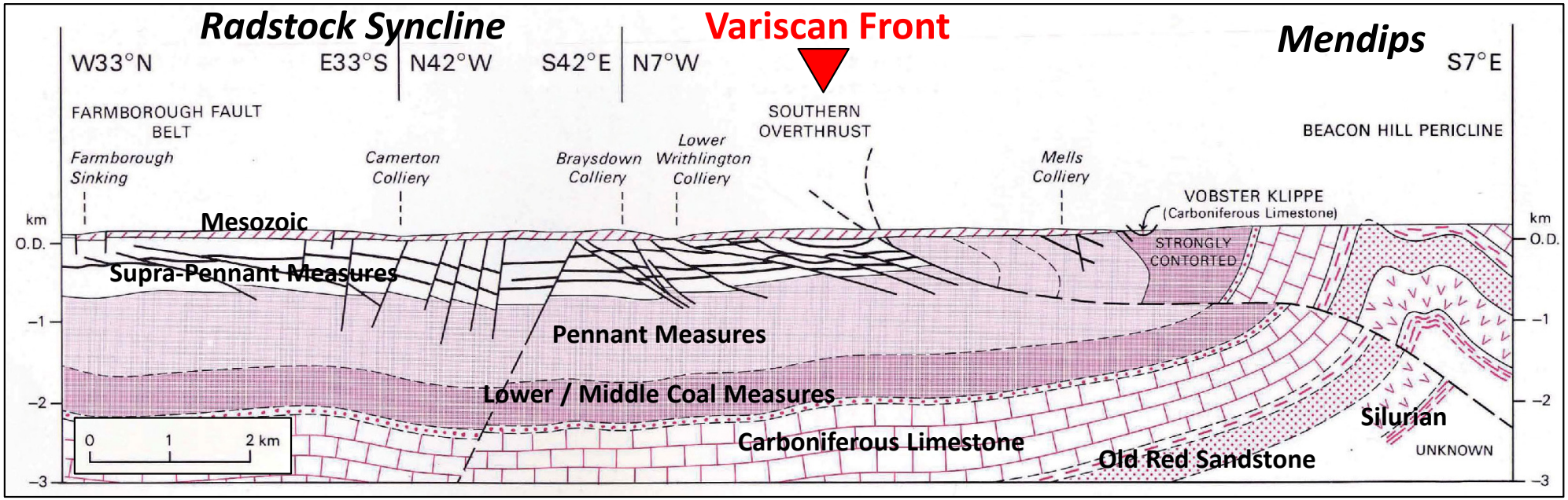
- Coal Measures were mainly deposited north of the Wales-London-Brabant High
- Deposition & structure in the South Wales, Forest of Dean, Bristol-Somerset & Kent coalfields to the south was strongly influenced by phases of Variscan deformation & by post-orogenic uplift & erosion

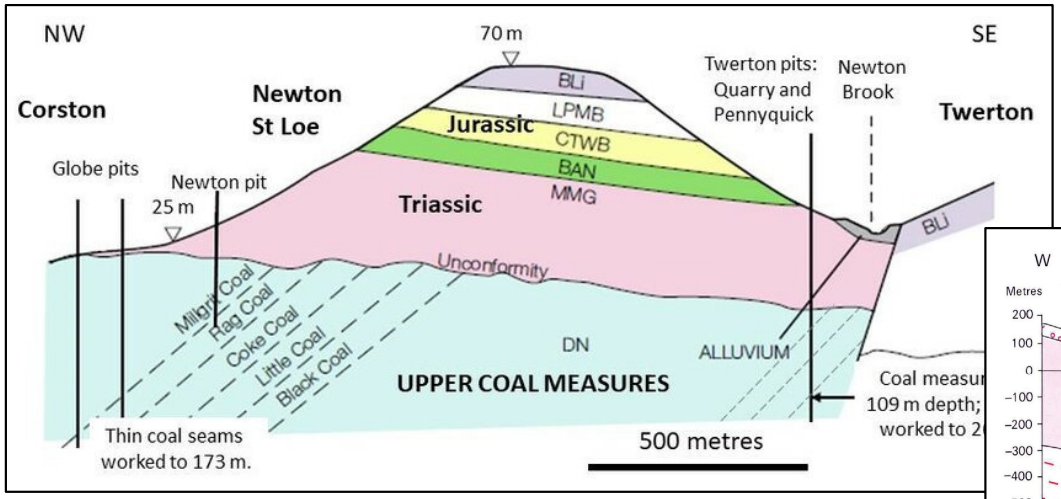


Source: BGS



Spears, 2015

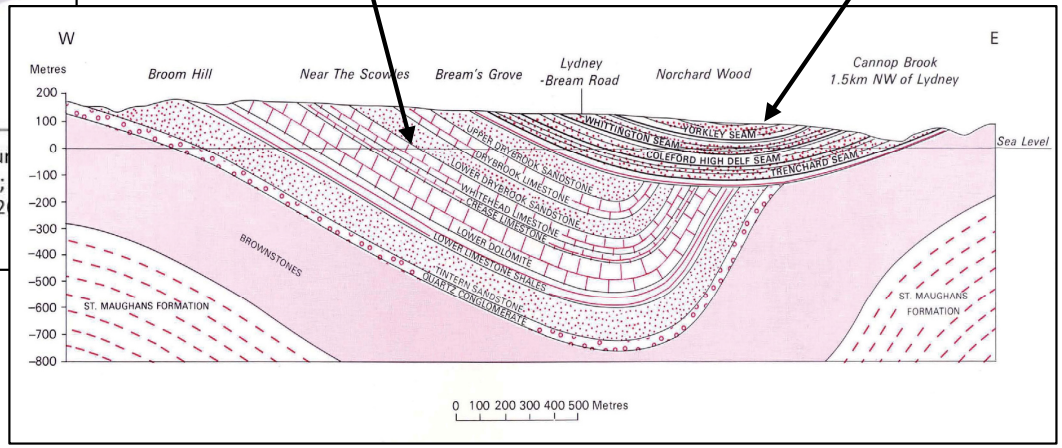




Get refs

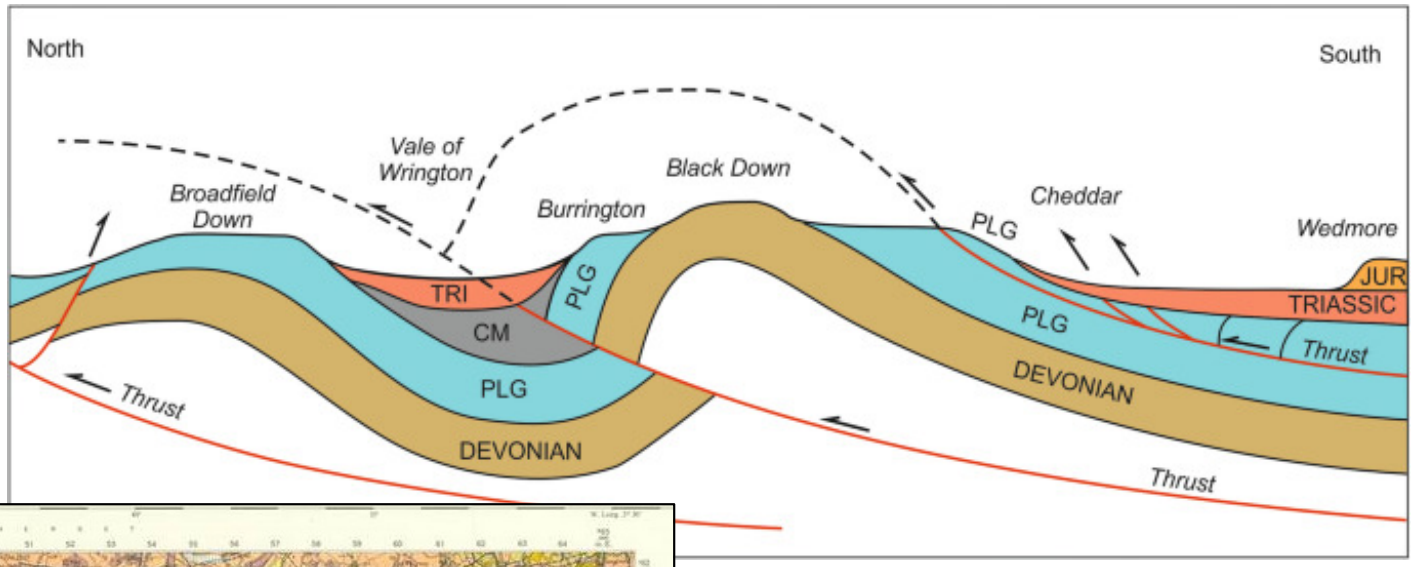
Upper Visean c. 335 Ma (Drybrook Sandstone)

Westphalian D - Asturian c. 310 Ma (Upper Coal Measures)

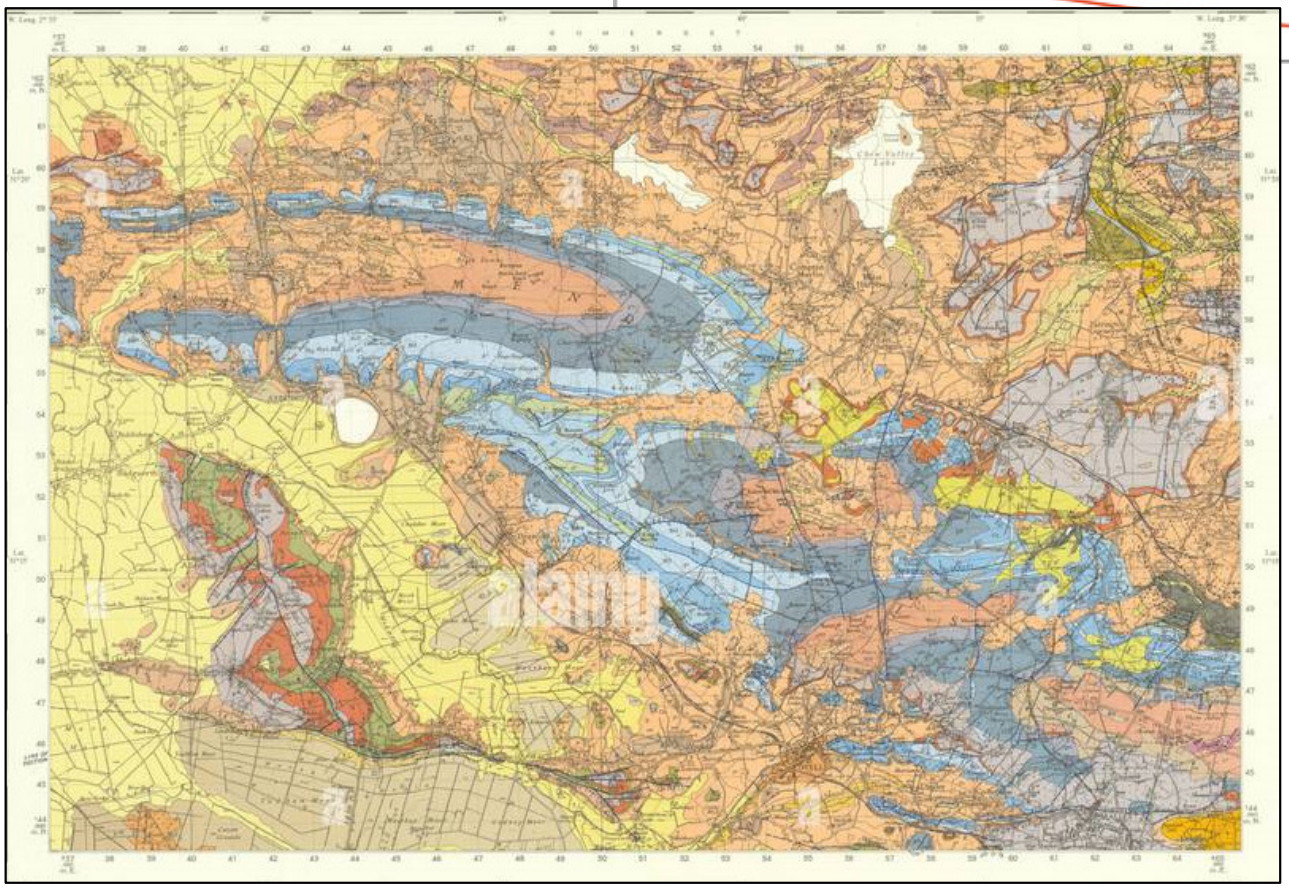


Forest of Dean - two phases of Variscan folding

The Mendips & the Somerset Coalfield



Farrant, 2020



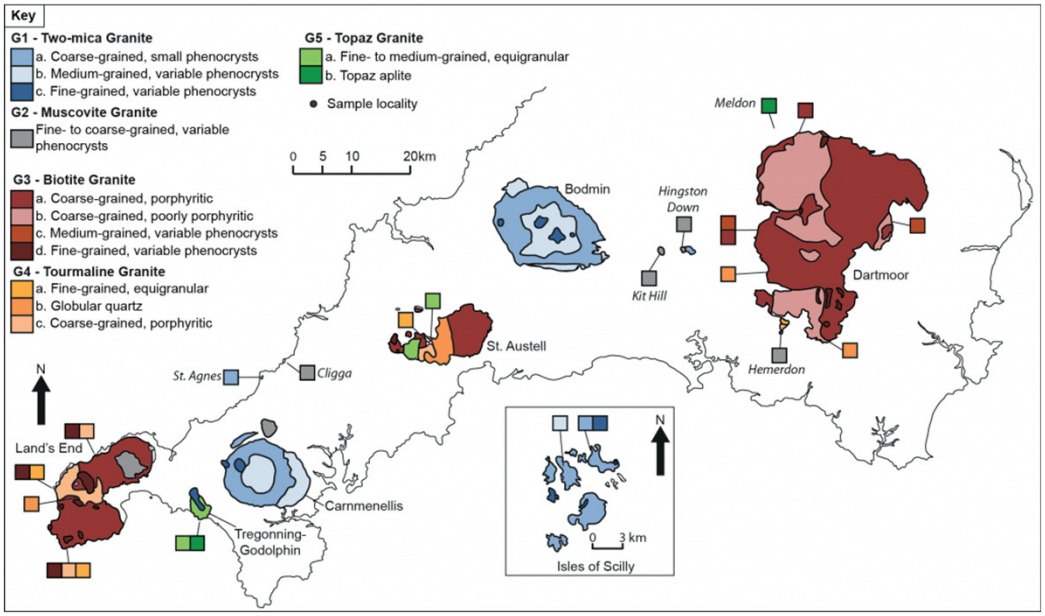
The Mendips

- **Early Permian:** post-orogenic crustal extension
  - Rift basins formed exploiting Variscan structures
  - **C. 295 Ma** - early bimodal syn-rift volcanism (Exeter Traps)
  - **292-275 Ma -** several intrusions emplaced stimulated by extension - forming Cornubian batholith:
    - Vertical migration of late orogenic magma & associated high-temperature, metal-rich hydrothermal fluids
    - Partial melting facilitated by emplacement of mafic magmas

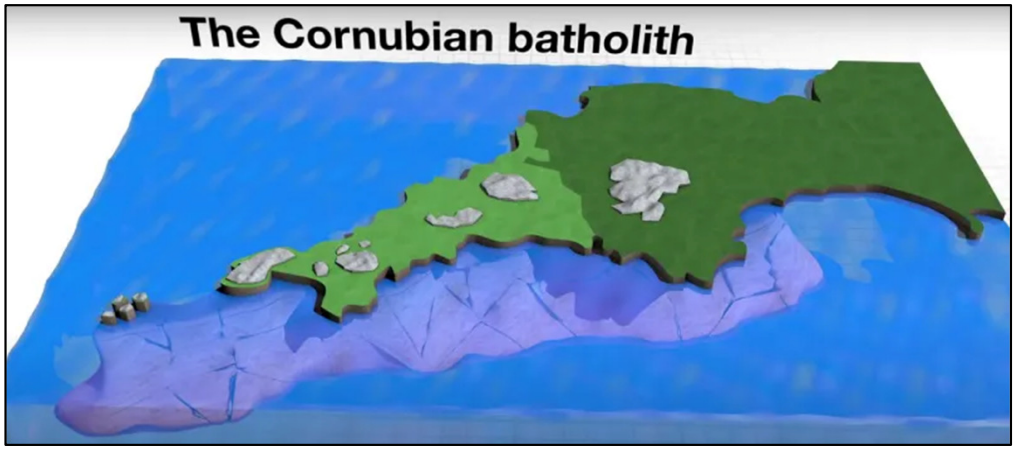
      Metasomatism - tin, copper, iron & arsenic ores

      Lithium-rich minerals in pegmatites
  - *The Cornubian batholith was unroofed by the late Permian - granite clasts in St Cyres beds - c. 250 Ma*

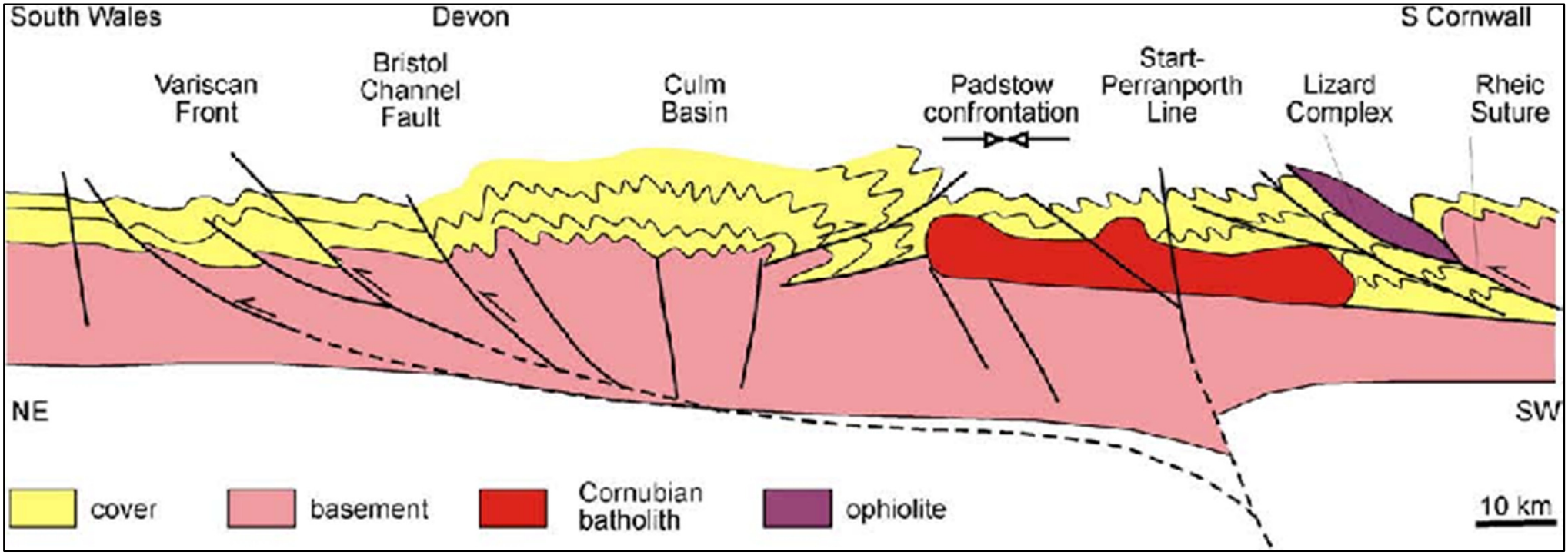
Variations in granite mineralogy



Simmons et al., 2016

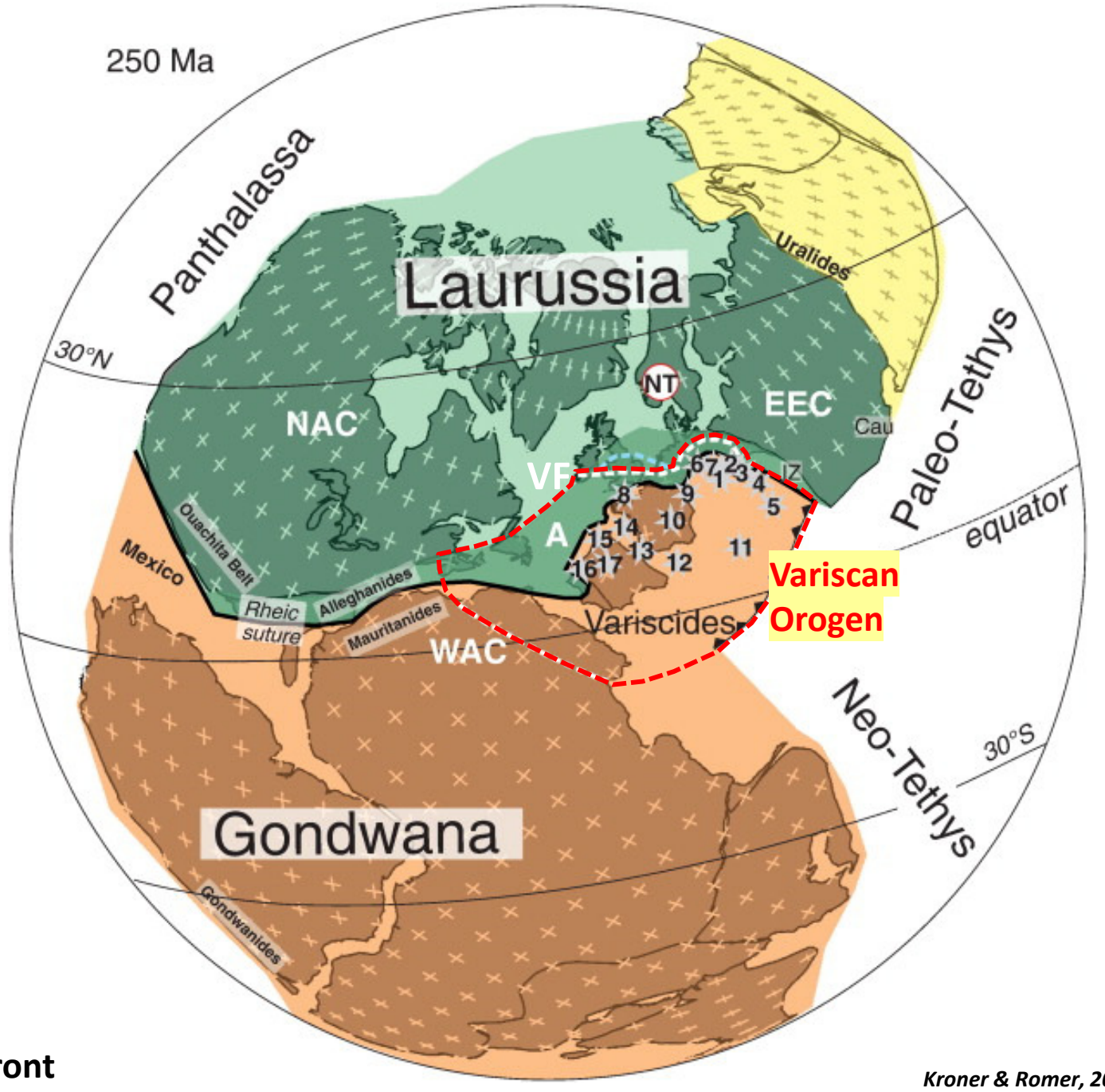


Cornwall - consolidation, early extension & granite emplacement



Nance et al., 2010 after Warr, 2000

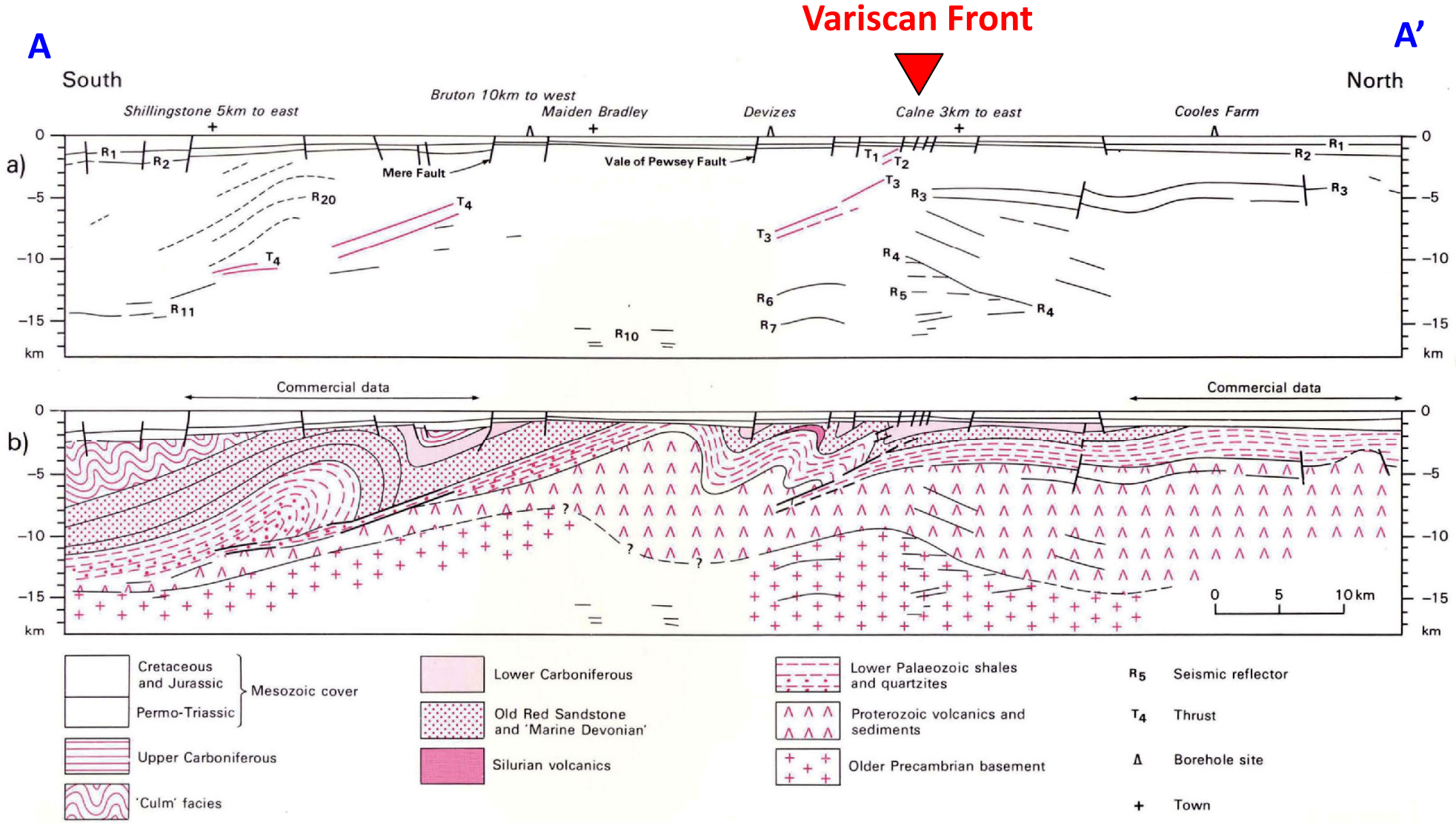
Deep Variscan structure - SW England & S Wales



A: Avalonia
VF: Variscan Front

Kroner & Romer, 2013

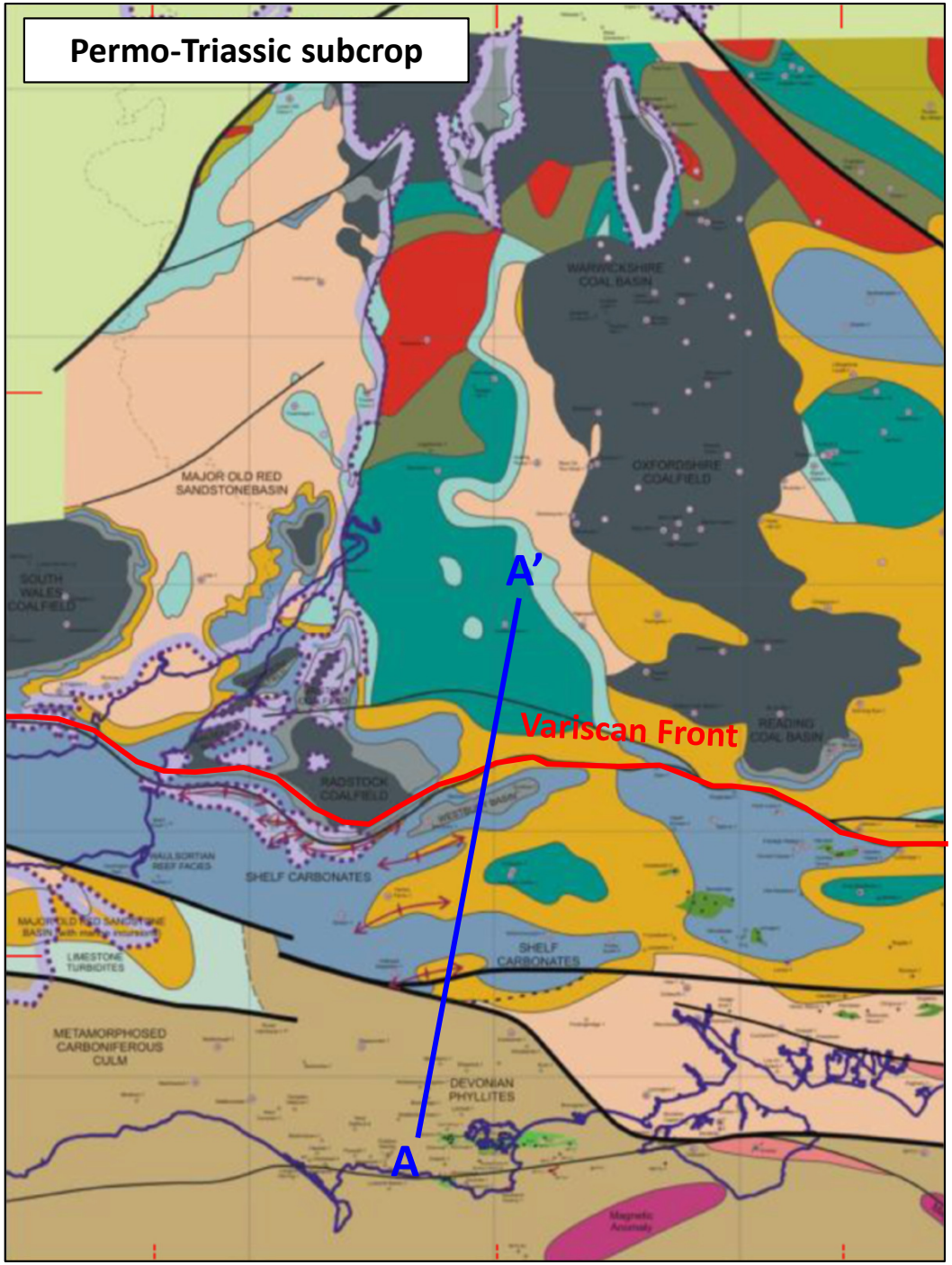
Consolidation of Pangaea - 250 Ma (early Triassic)



North–south section showing:
a) principal reflectors identified from seismic reflection sections
b) geological interpretation of reflection events (after Chadwick, Kenolty & Whittaker, 1983)

Chadwick et al., 1983

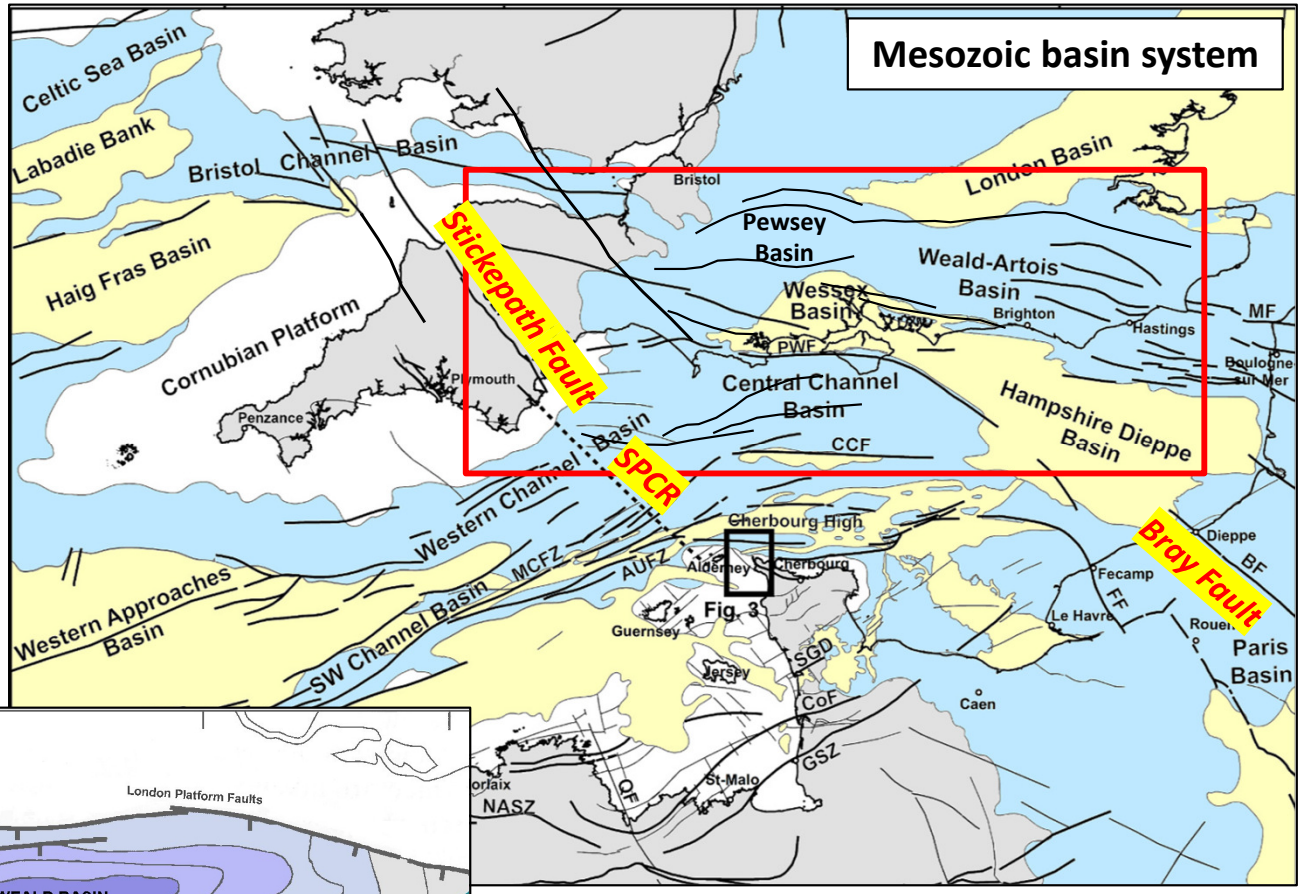
The Variscan Front - seismic line A-A'

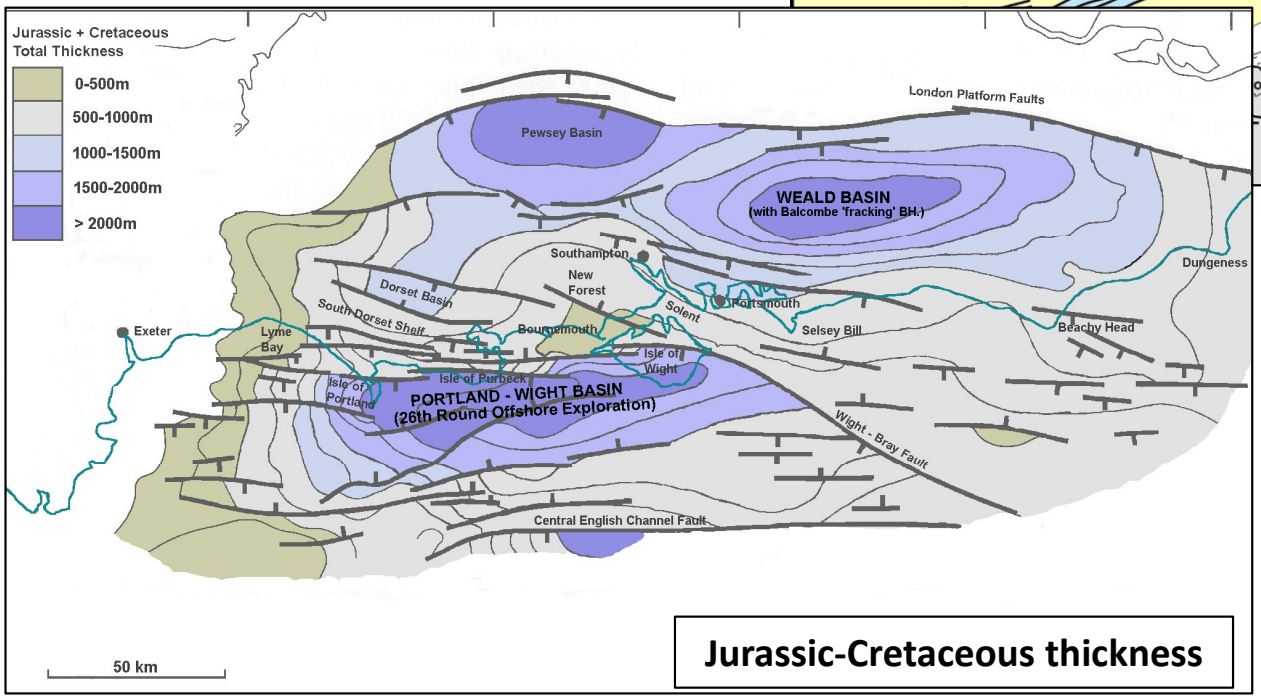


The Variscan Front - line A-A' location

Post-Variscan extension

- Primarily late Permian to early Cretaceous
- W-E extensional faults exploiting re-activated Variscan thrusts south of the Variscan Front
- Structural control of NW-SE Variscan shear faults (e.g. Wight-Bray Fault & Sticklepath / Start Point-Cotentin Ridge (SPCR)
- Syn-rift extension ceased in Aptian with thermal uplift / erosion





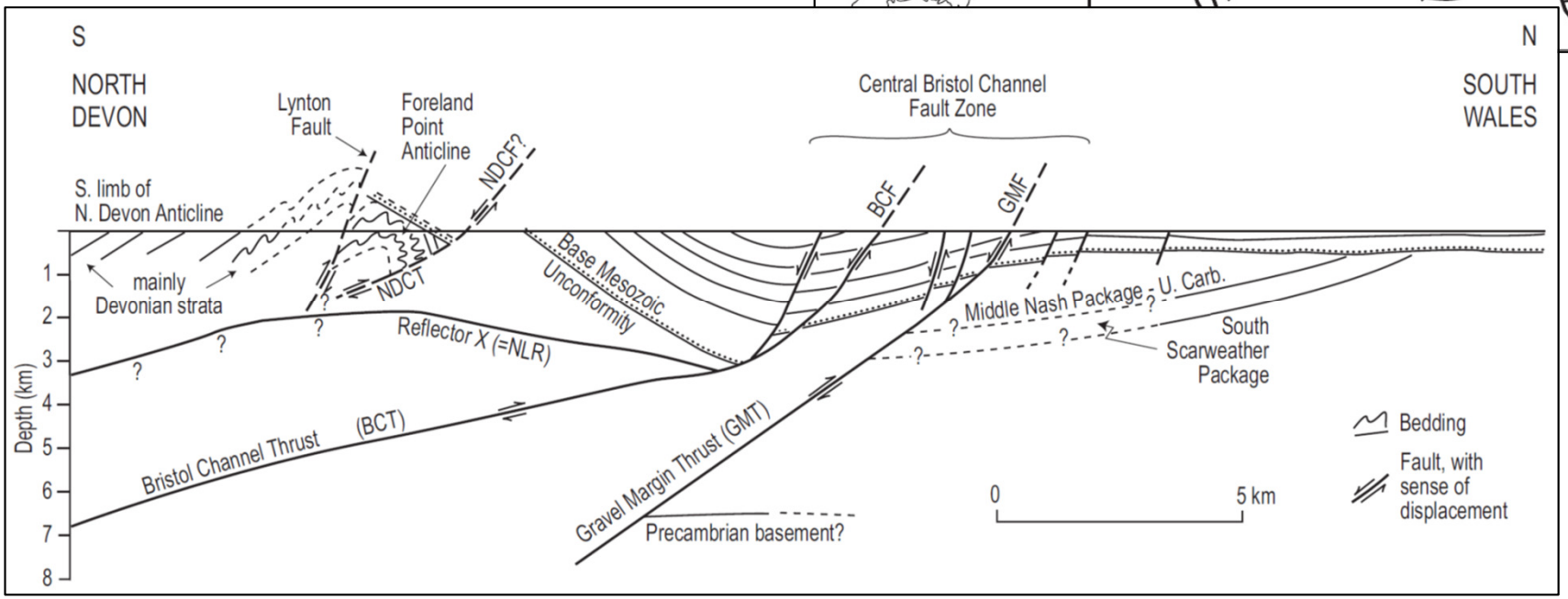
Jurassic-Cretaceous thickness

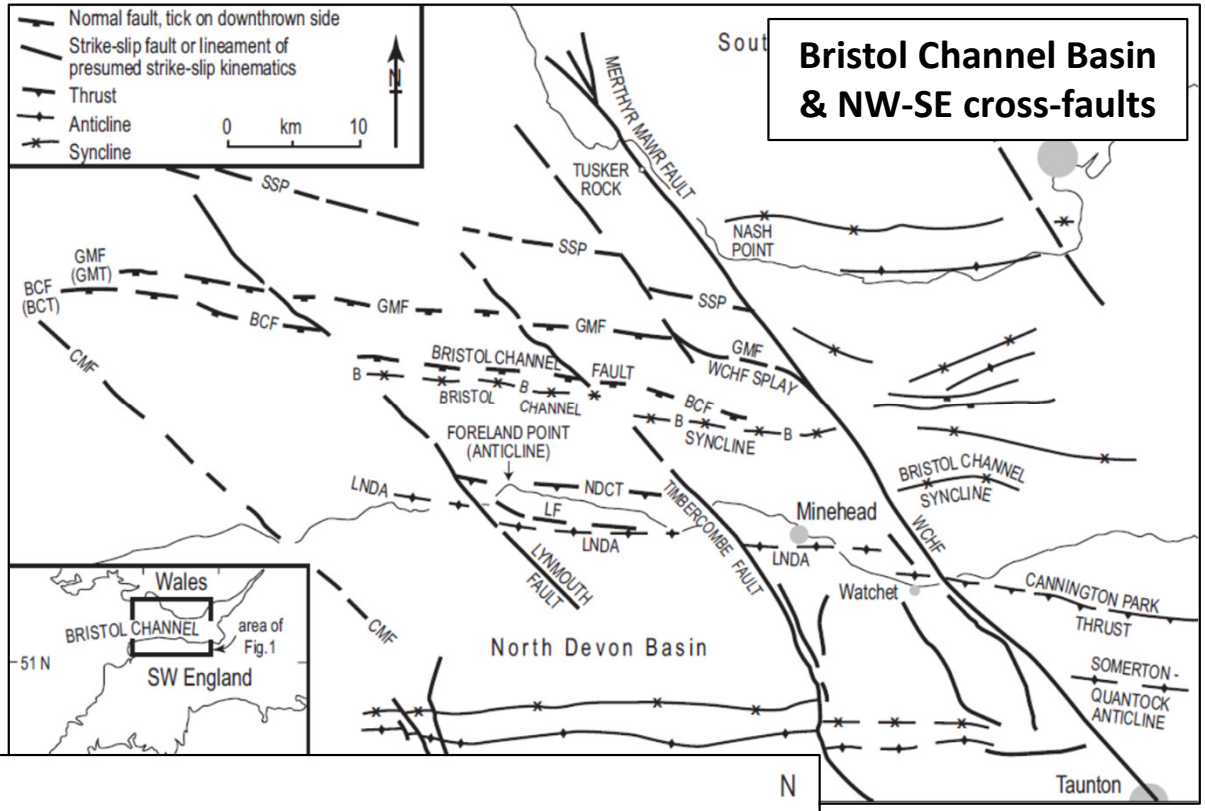
Kaci et al., 2023, after several authors

Source: Ian West - Geology of the Wessex Coast webpage
After Underhill & Stonely, 1998 & Hamblin et al., 1992

Triassic / Jurassic extension & rift basins

Bristol Channel Basin - reactivated Variscan thrust





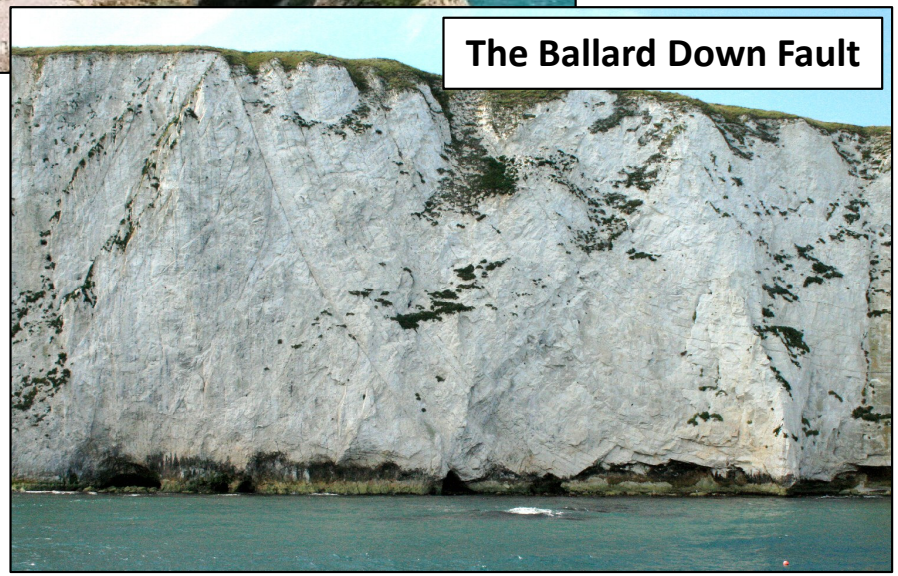
Miliorizos et al., 2004

Triassic / Jurassic extension

- **Late Cretaceous:** early Alpine compression
- **Oligo-Miocene:** main phase of reverse movement & inversion along major Mesozoic extensional faults

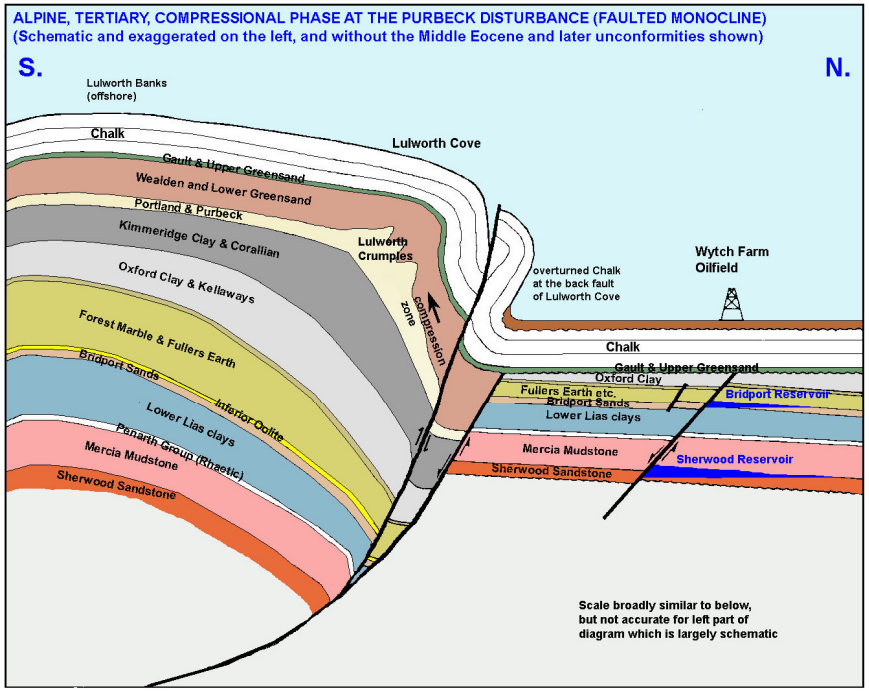
  Alpine compression directed from the south - uplift locally exceeds 1,000 m over Weald & Channel basin depocentres

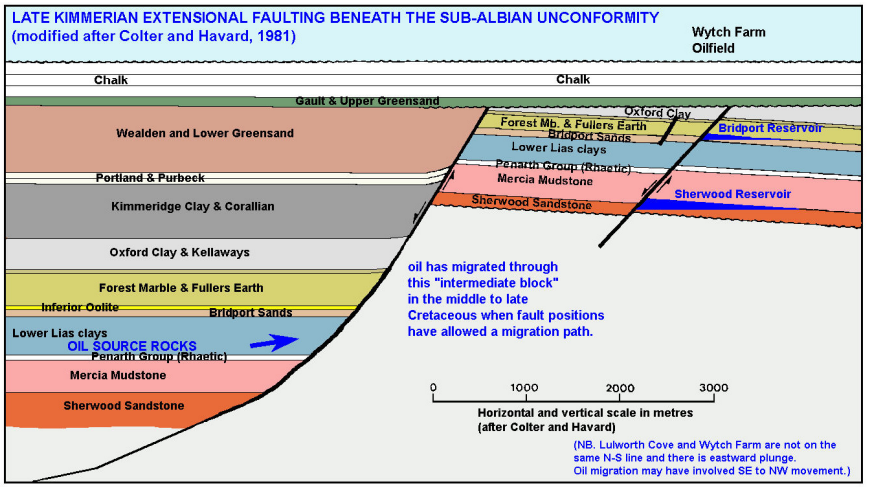
The Lulworth Crumple



The Ballard Down Fault

Alpine inversion - Purbeck Disturbance





Source: Ian West - Geology of the Wessex Coast webpage
After Colter & Havard, 1981 & others

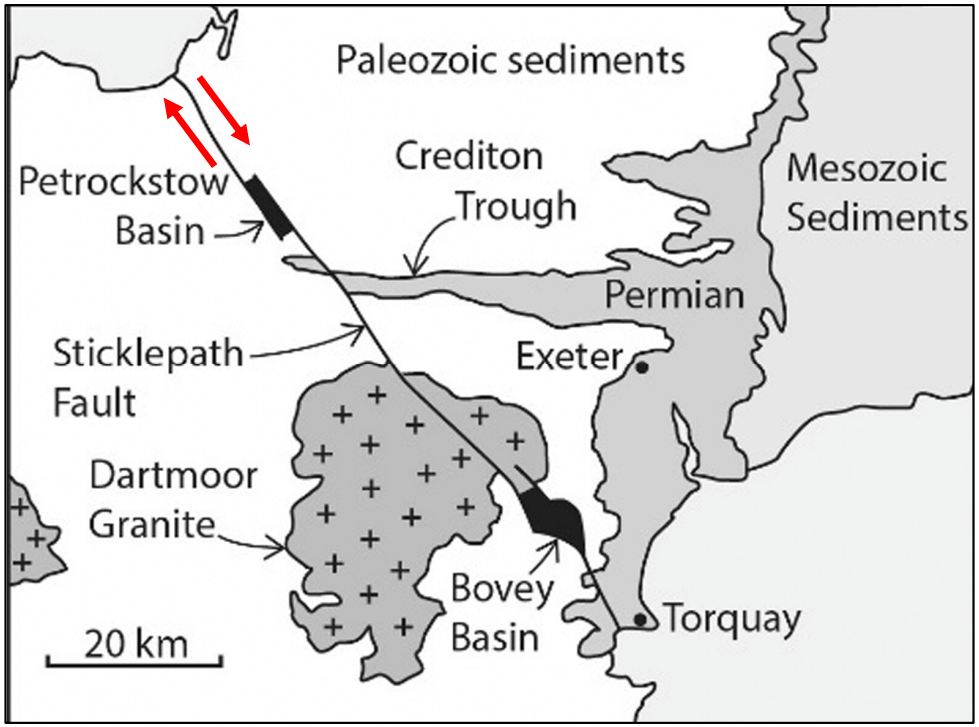
Late Cretaceous / Tertiary (Alpine) inversion

The Variscan Stickepath-Lustleigh Fault was rejuvenated as a result of Alpine compression in the early Tertiary, with dextral movement offsetting the Permian Dartmoor granite & Crediton Trough

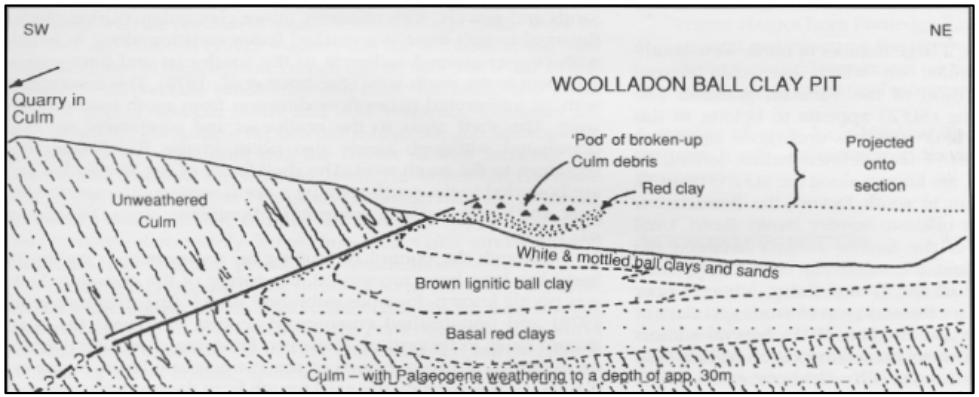
- The Bovey, Petrockstow & offshore Stanley Bank Basin formed as small transextension rifts with a late Eocene - mid Oligocene (35 - 28 Ma) sediment fill of fluvial sands & gravels & lacustrine clays & lignites of more than 1,300 m (in Bovey)
  - *Basin development ended with reversal to sinistal transpression with folding / thrusting*
- Lundy Island is a felsic granite pluton / dyke complex of late Paleocene & early Eocene age, which has been correlated to transextension on the Stickepath-Lustleigh Fault
  - *Volcanics correlate to ash markers in Denmark*

Ball clays - kaolinite-rich clays mined for pottery from the mid 17th century in the Bovey & Petrockstowe Basins with shaft mining from 1870s

- *Derived mainly from sub-tropical weathering of exposed feldspathic granites (Bovey Basin) & Devono-Carboniferous Culm slates (Petrockstow Basin)*
- *Current exports c. 220,000 tonnes / year*



Petrockstow Basin showing late over-thrust



Bristow et al., 1992

The Sticklepath-Lustleigh Fault; early Tertiary basins & volcanism

Tin

Cassiterite with tin grade 1.2-1.6% - from hydrothermal veins flanking granite stocks - coincident with granite emplacement

Production from c. 2,100 BC (primarily placer to late Medieval) - South Crofty mine closed 1998

- Planned developments:
  - South Crofty (Cornish Metals)
  - Great Wheal Vor (Cornish Tin)
  - Redmoor (Cornwall Resources)

Lithium

Polylithionite (lithium mica) pegmatite & aplite sheets flanking Tregonning (Godolphin) & St Austell granites. Lithium enriched brines flanking the Carnmenellis granite:

- Hard rock projects
  - Cornish Tin - Tregonning granite
  - Cornish Lithium (Trelavour) & Imerys British Lithium (Gunheath) planning to extract lithium-rich minerals from china clay waste on the St. Austell granite
    - Both companies are on pilot production
- Brine Extraction:
  - Cornish Lithium - United Downs (Carnmenellis granite) - 2x 1,000 m boreholes drilled with Geothermal Engineering - appraisal drilling ongoing

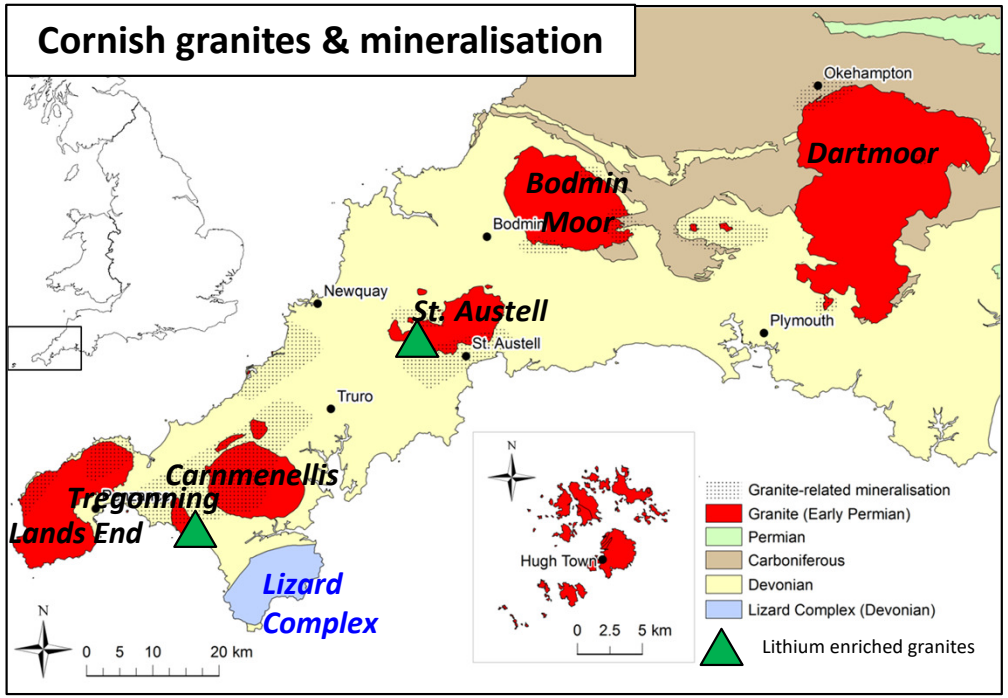
China Clay

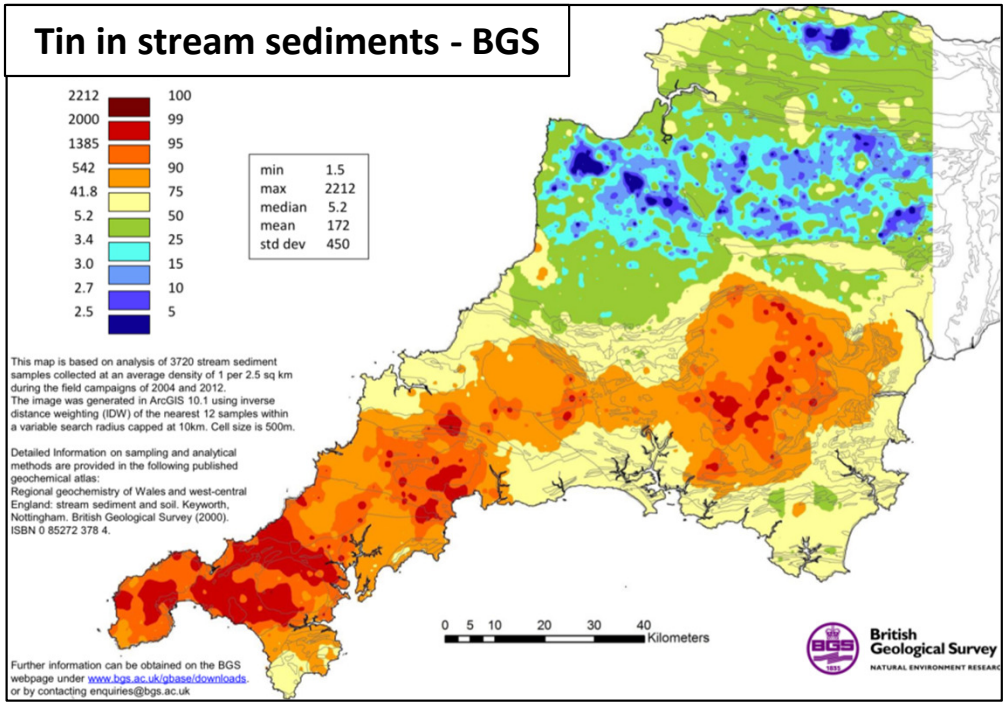
Kaolin clays derived from heavily decomposed biotite granites; mostly St Austell Granite - probably resulting from hydrothermal alteration in the Cretaceous & early Tertiary

- Production 1768 - present
- Cumulative > 165 mm tonnes (to 2018)

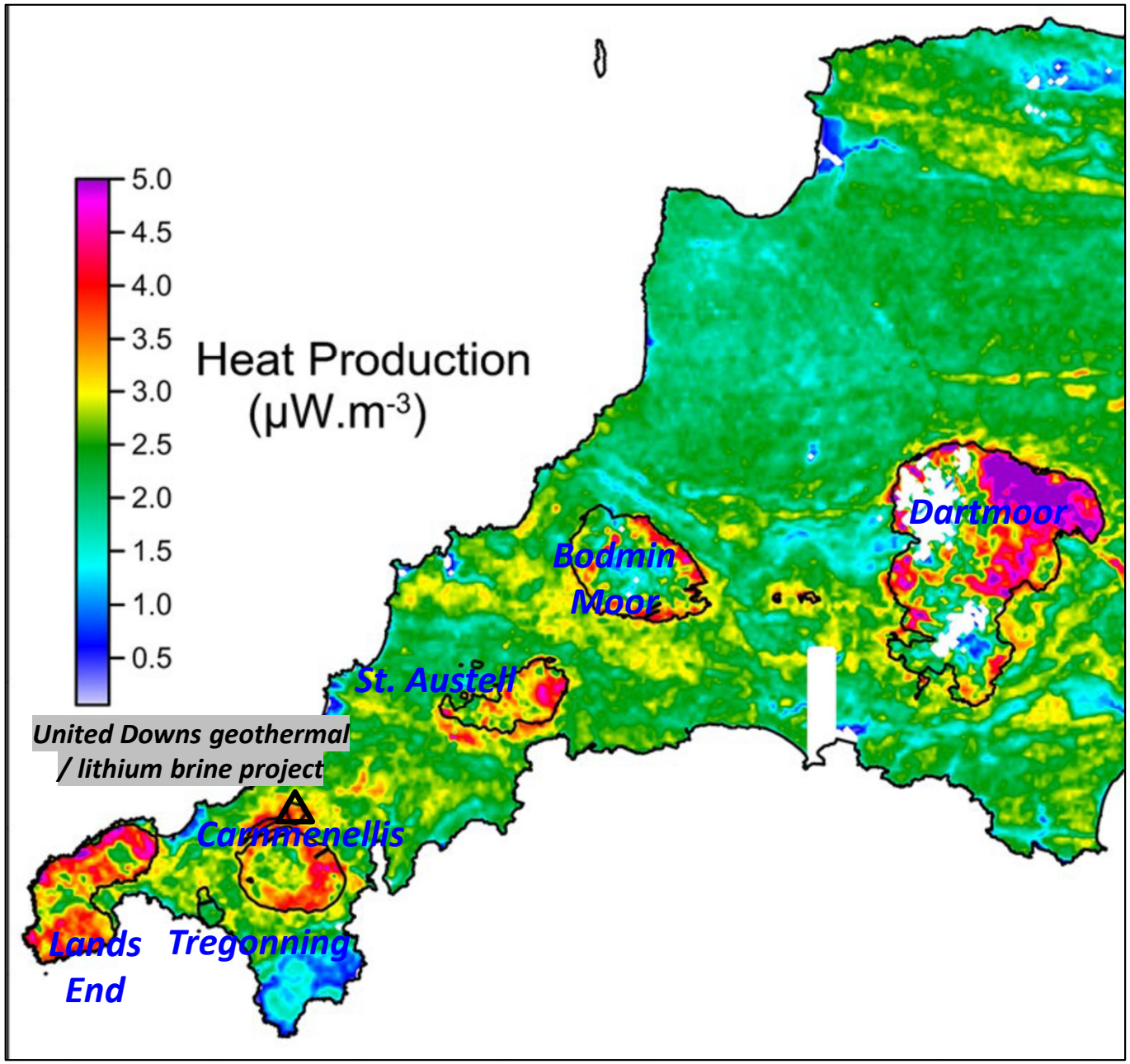
Geothermal

- High geothermal gradients from radioactive elements in granite
- Co-production with lithium production; United Downs (Geothermal Engineering) - first commercial UK geothermal project





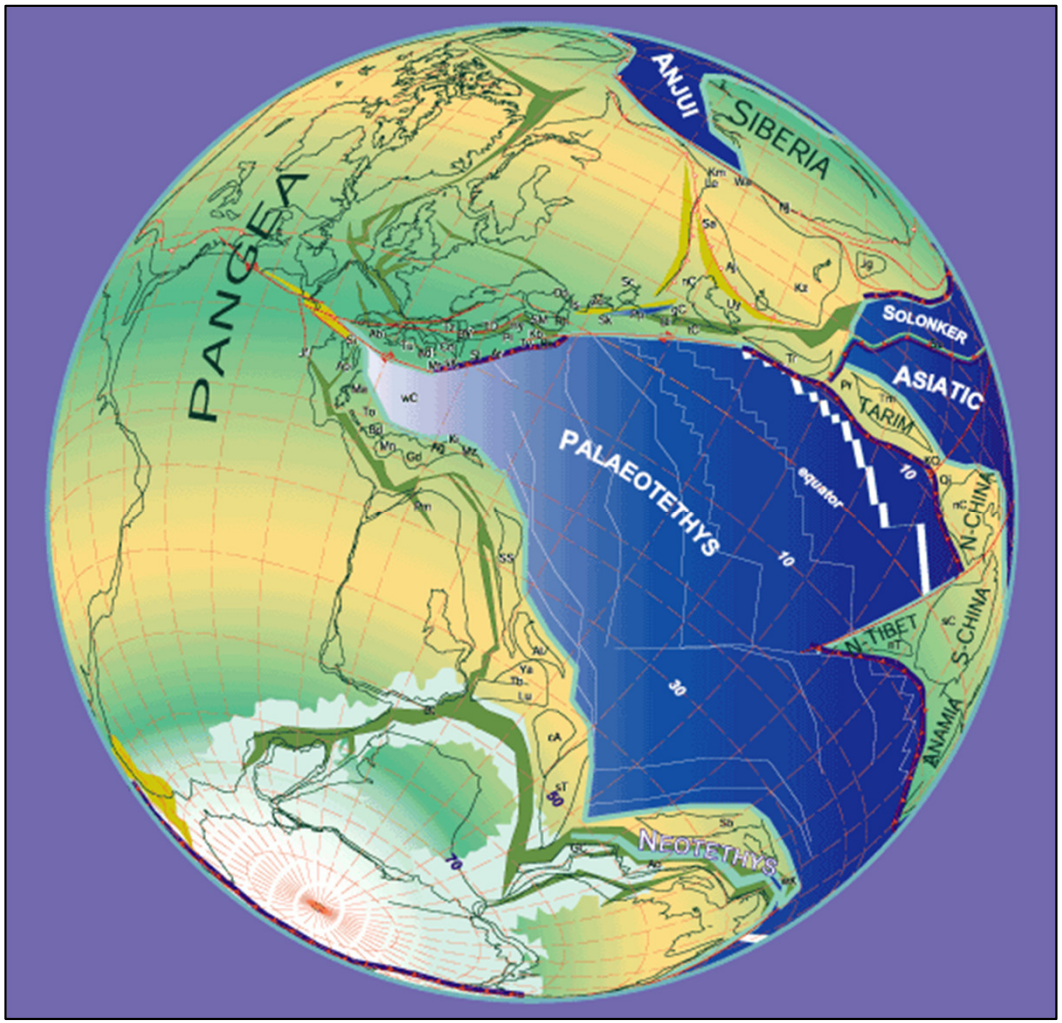
Commercial - Cornish granites & mineralisation



Beamish & Buzby, 2016

Variscan granite heat production

The Variscan Orogeny



Thank You